INDUSTRIAL
ELECTRONICS
MADE EASY

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How to get the most out of your *VOM*

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introduction

T HE face of industry is changing because of the introduction of electronic devices, spurred by the demands of automation. Electronic processes, controls, recording and measuring are beginning to find their way into all the likely places in industry, and into some not so likely.

Electronic measuring devices in industry are not new, nor are electronic processes. Some of them have been in use for decades, without being especially noticed. Only when they are applied to new situations where such equipment was not used before, is our attention focused upon them.

Even electronic control is not new in industry. For many years photoelectric controls, thyratron-welding controls of many kinds, rectifiers, oscillators and servo-amplifiers have played their part in the industrial scheme of things.

Never before has the demand for technicians familiar with these kinds of devices been as great; and this demand can be expected to grow steadily from now on, as an increasing number of machines and control devices replace the human element in industrial processes, calling in turn for even higher human intelligence, skill and experience to keep the complicated machinery working. For no matter how rapid, precise and untiring the new controls are, they are not infallible and, without proper

supervision, considerable money could be lost in unexpected breakdowns.

The purpose of this volume is to familiarize the reader with some of the characteristics which industrial electronic devices have in common with other electronic and radio equipment, and with some of the special requirements unique to industrial equipment. These characteristics must be familiar to the technician who intends to service such equipment.

It is impossible to cover all facets of industrial-electronics servicing in one volume adequately. The best we can hope to do is to provide the reader with an insight, a general understanding of the special problems to be met in this kind of service work, the nature of such service, the instruments and procedures used and the dangers to be avoided. Although reading this book will not qualify the reader as an industrial service technician, at least it will give him an idea of what the field consists of so that he can determine for himself whether the servicing of industrial electronic equipment would provide him with a satisfying and lucrative career.

TOM JASKI

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industrial
electronics
what is it?
where is it?

THE first question generally asked is "What is *industrial* electronics as distinct from all the other kinds of electronics we know, and what does it include?" The first part of this question is the more difficult to answer, for it requires that we draw a line somewhere between one branch of electronics and all the others. Any such distinction may be invalid the day-after-tomorrow. Therefore we shall answer that one generally by saying that any electronic devices which comprise a regular part of industrial processes will be considered industrial electronics. It will thus include all those applications in which electronics is the major ingredient in the process, as well as those in which electronic devices serve only to help control a process by measurement and feedback-type controls, or where electronics is involved only in recording data about the process.

In this way we have automatically started answering the second part of the question, namely, "What is included?" We know that some processes in industry depend on electronics as an essential, functional part of the program. This we find in such applications as dielectric heating (heat applied to *insulating* materials), induction heating (heat applied to *conducting* materials) and microwave cooking (Fig. 101) which is related to both, but mostly to the former. We can also consider in this category any processes

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using electrolysis to separate constituents of a solution, plating done by purely electronic means without the conventional plating "bath" and, as another extreme, a printing process called xerography in which the letters are deposited on the paper electronically by charged particles on a surface.

In the other categories we can include all the various means

Fig. 101. *Modern "radar" oven cooks foods in unbelievably short time.* (Raytheon Corp.)

of control, from controls directing the operations of a large oil refinery to the simple photoelectric safety control on a punchpress, which protects the operator from accidental exposure of his hands in the machine when its crushing force shapes a metal part. Other applications include such items as electronically-controlled printing presses, elevators, toothpaste-filling machines, postage stamp printing machines and the leveling controls for a huge steam shovel.

In the measurement class we find many processes guided in accordance with precise data obtained electronically through temperature, pressure, position, density, speed, weight and humidity controls. We find, in this category, equipment to detect pinholes in enormous sheets of steel, or very tiny particles of metal in boxes of baby cereal; counters which count every bean sealed into a package of colorfully-printed cellophane; automatic testers which accept or reject vacuum tubes, capacitors or resistors according to predetermined tolerances; radiation detectors which auto-

matically warn of danger when the radioactivity level in a process becomes unsafe, and, on the other hand, gages for registering the level of liquid in tanks which use radioactivity as their active element. Those are but a few examples of the endless variety of electronic measuring and control devices used in modern industry.

Another category would include instruments which are used purely for measurement, such as the electronic recorders which keep a precise count of the gallons of oil in a refinery or quarts of milk processed in dairy machines, the sensitive bridges which keep track of the flour in storage bins tall as a skyscraper, and the gages that tell the exact temperature of tiny furnaces used in transistor manufacturing. This field makes use of sensitive transducers which translate mechanical forces and physical quantities into electrical signals, which are, in turn, transformed by means of various kinds of recorders, gages and indicators into continuous records of the processes under observation for the purpose of maintaining production control and to facilitate troubleshooting in case of production difficulties.

Finally, there is a large group of electronics equipment used in industry for communication of all kinds. These are often used together with equipment in the other categories. For example, we may mention such applications as industrial closed circuit TV systems, which permit one man in an operating position to keep careful watch, simultaneously, over many gages widely separated in a plant; telemetering systems which convey data over considerable distances for control, coordination and recording purposes; and the familiar industrial public address and music systems, special intercoms and portable, pocket sized communicators for large warehouses. Other examples in the communications category include alarm systems of all types and proportions, and for all kinds of purposes, from keeping out intruders to warning of fire, flooding, overheating and the presence of dangerous gases.

Industrial electronics viewed in all its facets is truly an enormous spectacle that staggers the imagination. All this equipment operates silently, swiftly and accurately and, for all the customer can tell, forever without the slightest hitch and hesitation. But this is reckoning without the thousands of service and maintenance people who are always alert to possible failures and breakdown of this equipment which, despite the emphasis by design engineers on maximum reliability, cannot be made completely 100% dependable without becoming economically impractical. For this reason the manufacturers of industrial electronic

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equipment usually provide excellent service facilities to their customers because of their realization that a single breakdown might cost the customer millions of dollars in lost production. As part of this program they help to train customer maintenance men in the servicing of each separate device as it is installed in the plant. As a result, we have many service personnel who are experts on one particular make of one specific class of instruments, and a large group of technicians who are thoroughly familiar with a substantial variety of electronic devices used in their particular plant, but few who can approach *any* electronic device in industry with confidence, knowing that whatever the gadget is, they can fix it.

It is obviously impossible to take up all aspects of industrial electronics servicing in a single book. However, by pointing out the similarities between these devices and those with which you are already familiar from radio, hi-fi and television work and study, we intend to show you that the basic circuits involved in these devices are the same, and that we simply have many new combinations of circuit blocks already familiar to the reader but now used for different purposes. This is the goal we hope to achieve in this book.

A bit of history

Because we are getting more and more accustomed to new electronic devices in our daily environment, which a decade or so ago were simply laboratory oddities, we assume that this influx of electronics is something new, something of today and not yesterday, and something even more of tomorrow. What we do not realize is that electronics, in one form or another, has played a major role in some of our industries for many decades — a role of great importance, and without which we would not have some of the many products we now take completely for granted.

In the late 1880's Nicola Tesla invented a process for electrolytically separating iron from its ore. Call this the beginning, if you wish. But long before that, in the early part of the 19th century researchers were aware that metals could be heated with induced electric currents, the principle of induction heating. It was in the early 1900's, however, that the first practical induction furnaces were produced by Northrup, which used high frequencies for melting metals. But it was not until almost 25 years later that induction heating was applied in practice to a variety of metal processes requiring intense heat. In other words, this kind of industrial electronics has been with us for several decades.

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Dielectric heating was even slower in getting started. Although the heating effects of electric fields in capacitors of radio transmitters had been noticed almost from the beginning of radio broadcasting in the early part of the 20th century, practical applications of dielectric heating did not appear until the mid-30's, when the idea was first applied to the process of drying tobacco leaves. Today, dielectric heating is utilized in a wide range of industrial processes.

Electronic control also is not entirely new. In 1890, the same Tesla who invented the three-phase induction motor and generator, which are the backbone of industrial power, demonstrated the use of electronics for the remote control of a model boat. The idea was so far advanced for the times that few besides Tesla could understand the possible applications of such devices. Today, as a direct result of the development of reliable devices, tubes and components, electronic controls are used in all phases of industry, as well as in military, commercial and domestic fields.

Electronic measurement, using the term as distinct from electrical measuring methods, is also a relatively recent technique, although ideas in this field were developed and applied soon after the vacuum triode was introduced. The development of oscillators made possible a number of measurements which had been impossible before. Who would ever think, for example, of measuring the inductance of several inches of straight wire without the use of very-high-frequency measuring devices? On the other hand, such a measurement is only of importance at these very high frequencies. The introduction of electronic measuring devices closely followed the needs of the communications industry, but, once developed, they were readily adapted for other purposes.

The introduction of the cathode-ray tube by Johnson and van der Bijl in 1922 gave impetus to the development and use of numerous electronic measuring devices. Now, as we look at the technician's array of tools and equipment, the cathode-ray oscilloscope is one of the most important testing and measuring devices is his arsenal, along with the electronic vacuum-tube voltmeter, wattmeter, frequency meter and the various generators to create the signals needed for many measurements.

What about the future? That depends on what you call the future. If you are thinking in terms of electronic controls in industry, of machines operating without the benefit of human hand or judgment, the future is here and now. Already, many products in our complex economy are made entirely by auto-

matic machines which also count, inspect, pack and, after shipment, often dispense the product automatically. With some imagination we can foresee the electronic control of many additional production processes. For example, we now have fully-automated equipment for the automatic assembly of printed circuit boards, circuit modules and micromodules, produced entirely by machine. Furthermore, completely automatic wiring machines have been invented which are so versatile that, upon instruction from a computer, they can wire a series of different devices accurately and precisely without human intervention. Although there will be a gap between what we *can* do with electronics in industry and what is *being* done, you can be certain that the future application of electronics to many processes will require the skills of a great number of qualified and experienced electronic technicians for the installation, maintenance and servicing of this equipment.

What is being done *now?*

Perhaps the simplest way to get an idea of the possibilities in the field of industrial electronics today is to take a look at what kinds of industrial electronic devices are being used and where they can be found. This will be a limited sampling only, and the list will be confined to the more generally applied equipment.

First let us look at dielectric-heating generators which are generally used where considerable heat evenly distributed throughout the material is needed in the processing of dielectric materials. The principles involved in dielectric heating will be discussed in chapter 3.

We shall briefly mention only a few examples of the application of dielectric heating to industrial processes. Dielectric generators are used extensively in wood gluing processes in the plywood industry and in cabinet and furniture factories. In this case, their principal purpose is to promote rapid drying of the glue, thereby cutting down the drying time from days to minutes. They are also utilized in the plastics industry for heating the plastic material as well as the forming mold.

Dielectric generators are used in bag-sealing machines to seal plastic food and merchandise bags. Similar sealing machines are used for the manufacture of plastic toys and such items as golf balls. Dielectric generators are used in the food industry to dry (dehydrate) foods, and in this process they have the advantage of not discoloring foods as conventional ovens do. Precooked foods are prepared in dielectric fields and so are hot dogs in automatic

vending machines. Rubber product factories use the generators to heat rubber for molding and to vulcanize raw rubber. Plastic seat covers are "sewed" by dielectric heat, and plastic and wood wall panels are glued together in similar machines. Foundries use dielectric fields to dry and bake cores for forms, and pottery factories bake clay products in a fraction of the time required for
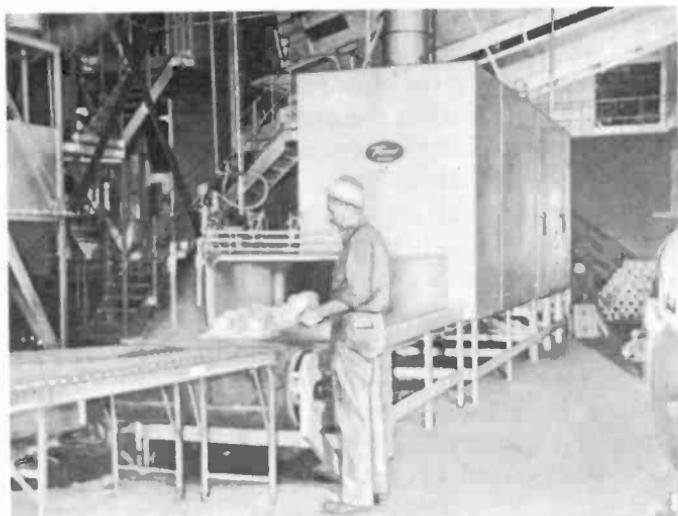
Fig. 102. *Large dielectric generator being used for the baking of foundry cores.* (The Girdler Company.)

conventional ovens. Green lumber for cabinet factories is kiln-dried by dielectric generators, and in one of the largest types of installations, large sheets of plywood are laminated (Fig. 102).

A final example of dielectric heating is the "radar" cooking range[1] which derives its name from the fact that it operates at microwave frequencies. Microwave cooking has found many applications in food-processing industries as well as in restaurants where it can achieve in a few seconds what would normally take many minutes by conventional cooking methods.

Let us next discuss the industrial application of induction generators. Induction heat is used in the metal industries in various forms. In some of the larger installations it is used to melt and alloy various metals. Parts are heated in induction coils for hardening and sometimes for brazing. Large ingots and forgings are preheated with induction generators (Fig. 103) because the

[1]Better known as the Radarange, manufactured by Raytheon Corp.

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process is much faster and more thorough than conventional heating.

Annealing (removing temper) and soft soldering are two more applications of induction heating. It is also used in heating glass for the manufacture of vacuum tubes. This is possible because glass, when preheated to about 600° F becomes a conductor, even though it is an insulator at room temperatures. For this reason, induction heating can be used to heat both the glass and the elements in a vacuum tube. Extreme heating of vacuum-tube elements without heating the glass can also be done with induction generators, and this is used in the degasing process in vacuum-tube manufacture. Zone melting of semiconductor material is done in the field of an induction-generator coil. Sometimes parts which are to be shrunk together are quickly heated in such a coil and then assembled, for induction heat can be adjusted, as you will see, to heat just the surface of a piece of metal or to heat the entire piece evenly.

Another form of electronic heat is produced in electronic welding machines, which are commonly encountered in sheet-metal products factories and in the vacuum-tube industry where small thin metal parts must be spot-welded together. Another common use of electronics is for the control of both conventional and special arc-welding machines. High-frequency arc welding can also be found in sheet-metal factories, and is particularly applicable where local heat is required without substantial heating of the rest of the metal.

It may be appropriate to point out here that metals can be welded without heat by ultrasonic welding machines that shake the surface molecules of the metals so they intermingle. Of course these machines are powered by electronic generators. Ultrasonic generators are also used in cleaning and washing, homogenizing, sterilizing and purifying, chemical mixing, and in such tools as ultrasonic grinders, drills and soldering irons. Ultrasonics is also used in flaw detection and gaging systems. Instruments of this kind are found in steel mills and metal fabricating plants, automotive plants and diesel engine factories. All of these comprise a special class of electronic equipment which will be discussed in some detail later on.

Other classes of industrial electronic equipment can be found in just about any kind of industry. Photoelectric controls are used for detecting motion or the presence of an object where it should not be. Other photoelectric devices are used for gaging

the thickness of wire, for example, or the density of smoke in a stack, or flaws in painted surfaces which reflect differently from other areas, and for such applications as sorting objects by color. Photoelectric cells can be used to indicate liquid level or the density of a solution by passing a light through the liquid or a portion of it. They are also used for "reading" instructions punched in tape or cards which are employed to control large machine tools from a programming device.

Fig. 103. *Large induction generator being adjusted by technician.* (General Electric Co.)

Photoelectric control, which converts information in light beams to electrical signals, is one way of controlling processes electronically. There are many other such controls — temperature controls using thermistors and thermocouples; controls where stress or strain is translated into electrical signals by strain gages; pressure controls; level controls; vacuum controls; speed controls and a host of others. Counting itself can be a means of control. A preset counter, after a preset count has been reached, can perform a control function and then promptly reset and start

counting again. Weight can be a control factor as can size, thickness, motion and speed, density, viscosity, and all sorts of electrical values such as resistance, voltage, conductivity, current, frequency, etc.

Controls do not always require some kind of transducer for converting the original measured quantity to a suitable control signal to operate automatic equipment. Some large machine tools for example, can be controlled by what is called a "program." The machine goes through a predetermined sequence of operations to produce its product. This "program" can be provided to the machine in a variety of ways. It can be fed into the servo control system from magnetic tape, punched paper tape, a magnetic or mechanical memory drum (a mechanical memory drum is like the drum in a music box, with switch contacts instead of tines) or even punched cards as used in business machines. This then becomes truly automation for these machines may produce the same part over and over, or a collection of different parts, depending on the instructions provided for the operation.

If the operation is repetitive, timing is usually one of the most important control factors and can be performed electronically in many ways. The controls and program devices can simply be a series of timing controls, rather than a complex set of instructions. A simple example of such a system is the home automatic washer, which goes through its single predetermined sequence, regulated by timing controls. Timing always plays a role in electronic controls, even if it is a minor one at times.

Recording is a large item in industrial electronics, and very many times the recorder is the controlling device also, recording and controlling on the basis of the same electrical value at the input. Sometimes the recorder is primarily a control device and the recording function is secondary and provided to make a record of deviations from a norm which occurred and which were corrected by the device. This then gives the operators of the process an opportunity to regulate other values in the system so that the least amount of correction is required, and the process operates more uniformly over longer periods of time.

In many cases a process takes place so rapidly and the product is produced in such vast quantities that the only way to keep track of what is produced is by some means of automatic recording, often with just a counter having printed readout. A readout is an electronic counter with a printer attached, which several times per second will print the sum of what has been produced or the

amount produced in that fraction of a second. In this way, counters with printed readout can also be considered recorders and, as we go further in the direction of automation, more and more recording will be done in this "digital" manner, since the automatic plant functions best on a digital system.

In the chapter on electronic counters we will briefly discuss the basis of the most popular digital system in such control, the
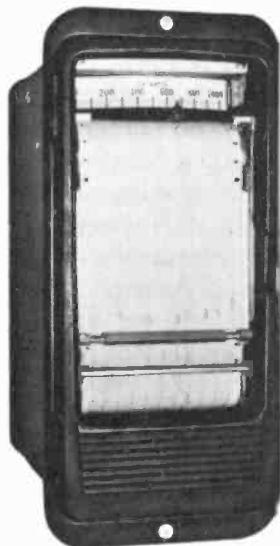
Fig. 104. *Industrial recorder of the single-channel type. This unit supplies a record of power consumption.* (Westinghouse Electric Corp.)

binary system, and how it can be converted to and from the more common decimal system. The binary system is not only important in control but also in digital computers, which are based on it.

Recorders keep track of all kinds of quantities, but they can register only electrical values and changes in them. Therefore the transducer is ever present with the recorder, unless strictly electrical values are to be dealt with in the system. Typical units in industry record such values as temperature, gas pressure, liquid level, steam pressure, weight, salinity or conductivity (Fig. 104). But remember that a great number of these do not necessarily require electronics. Thus such items as pressure of any kind, vacuum and temperature may also be recorded by mechanical means. Even multiple records can be made mechanically, and very ingenious

bellows and pen–arm arrangements have been designed which can keep track of as many as six items on a single chart. However, this is not common, for when many values are involved we will ordinarily use a multi-track electronic recorder which can keep track of 12 values simultaneously. Actually, the records are not exactly simultaneous. The recorder samples each value to be recorded periodically and prints an appropriate and distinct mark for each record once a second or more often if required.

Industrial communications systems are familiar in principle at least, to most who will read this volume. Thus you may find intercom and paging systems in all manner of factories, warehouses and plants. In fact, it is safe to say it is a rare plant which does not have some form of internal communications system. And some of these systems will set up special requirements for maintenance and adjustment, as dictated by the conditions in the plant. Closed-circuit TV is a part of industrial electronics, and we will have something to say about the servicing of such systems.

Too often the subject of industrial electronics service is shrouded in mystery, as if it were some branch of electronics requiring special skills, special secret knowledge, very special equipment and maybe even special kinds of service technicians. You will realize, when you have finished reading this book, that, mostly, the service consists of calm evaluation of the function of the circuits, what their similarities are to circuits in other kinds of electronics, and how their malfunctioning can be detected and corrected. Special knowledge is involved only insofar as the particular instrument is concerned, and even there many of them are alike. And the calibration of industrial equipment, although perhaps sometimes very critical work, should not present serious difficulties to someone familiar with painstaking adjustment of TV receivers and accustomed to wrestling with "mechanical monsters" such as record changers and tape recorders.

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comparing
communications
and
industrial
electronics

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A LTHOUGH there are many similarities between communications and industrial electronics, there are perhaps as many differences. However, the differences are not fundamental. Rather, they are concerned with practices and custom and with special requirements to be met in industrial installations. Generally, the differences appear in special stress on reliability, durability and low maintenance cost, special safety provisions to meet health, safety and industrial codes of local, state and federal agencies, and in packaging and appearance.

After all, in an oscillator, the basic circuit does not change merely because it is applied in a different setting. But there are industrial circuits which will look very strange to one accustomed to communications practices. For example, industrial power generators are often built without any power supply filtering, something unthinkable in communications. Very sophisticated and accurate control devices are built to use 60-cycle ac directly, without any dc power supply.

Components in industrial applications are often heavier than those in communications, but many of them are very similar. The

COMMUNICATIONS	INDUSTRIAL	COMMUNICATIONS	INDUSTRIAL
ANTENNA		PILOT LAMP / LETTER FOR COLOR	
BATTERY		WIRES CROSSING (NO CONNECTION)	
FIXED CAPACITOR		WIRES CROSSING (CONNECTED)	
VARIABLE CAPACITOR		NONE	POWER WIRE
RESISTOR (FIXED)		GROUND BUS	NONE
RESISTOR (VARIABLE)		NONE	CIRCUIT WIRE
TAPPED FIXED RESISTOR		CONTROL WIRE	NONE
CONNECTOR		FUSE	
PUSHBUTTON SWITCHES (N.O. N.C.)		GROUND / CHASSIS	
MANUAL SWITCH		NONE	THERMOCOUPLE

Fig. 201. *Comparison chart of symbols.*

DIODE (KENOTRON)

DUO-DIODE (FULL-WAVE RECT)

TRIODE (PLIOTRON)

PENTODE

NEON LAMP

PHOTOCELL

THYRATRON

NONE

IGNITRON

SEMICONDUCTOR DIODE

PNP TRANSISTOR

NPN TRANSISTOR

PNP TETRODE TRANSISTOR

CONTROLLED RECTIFIER

PNP FIELD-EFFECT TRANSISTOR

UNIJUNCTION TRANSISTOR

THERMISTOR

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CIRCUIT BREAKER

NONE

MAGNETIC OVERLOAD

NONE

THERMAL OVERLOAD

INDUCTOR (AIR CORE)

INDUCTOR (SLUG TUNED)

TRANSISTOR (IRON-CORE)

NONE

3-PHASE TRANSFORMER

NONE

REACTOR (SATURABLE)

RELAY COIL

ARM

RELAY (SLOW CLOSING)

SO

ARM

RELAY (SLOW-RELEASE)

SR

RELAY (SLOW-ACTING)

SA

RELAY CONTACT NORMALLY CLOSED (N.C.)

RELAY CONTACT NORMALLY OPEN (N.O.)

RELAY CONTACT
SPDT

NONE

RELAY CONTACT (DELAYED-OPENING)

TDO

NONE

RELAY CONTACT (DELAYED-CLOSING)

TD

LS
(N.O.)

LIMIT SWITCH

LS
(N.O.)

great stress on reliability often makes it necessary to allow greater margins of safety, for example in transformers, which will be built larger and sturdier for industrial purposes. Unfavorable environmental factors, such as extreme temperatures, steam, vapors of different kinds, corrosive fumes, dust, explosive gases, vibration and mechanical damage possibilities place particularly severe demands on the enclosures and wiring of industrial electronic devices.

Vacuum tubes used in industrial devices may be like, or very similar to those in communications gear, but more often specially-constructed ruggedized tubes are used. Their extra supports and special structures are more capable of withstanding extreme mechanical vibration. Often vacuum tubes in industry are very large, and some special kinds are used which are never found in communications. On the other hand, some of the communications special tubes, such as magnetrons and klystrons, have been pressed into industrial service when needed.

In this chapter, we will emphasize the differences in each of the foregoing classes of equipment and devices, but we will report on some kinds of electronics which have no equivalent in communications. Needless to say, we will not be able to report on *all* practices and devices, systems and customs, equipment and circuits. A choice has been made which will cut across many of the existing subdivisions in industrial electronics, since it is our aim to give you the "feel" of industrial electronics, rather than to try making you into an expert.

Symbols, diagrams and drawing techniques

When you look at an industrial diagram for the first time, you may have difficulty reading it. The symbols you are accustomed to have been mixed up with a new bunch which are unfamiliar. This is partly the result of not too successful attempts by manufacturers to standardize diagrammatic symbols. Then, too, there has been the frequent necessity to have the diagrams fit in with power circuit diagrams, which use symbols much like those used in the *industrial* circuit diagrams.

Fig. 201 is a chart of symbols used in industrial practice and in communications. Note that the symbols for vacuum tubes are the same, but that resistors and capacitors are different. In industrial diagrams you may meet two parallel lines which look like a capacitor, but in fact are relay contacts. Or two parallel lines with a slant line through them, which looks as if someone started to draw a variable capacitor and forgot to draw the point on the

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arrow to indicate variability. This is a normally-closed relay contact. In drawing transformers, we often omit the lines representing the cores. In industrial practice, this is time-saving and quite justifiable, since we seldom use high-frequency coils and there is not so much chance for confusion. Sometimes coils and transformer windings are shown as you have been used to seeing resistors, a 60° zig-zag line. Other symbols in the diagram will provide clues to what system is used, and generally the draftsman will at least be consistent in the type used.

The American Standards Association (ASA) has tried to standardize symbols, but great difficulties arise in getting such symbols universally accepted. Many engineers and draftsmen in industrial electronics jobs were originally communications engineers and carry with them old habits of presentation. Manufacturers had extensive files of diagrams and catalog engravings before standardization became an obvious necessity, and the cost of changing all existing drawings is usually prohibitive. Magazines such as RADIO-ELECTRONICS, which count among their readers many communications-oriented technicians and engineers, continue to use communications symbols for good reasons. But large manufacturers, such as G-E, Westinghouse and many others are equally justified in using the new symbols, since their electronics equipment most often is part of a system, including also a great deal of power and control which could not be drawn in communications symbols. In this volume we will go along with magazine practice and show most diagrams in symbols familiar to you.

It is always simply a matter of time before a practice becomes adopted, and eventually industrial electronics will play such an important role in our lives that there will be a tendency to unify the symbols, generally favoring the industrial ones. But this may be a long time away. Meantime you must get along with the mixture and compromises now used.

Wiring and elementary diagrams

Not only symbols are different. Drawing practices also vary. In industrial diagrams, we have long used *wiring* diagrams and what we call *elementary* diagrams, unlike the schematic diagrams used in communications. Fig. 202 illustrates the difference between the three kinds with a diagram of the G-E CR7505K108 photoelectric relay. Notice that in the schematic wiring diagram *(b)* such items as relay contacts are drawn adjacent to the coil, and that this is also true in the panel diagram, which tends to show the parts in a placement which is quite close to the actual physical relationship.

Fig. 202. Three methods of presenting the same electronic circuit.

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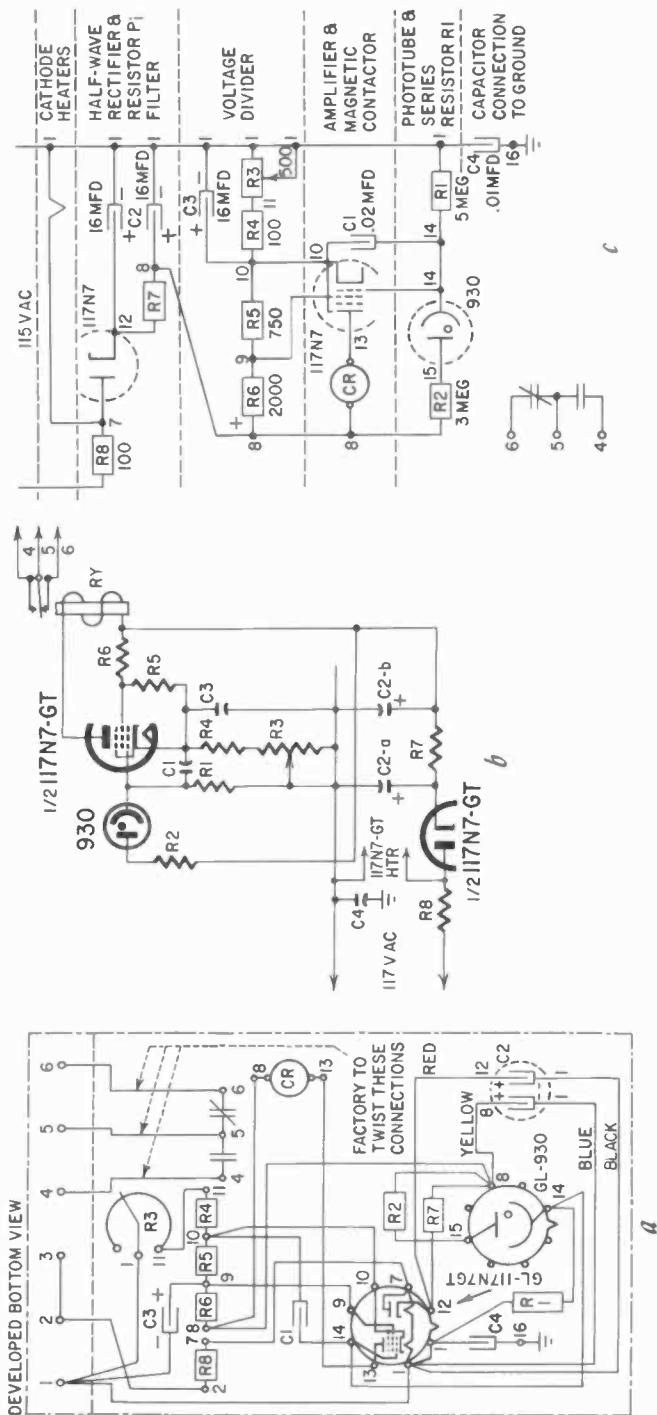
But in the elementary diagram *(c)* we do not concern ourselves with this. There we are concerned primarily with showing the *sequence of events.* Thus if A must happen before B, we show A first, then B, even if they are part of the same piece of equipment. If we have a transformer and items fed by various secondaries, they are separated in the elementary diagram. We will cheerfully draw all the secondaries where they are needed, and thus scatter the parts of the transformer all over the diagram. This is graphically illustrated by separation of the relay contacts from their coil. Of course, parts thus separated must be adequately labeled for identification.

The practice of drawing elementary diagrams came in vogue with the introduction of complicated relay control diagrams, where the circuit often could not be understood without a clearly indicated sequence of events in the diagram. They served so well there that the practice was carried over into other kinds of circuits.

But this is not all. There may be other differences. One of them is illustrated in Fig. 203, in a very much simplified way. While in communications we draw all lines even if this means drawing many parallel lines, in industrial diagrams we may have so many parallel wires that the drafting becomes impractical. Then the draftsman will pull these wires together into one line and will designate the origin and destination with a number as shown. This does not mean necessarily that these wires would be cabled together, although they often are. Generally it is simply a convenience adopted for simplification of the diagram, while in communications we avoid this for the very reason that the assumption might be that these wires are cabled.

We can go one step further and omit the lines altogether, simply designating the origin and destination of the wires. This is a long established practice in wiring diagrams such as are used in large powerhouse switchboards and control systems, and is being carried over into industrial electronics. For one accustomed to reading such power diagrams this presents no problem, but for a communications technician, who is accustomed to having every line drawn, they may need some study. Yet it seems a logical and commendable simplification which saves much drafting time and keeps diagrams quite uncluttered, a necessity when the systems get large and complicated.

Single-line diagrams

Long familiar to communications are the *block diagrams,* which have their equivalent in industrial diagrams when we draw *single (one)-line diagrams.* These are essentially similar to block dia-

grams, except that instead of empty "blocks" with designations written in, the single-line diagram often show the more graphic symbols common to the power business. Fig. 204 illustrates the difference. Single-line diagrams were introduced for the same reasons as block diagrams: simplification and a quick view of an entire system and its major components.

Construction diagrams

A fifth kind you may encounter is the *construction diagram*. This is very much like the "wiring" diagram, and sometimes serves the same purpose. The construction diagram illustrates components in their actual physical relationship, with quite a bit more
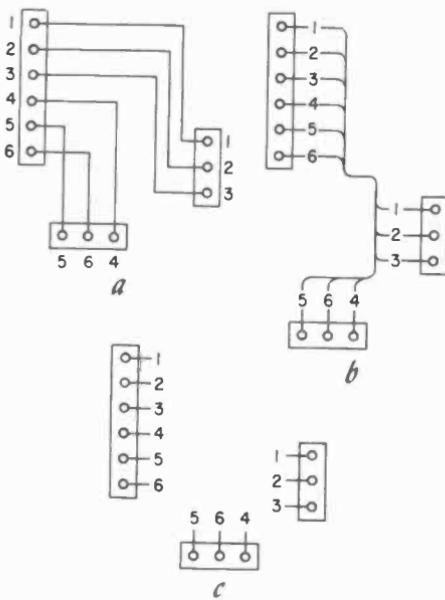
Fig. 203. *Schematic in (a) indicates wire connections between terminals. Connections in (b) and (c) could indicate individual wires or multiple wire cables. Additional data on the print would clarify this.*

accuracy than a wiring diagram, but with only the terminals shown. Thus, rather than vacuum tubes and transformers with their internal construction schematically presented, only circles or rectangles will be shown with the actual terminals and socket connections. Unless one is quite familiar with all the components involved, it is almost impossible to determine *function* from a

construction diagram. The construction diagram will also indicate how wires are to be dressed, whether or not they are to be cabled, and how various parts must be fastened. Usually several construction drawings are needed for one chassis.

These are the most important differences in diagrams you may have to cope with. There are many hybrids — wiring and construction diagrams mixed, schematics and elementary diagrams mixed, wiring schematic diagrams combined and so on. Nor can you expect to find a pure application of symbols of one kind or another everywhere. But knowing about the possible differences is half the battle in coping with them.

Industrial circuits

In industrial electronics a preponderance of circuits designed for control are utilized while a limited number of circuits commonly used in communications will also appear in industrial applications mostly in the various instruments used. For example, counting circuits, not a part of communications per se, are very important in industry. You will find considerable data devoted to them in Chapters 5 and 6.

Industrial controls of all kinds using photoelectric and timing circuits and certain kinds of phase-shift circuits are entirely strange to the communications field. A number of these can be found in Chapter 7.

Industrial power generators are very similar to simple communications transmitters, with the exception of the power supplies. Chapter 3 deals with such generators in some detail. These generators must not radiate beyond their immediate working area, and thus differ also in that respect.

Completely strange to communications work are the static switching circuits discussed in Chapter 8, and the somewhat more familiar circuits in Chapter 9, which deal with transistors and other nonlinear elements. These are more closely related to computers, as are the other logic circuits discussed.

A new class of devices are the recorders of Chapter 10. The amplifiers in these are quite different again from those used in communications. Here you will encounter dc amplifiers, and amplifiers using ac instead of dc to supply power.

And finally, there are the multitudes of transducers, a few of which are discussed in Chapter 11, also foreign to communications.

We can sum up by saying that in industrial electronics we are primarily concerned with two functions, control and measurement.

And the two are interrelated, for to control with any accuracy we must measure.

In industry, circuits should be kept as simple as possible, with as few components as we can manage. Each additional component is a balance proposition between increased accuracy or function complexity and *reliability*, since each component is a potential source of trouble. The use of ac as a source of plate power for direct use in amplifiers is based on the desire to eliminate the rectifier and filter system as potential trouble sources, not on cost. If we can do a job so much better with a dc supply that the additional components are warranted, we would certainly do so.

Sometimes the impression is given that industrial electronics is a crude kind of affair, dealing with large power or very approximate measurement and control. Nothing could be further from the truth. Some industrial controls work with high accuracy in measurement as well as control, and often under exceptionally
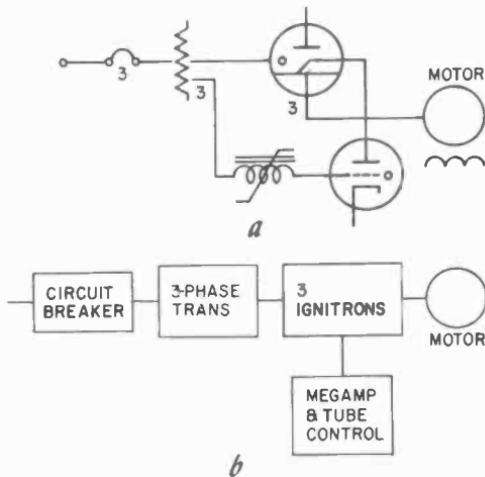
Fig. 204. *Block diagram and single line diagram are different ways to show the same circuit.*

difficult circumstances. It is one thing to measure a temperature rise of a few degrees at room temperature, but quite another to do the same thing at several thousand degrees. It is easy enough to weigh and balance a few pounds or ounces accurately, but much more difficult to do the same thing with the same degree of accuracy when weighing 60 tons of material in a hopper all at once! Industrial electronics, in fact, is often more difficult and demanding than communications practices, and many special circuits have

been developed to do the job adequately. This includes many jobs of control which for a long time were considered "impossible." Many times industrial electronic controls have come to the rescue where other controls would have been possible but extremely cumbersome. Thus the delicate remote "hands" of a servo system designed to handle radioactive materials safely and as delicately as with one's own fingertips, depend on electronic control circuitry. In machine control, electronics provides accuracy which could not even be read, let alone adjusted, by human beings.

Industrial components

When we speak of components in electronics, we more or less naturally think of vacuum tubes first. Many of the vacuum tubes used in industrial electronics are identical to those used in communications; you will recognize many of the numbers, shapes, sizes

Fig. 205. *Forced-air can be used to cool tubes. Holes around the bottom prevent heat build-up in the base.*

and bases. But even then you may be dealing with special versions such as the so-called ruggedized types which have been specially built for military applications to withstand severe vibrations and environmental conditions. Industry has happily adopted the use of similar tubes in equipment subjected to similar environmental conditions, thus solving some of the reliability problems that plagued the application of electronics to industrial problems in the beginning.

Unless you are accustomed to dealing with transmitters as well

as receivers, you may not be familiar with some of the larger versions of vacuum tubes often used. Fig. 205 shows one that might be used in dielectric generators of moderate size. A number of these tubes can be and often are used in parallel. The radial-beam tetrode is very familiar to amateurs and transmitter engineers. This tube is capable of as much as 1,600 watts continuous plate output. A more modern type is the ceramic version of a power tube (Fig 206), also a tetrode, but cooled by air blown through the fins, and capable of a maximum of 3,600 watts of useful output.

Other tubes are capable of even greater power output and can handle as much as 10 kw. Beyond this size, we generally employ water-cooled tubes such as the one shown in Fig. 207 and its larger cousins.

Water-cooled tubes pose special problems for service technicians. Although these tubes can not long remain in operation without
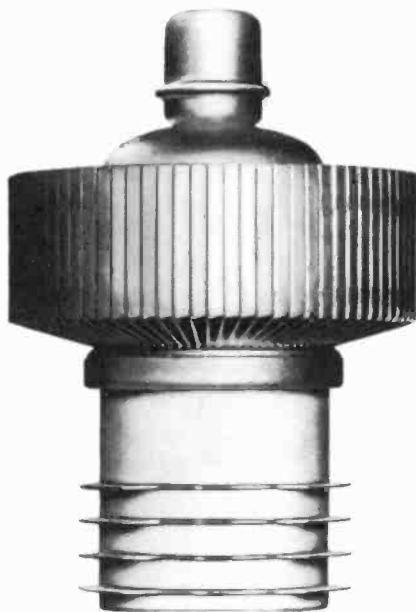
Fig. 206. *Forced air conducts heat away from the radial heat dissipating fins.*

a proper supply of cooling water, cold water cannot be used directly. The temperature stresses in the metal and in the seals would be too great. The tubes are most often cooled by water held in a closed circulating system which allows the proper regulation of water temperature and the maintenance of the purity of the water. Contaminated or hard water might clog the cooling

comparatively small one is water-cooled, since without proper cooling, de-ionization might be irregular.

The next step up from ignitrons are the mercury-pool rectifiers, which function in a similar manner but are many times the size of ignitrons. Some mercury pool rectifiers have been made for currents of 20,000 amperes. Many of the larger ones are used
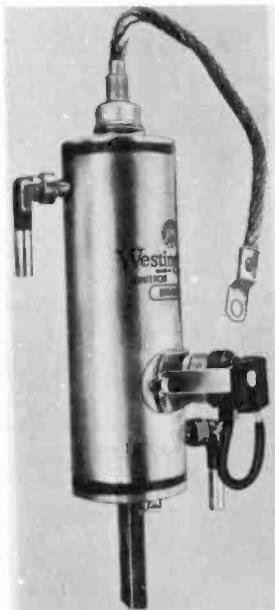
Fig. 209. *Heavy current applications call for the ignitron, the big brother of the thyratron.*

by railways for supplying dc power to the system, and in the metal-processing industries for electrolytic deposition of copper and in the manufacture of sponge iron and aluminum. (A cross-section of a mercury-pool rectifier is shown in Fig. 210.)

Magnetrons are shown in Fig. 211. Those illustrated are smaller than the magnetrons used in Radaranges. Other special tubes you may have to deal with include the vidicon and the photoemission image orthicon, both camera tubes. The circuit for the vidicon (Fig. 212-a) is discussed in Chapter 11. The orthicon is shown in Fig. 212-b.

Photocells are a regular part of industrial equipment, and may range from the sensitive photomultiplier used in instrument applications to the simple solar cells applicable in control.

Another special kind is the counter tube, particularly the decade type. Two representative units are discussed in Chapter 5, the gas type Dekatron and the magnetron beam-switching tube. A special variety of indicator tube, the Nixie, is in effect a neon tube with one anode and a number of cathodes in the shape of numerals or letters. It is only used for numerical readout of counters and computers, and does no counting.
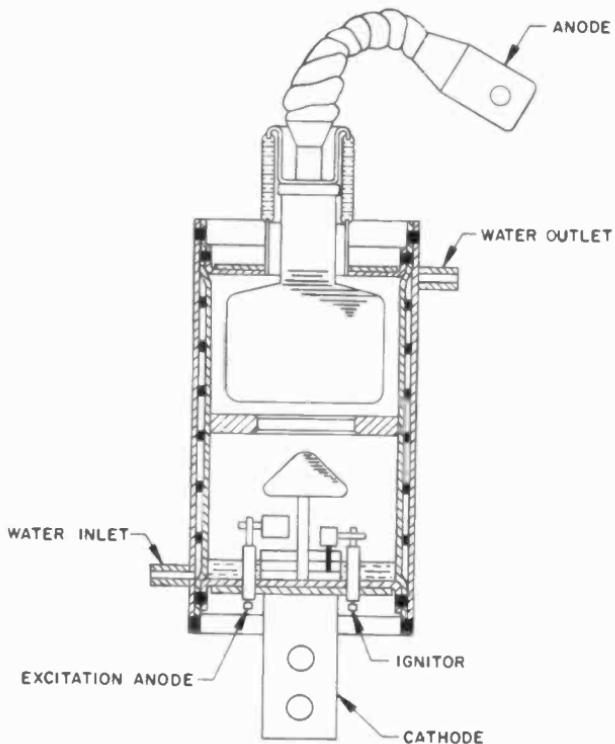
Fig. 210. *Drawing of a typical mercury-pool rectifier shows location of connections. Tube is enclosed by a water jacket.*

Geiger-Muller tubes (Geiger or G-M tubes for short) are specially designed for measuring radiation. High-vacuum types made of extremely thin glass or metal, or supplied with an extremely thin mica window, they contain a small amount of gas. They operate on what is called the "gas-multiplication" principle. A particle entering the tube at a relatively high velocity will, in its path through the tube, create a number of ions which are then attracted to the anode, usually a thin wire with a very high voltage

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(up to 1500 V) on it. The ions striking the anode create a quite measurable pulse. Some Geiger tubes are shown in Fig. 213.

There are also other ways of measuring radiation, such as the photomultiplier, which is used in conjunction with a crystal possessing the peculiar property of creating light when particles strike it. The particles used are generally sodium iodide crystals, and they are mounted directly against the tube face, so that any light within the crystal is detected by the photomultiplier. This is known as a scintillation counter, and it is very sensitive.

Industry also uses special tubes such as cathode-ray type storage tubes, which can hold an image for an indefinite or sometimes for a limited time. In these the phosphor layer is so designed that a charge is maintained which keeps the image visible for the desired time. There are other tubes for special applications which are not strictly industrial which you may, nevertheless, encounter, but, as a rule, the tubes discussed are representative of the field.

Semiconductors

Semiconductor devices have long been used by industry. The first one was the selenium rectifier, which was made in very large ratings for industrial work. Germanium, and particularly silicon, are replacing selenium rectifiers. A silicon rectifier, which can be controlled like a thyratron, can be used in a large number of applications. For details, see Chapter 9.

Transistors are already in use in industry to some extent, but not as much as they will be when they are manufactured for larger currents. Unijunction transistors, trigistors and several other semiconductor devices applicable to industrial electronics are all discussed in Chapter 9.

Inductors

Transformers in industry are indistinguishable from those used in high-quality communications equipment, and no purpose would be served by describing them in detail. Other devices physically comparable to transformers are the saturable reactors and magnetic amplifiers. Their operation and application is covered in Chapters 8 and 9. Some, especially those for control-system applications, are molded in plastic. Their operation in control systems is explained in detail in Chapter 8.

Resistors and capacitors

Resistors and capacitors are generally familiar types, although you are likely to find more of the canned, oil type capacitors, since they are better suited for operation in the difficult environmental

conditions frequently encountered in industry. It might be advisable to point out here that the capacitor insulators should be cleaned periodically during routine maintenance checks, while observing the usual precautions for discharging them first.

Large molded-base sockets with screw type terminals, and heavy-duty supports, terminal boards and tie points are used in industry

Fig. 211. *Magnetron construction is much more complicated than ordinary vacuum-tubes.*

because there is virtually never any need for miniaturization. In fact the sacrifices made in reliability, repairability, economy and freedom of access to gain compactness are often a detriment in industry. Industrial equipment is built in large enclosures, with plenty of space for ventilation and easy access to components and terminals. In other words, there is an altogether different philosophy in its design, with emphasis on ruggedness rather than compactness, reliability rather than light weight, and durability rather than economy.

Industrial enclosures

Communications equipment is often installed on open relay racks, particularly when space can be assigned for them separate from the rest of the building. Frequently, a basement is used because cables often come in underground, and the basement is the nearest place.

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In industry, equipment is seldom concentrated in a single location, and most frequently is in close proximity to each machine that it controls. Open relay-rack mountings are, therefore, obviously both uneconomical and unsuitable. It is preferable to have separate cabinets, wall-hung or suspended from the machines or self-supporting and set on the floor near the machines.

If the atmosphere in the plant carries any quantity of dust, the box must be dust-tight with a gasket in its door. Ventilation is then supplied by blower through air filters which will also require periodic maintenance. Where there is a possibility of water or moisture splashing on the equipment, the gasket must be waterproof and the air filters must also be designed to keep moisture out.

In industry you will also see enclosures which are explosion-proof. Contrary to popular belief, an explosion-proof enclosure is not designed to *exclude* an explosion so much as to contain it. The enclosure will be compartmented, with seals between compartments, so that an explosive gas or mixture entering one compartment cannot get to another. The case is sufficiently strong so that, if the gas should explode within a compartment, it will be contained and not start an explosion in adjacent compartments or the general environment.

Industrial enclosures are specified and standardized by the National Electrical Manufacturers Association (NEMA). For industrial controls their standard is NEMA ICI 1949 which describes and classifies enclosures according to their ability to withstand environmental conditions. Type 1 is a general-purpose enclosure. Type 2 is similar but with a drip shield to keep dripping moisture out. Type 3 is weather-resistant and can be left out in rain or blizzards. Type 4 is watertight — in other words, not submersible, but capable of withstanding a direct splash from a hose. Type 5 is dust-tight; Type 6 submersible; and Type 7 is explosion proof for hazardous locations where explosive gas and vapors are present. There are several classes of Type 7 enclosures. Types 8 and 9 are also for hazardous locations; Type 10 is approved for mines; Type 11 is acid- and fume-resistant, and Type 12 a general industrial applications enclosure, normally nonventilated to keep out flying material such as metal chips, etc. NEMA standards specify thickness of metal for all of these enclosures, the method in which the doors are fastened, maximum sizes and volume, temperature rise allowed, etc.
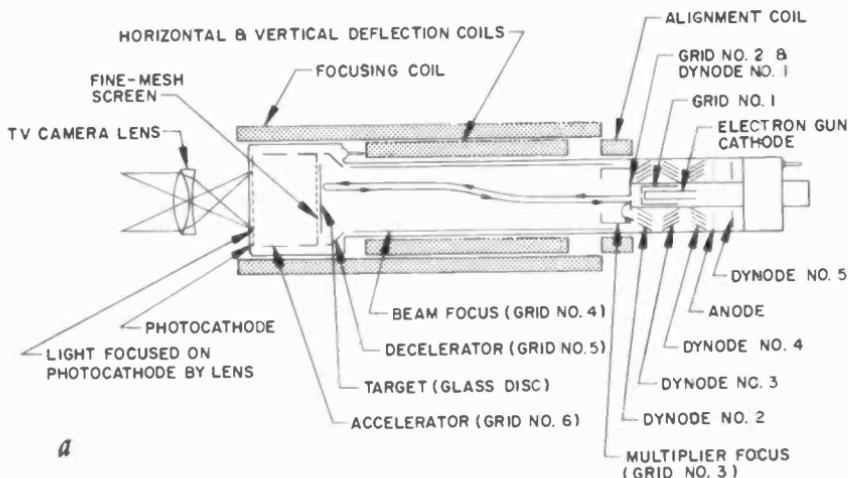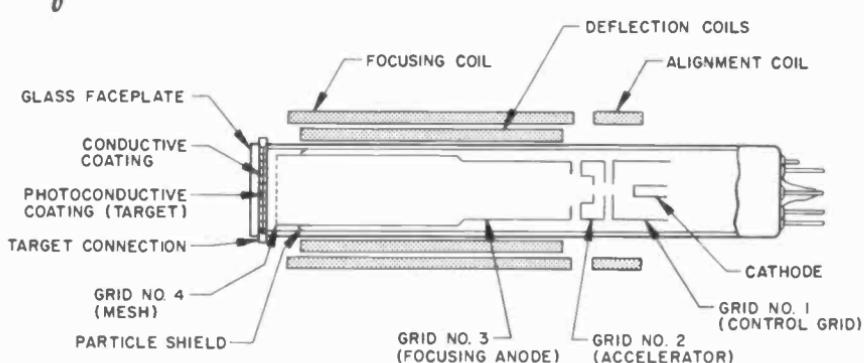
Fig. 212. *The vidicon (a) and orthicon (b) are used with lens systems as signal pick-up tubes in industrial and broadcast TV.*

Insurance underwriters also have standards which must be met, and it has long been a practice that union electricians will not install any equipment that is not underwriters approved. The reasons for this are not primarily a result of "union politics" but are generally a matter of responsibility. If a piece of equipment is installed and blows up, someone is likely to try to blame the electrician for the failure. The underwriters' label guarantees that the equipment meets minimum safety standards, and gives the installing electrician some measure of assurance that the equipment is not going to kill someone on the second day it is in use.

Rules, regulations and codes

Any equipment installed in a plant where contact by employes is possible will be subject to local, state and possibly Federal safety regulations. Nationally, installations are designed to comply with the National Board of Fire Underwriters Safety Code, called National Code for short. This is a code set up for safety of personnel by fire and liability insurance companies. They will not insure equipment or installations which do not meet inspection. The code has been generally adopted by city inspection and fire departments as well, and all of these must be given access to the plant for inspection. Utility companies will not supply power to uninspected equipment. Even major changes of any kind to the equipment require a permit from these departments in many cases. It is always a good idea to check with them if changes are contemplated.

Some local or state authorities have stringent rules for installations, particularly when large numbers of people work in the same room with the equipment, and just complying with the National Code may not be adequate. If equipment is installed on Government property, Federal regulations must be met. Generally, safety requires that any power wiring carrying over 50 volts must be concealed or completely enclosed so that no one can touch a live wire, terminal or contact. Certain requirements are set for the wire and cable used so that overloads will not heat the cable excessively. Special requirements must be met for dangerous high-voltage equipment (above 250 volts). Much of the power equipment operates on a 440-volt (and higher) 3-phase supply.

Equipment containing oil or other inflammable substances must be shielded or separately enclosed, unless the filling can be replaced with a noninflammable substance such as is used in many power transformers. Temperature conditions must be met to prevent the equipment itself from heating to dangerous temperatures, causing breakdown and possible fire. Specifications are set for insulation requirements for different temperature ranges and mechanical-fatigue conditions.

Industrial power sources

When installing, repairing or preparing to service industrial equipment, keep in mind that 110-volt power is the exception rather than the rule in industrial installations. More likely you will encounter 208, 230, 360 or 440 volts. Here's why: Most in-

dustrial power sources are 3-phase. The 3 phases can be separated, but a single phase from a 3-phase, 220-volt supply would be $220/\sqrt{3} = 125$ volts, not 110. A 120-volt, single-phase line is likely to come from a 208-volt, 3-phase supply. On the other hand, if your single-phase supply is 208 volts the main supply would be 360 volts, 3-phase.

Ground

Some of the supplies are grounded, and some are not. If you have to work on the equipment, it is advisable to determine beforehand the voltages to ground. A 3-phase system may be grounded but not symmetrically. For example, in what is known

ANODE–THIN WIRE WITH SPRING SUSPENSION

CATHODE–THIN METAL OR METALLIZED GLASS

IB87 & IB88

IB89

IB67
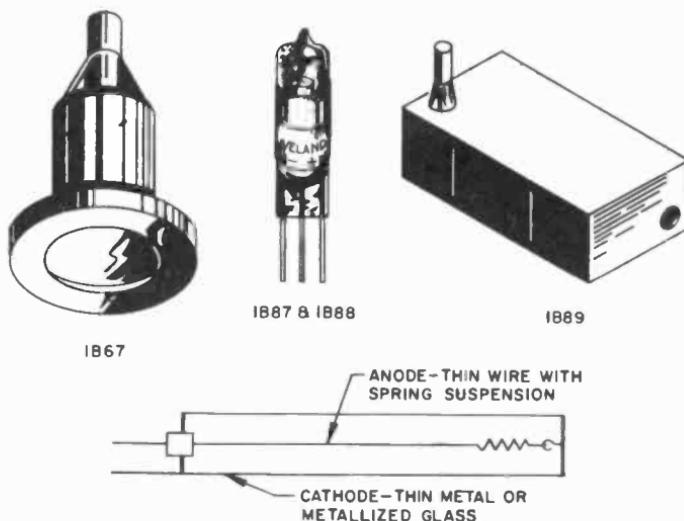
Fig. 213. *Geiger-Muller tubes have a variety of shapes. The basic internal construction is shown.* (Victoreen Instrument Co.)

as a 4-wire delta system, 110-volt power is obtained from a tap on one of the 3-phase windings of the power transformer. This is not an uncommon system where the power load is much greater than the lighting load.

Fig. 214 shows the different systems in use, and typical power symbols. Often, for safety or load reasons, separate transformers are used for the lighting and instrument loads, and single-phase or 3-phase, 4-wire transformers then step down the power voltage (usually 480 volts, 3-phase) to 120/208 or 110/220 for the lower-voltage circuits.

Special attention must be given to circuit protection at all

voltages. The National Code sets up branch-circuit specifications, and electronic equipment must conform to these. Failure of a circuit breaker to open a branch supply in case of a short circuit could result in the shutting down of an entire section of the plant, or even the whole plant itself. Failure of a circuit breaker
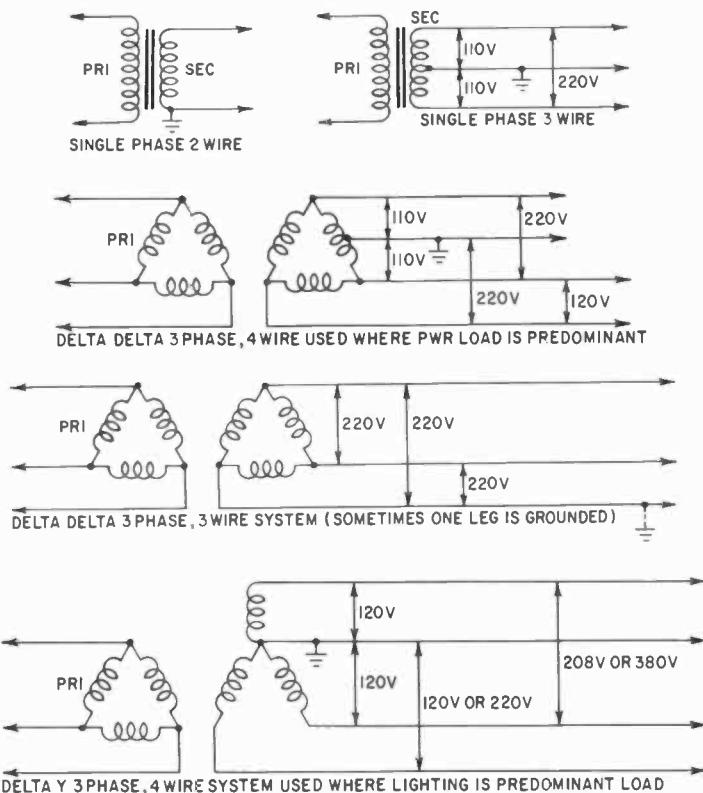
Fig. 214. *Single- and three-phase industrial power transformer and line connections, with related voltages indicated.*

can be caused by inadequate interrupting capacity, which should be based not on the normal current requirements of the equipment but rather on what the system would apply to the circuit breakers if a dead short occurred just inside the equipment. For this reason the circuit breaker on some kinds of equipment may appear to be too large for the load. In such cases the equipment may be integrated into a system which could blow it sky-high if the circuit breaker failed to interrupt a short-circuit surge of

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power. This is not just a figure of speech since equipment has been' blown clear through plant roofs because of the devastating electrical forces created by short circuits.

Similarly, any electrical bus system carrying substantial power should be adequately supported. With heavy currents in two copper buses going in opposite directions, the buses will try to separate; with currents going in the same direction, the magnetic forces involved will tend to pull them together. Fantastic short-circuit forces may result in the system.

Fuses and circuit breakers

For many years now fuses have been supplanted by circuit breakers in most applications, but in some modern industrial equipment more up-to-date fuses may be used in place of circuit-
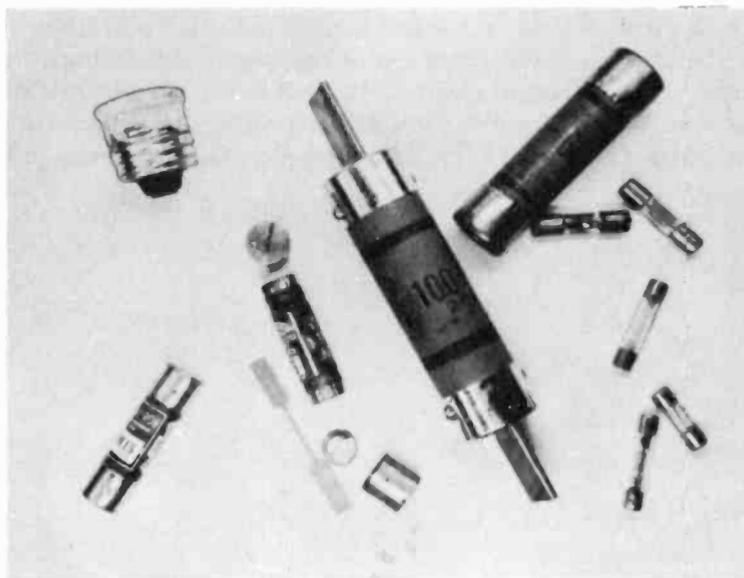
Fig. 215. *Fuses range in size from small instrument types to the giants having ratings of 100 amperes. Some of the larger ones have a replaceable element.*

breakers. Modern fuse design takes into consideration the interrupting ratings, and such fuses are quite different from those of 20 years ago. The power end of industrial equipment must be properly integrated into the plant system in accordance with code specifications, and should not be a haphazard, unplanned network with minimal branch-supply protection (Fig. 215).

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Summary

From the foregoing, it is readily apparent that there are substantial differences between communications and industrial electronics equipment. Industrial equipment often must stand up under more severe environmental conditions, usually operates under heavier duty cycles, and furthermore, is likely to receive less attention from maintenance personnel. Some of the differences in diagrams, circuits, components and methods, as well as installations, have been discussed.

In regard to specific location of electronic control equipment, it will often be installed in an inconvenient place, from the technician's viewpoint, since in many cases control equipment was often added long after the plant had been in operation, and after most of the available space had been assigned to production machinery and materials-handling equipment.

Finally, it is well to remember that in industrial electronics the reader is not facing something out-of-this world, something strange and unusual in terms of electronics, despite certain obvious peculiarities of this equipment. Now let us look at specific equipment — their uses, circuits and operation, in the chapters which follow.

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3 * industrial generators

THE principles of induction heating were developed well before our modern high-power vacuum tubes were in general use. Dielectric heating, on the other hand, found its greatest impetus with the increased use of many kinds of plastics, and with the growing demands from the food industries which must process, preserve and prepare expanding quantities of fine products to serve more demanding and particular customers. Dielectric heating also has had to meet the challenge of mass production in the furniture industry, of great importance in electronics in terms of cabinets and speaker boxes. Not all cabinets can be made from plastics, but even there dielectric heating does its part. In either case, induction or dielectric heating, the requirements for high-frequency power are substantial.

First, let us examine briefly the principles of these two kinds of heating, and thereby learn their differences. After that we will take a look at the equipment producing the necessary energy for the processes, and discuss servicing and other problems.

Principles of dielectric heating

In dielectric heating, an object made from a nonconducting substance is placed in a dielectric field; in other words, in the field formed by the plates of a capacitor. The electrodes of a generator may vary in size and shape, but they will always constitute some form of capacitance. When a material is put into such a field, the field will penetrate all through it. There is no absorption and no deflection — and it goes right through.
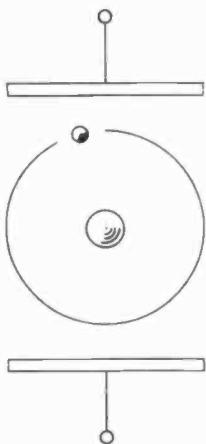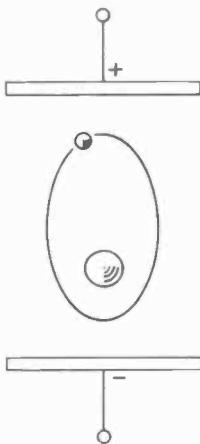
Fig. 301. *Normal electron orbit of atom (a) is distorted by dielectric field (b) created when voltage is applied to plates.*

This means that all the molecules (and even the atoms) of the material are subjected to this field.

An atom consists of a nucleus with electrons whirling in orbits around it. Fig. 301-a shows a single nucleus with a single electron. Of course, in practically all matter there is more than one electron in each atom. An electron is a negative charge. Placed near a negative electric-field charge, the electron will be repelled. If we let it meet with a positive-field charge, it will be attracted. Thus if we place the atom between two plates and apply a strong electric field to them, the path of the electron will be distorted as a result of such forces of repulsion and attraction. This is shown, greatly exaggerated, in Fig. 301-b. To accomplish this distortion of the electron path, we must apply a sizable amount of energy. This energy will be released when the electron snaps back to its original position when the field is turned off. However, since the energy is now in mechanical form, it has no place to go except into another form of energy — heat.

This, somewhat simplified, is the principle of dielectric heating. It follows that the heating which originates at the atomic level must be uniform throughout the material and very rapid. This is indeed the case, and the source of two of the major advantages of dielectric heating. It follows also that the more often we distort the electron orbit, the greater the amount of heat generated;

thus frequency is important. As a matter of fact, unless you use very high frequencies, dielectric heating is ineffectual. (As you will see, this same relationship is not necessarily advantageous in induction heating.) There is, of course, a practical limit to the frequencies we can use for dielectric heating, but the limit is imposed by the equipment, not by the principle. This kind of rf can cook any material which is nonconducting, even hot dogs and steak. But since hot dogs are not entirely nonconducting, some other principles are involved, and we will discuss the cooking of food at microwave frequencies later.

Principles of induction heating

Induction heating was discovered very early, when scientists noticed that the core of a transformer becomes warm, and sometimes very hot. This heating is due to two effects. First of all, there is a characteristic of magnetic materials which we call hysteresis. If we send a current through a coil which surrounds a ferromagnetic material such as iron or steel, we will magnetize this material. When we turn off the current, most of this magnetism disappears, but a small amount of it is left. We call this residual magnetism. To get rid of it, we must reverse the current and magnetize the metal in the opposite direction. This takes a certain amount of initial energy to remove the existing low-level residual energy. The energy required to remove residual magnetism can thus be considered a loss, and this is what we call the hysteresis loss. As with distorted atoms in dielectric heating, so with the magnetized domains in the metal. We have no place for the energy to go but into the metal as heat. One of the basic scientific laws of nature is that energy cannot be lost, only converted to some other form of energy.

At lower frequencies, this hysteresis loss, and the heat resulting from it, is very significant. As a matter of fact, the early induction-heating installations used only 60-cycle current, and many large electric furnaces operating on the induction principle still operate this way. These are not very likely·to require the attention of an electronics technician, so we will not spend any time on the subject. But, remember, a lot of steel and iron is melted this way.

Above 10,000 cycles, the hysteresis effect, although still present becomes insignificant compared to another effect — eddy-current heating. Eddy currents are circulating currents created in a metal or any conducting material when it is placed in a changing magnetic field. The electric induction coil has a current produced

in it when a magnet is moved in or out of the coil. You can try this easily yourself. Even a small magnet moved into the center of a coil of wire will create a deflection on a volt-ohmmeter in its sensitive ranges.

The surface of any metal object can be regarded as a coil. True, this requires a little imagination, but suppose that, as the result of the magnetic field, the current in the metal has a favorite path. The current might prefer to run in a circle, and thus resemble a coil. In fact, this is about what happens. The changing magnetic field not only *induces* the current in the metal, but also determines the *path* the current will take. Many of these currents in various localities in the metal, added together, form a substantial transfer of energy, which again is converted directly into heat. Since these currents occur in swirls and configurations reminiscent of eddies in a stream, they are called eddy currents. (They can be made visible by spreading the surface of the metal with very finely divided iron powder.) Note that in induction heating the object to be heated is placed in or near a coil, hence the name *induction*. (Eddy currents are *induced* currents.)

Eddy currents are not confined to low frequencies and, again, there is no *theoretical* limitation to the frequency which can be used for induction heating. But, as before, there are practical limits to the frequencies used in induction heating, mostly due to the equipment and some due to Federal Communications Commission regulations. The FCC has the power to regulate all forms of radiation as to frequency and power.

And there is yet a third kind of limitation on the frequency used in induction-heating installations — the so-called skin effect. As electrons are affected by electric charges in a field so they are also influenced by magnetic fields. In a TV picture tube, for example, a stream of electrons is sent out from a "gun," and are attracted by a strong charge (a very high voltage) on the anode of the tube. But to make the picture, this stream of electrons must be moved back and forth from side to side and from top to bottom like a paintbrush used to paint a wall. This motion of the electron beam is accomplished with strong magnetic fields created by the "deflection" coils. In other words, a magnetic field deflects the electrons from their original path.

This happens to electrons, no matter whether they are in a picture tube or in a metal wire. And, to make it even more insidious, the electrons will create their own magnetic field, which helps to deflect them. For moving electrons are like a moving conductor in a magnetic field — they will have a force exerted on

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them (as in a motor). The moving electrons can also be regarded as a current in a wire, creating a magnetic field by themselves. The result of all of this is that, when the magnetic fields become stronger, as they do when the frequency goes up (the induced magnetic field in a coil contains more energy at high frequencies), the currents in a wire or any conducting material will be forced, by their own magnetic fields, to the outside of the material. This means that in induction heating, as we increase the frequency, the material will no longer be uniformly heated, but instead will be heated more thoroughly on the outside than on the inside.

This effect is used to control the depth of induction heating. In fact, with this kind of installation we can do what we could never do with a flame applied to the surface of a metal object — we can accurately control the depth of surface hardening.

Induction heating is very fast; therefore, we can bring the outside of a sizable chunk of metal to a red-hot state while the center is still cold. If we do this fast enough, we can cool the outside again so fast that the metal has been made red-hot on the outside without ever heating in the center. Or, induction heating can be a local effect. In other words, we can heat a part of the surface *or* the center by specially shaping our coil to create eddy currents in a particular way only, thus avoiding undesirable heat in the rest of the metal. We can also vary the depth of heat by varying the shape of the coil. These controls are accurate enough so that one piece of work could be heated to many different temperatures over its mass.
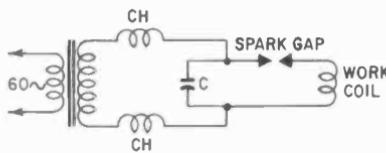
Fig. 302. *Spark-gap induction generator has its operating frequency determined by capacitor C and the work coil.*

Induction heating at higher frequencies, since it does not depend on magnetic effects in the metal itself, can be applied to any metal and, in fact, any *conductor*. Thus glass, which we normally consider an insulator, becomes conducting when we first heat it to 600°F. We can then apply induction heating to it.

Induction generators

Many induction generators are extremely simple devices. That

shown in Fig. 302 may look like a primitive generator — and indeed they stem from the days before high-power vacuum tubes were generally available — nevertheless, their operation has been so satisfactory that they remain in use today.

The generator consists of a power transformer, a spark gap and a tuned circuit, of which the work coil forms the inductance. Whenever the voltage reaches a level sufficiently high to break down the gap, a damped oscillation takes place in the tuned circuit. This happens 120 times a second: 120 times per second the generator puts out a short burst of high-frequency current. Fig. 303 shows the waveform produced by this type of generator.

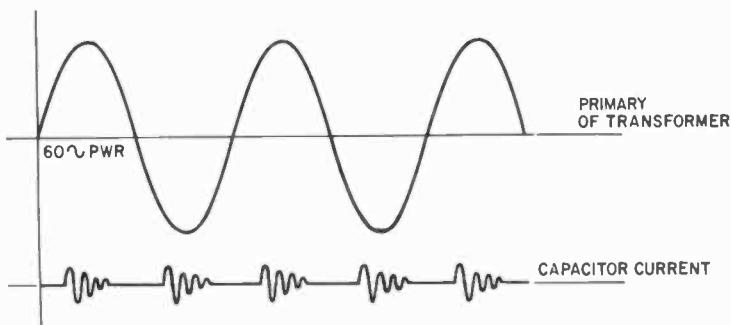Generators of this type have been made to supply up to

Fig. 303. *High frequency of spark-gap generator is modulated at a 120-cycle rate by the 60-cycle power line.*

several hundred kilowatts. Notice the chokes, which keep the rf from entering the power transformer, and of course the gap itself keeps the coil from shorting the power transformer. The coil would present almost a direct short to the transformer, for induction-generator work coils have few turns made from heavy wire or bus bar. Although a single gap is indicated, there is actually a multiple gap, with as many as 50 to 100 gaps in series. Gap spacing is critical and determines the breakdown voltage. Usually the gaps are made from pure tungsten to resist excessive burning. Cooling with air is often used on the gaps.

The frequency of spark-gap generators is determined by the tank circuit. Thus, by changing the work coils or the capacitance in parallel with them, you can adjust the frequency to whatever is desired. However, remember that the coil values will change with the work-piece in place, and the adjustment for frequency must be made when it is properly placed in the coil. Also the

heating of the work will change these values measurably, and a compromise between the cold and hot work-piece must be made. Although the depth of heating is affected by the frequency, this is not an extremely critical affair, except in some special cases where great pains must be taken for frequency accuracy.

The only serious problem likely to arise with the spark-gap generators is burning of the gaps. These must be periodically inspected and serviced, or replaced. In many cases, honing the gap surfaces will restore them for another tour of duty. Gap clearance must be carefully adjusted, and this *is* a critical job. Even a small change in each gap spacing would change the total
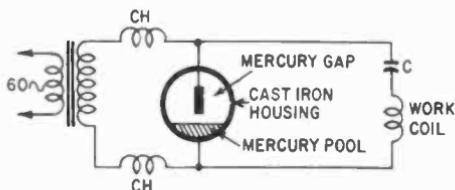

Fig. 304. *Mercury under pressure prevents vapor from forming and making the arc uncontrollable.*

gap distance considerably, and thus would affect the output of the generator. In fact, the accepted way of adjusting the current through the work coil is to change the gap, so that the spark will persist over more or less of the half-sine wave from the power transformer. The earlier the gap breaks down, the longer it persists, and the greater the average power produced by the generator.

Because gap problems are continual with such generators, more modern versions of the spark generator use mercury-arc spark gaps which last for a very long time. The principle is shown in schematic form in Fig. 304. It is essentially the same kind of generator with the simple difference in the gap. Although the one shown is a single gap, there are also dual gaps with two electrodes in the chamber. Essentially, the gap is a cast-iron chamber with a pool of mercury in the bottom. The chamber is filled with hydrogen gas under low pressure. Without the added pressure, the chamber would soon be filled with mercury vapor, and the duration of the arc might become uncontrollable. The electrodes are specially-tipped copper rods which can be raised and lowered for gap adjustment. The hydrogen above the pool is sometimes stationary and sometimes is circulated continuously from a large

tank. These mercury-arc type generators are available up to about a 40 kw rating.

Frequencies used with these generators, as well as the air-gap type, vary with their applications. For melting purposes, frequencies from 20 to 80 kc are used, and for other applications the frequencies may go as high as 400 kc. Such high values are primarily used where only surface heat is needed, as in case hardening and some kinds of brazing. Maintenance problems with these mercury-arc generators will be minimal, consisting mostly of keeping the electrode tips clean and adjusted and the work-coil connections free of corrosion.

When the triode power tube was developed, one of its early applications was in induction-heating generators. Fig. 305 shows
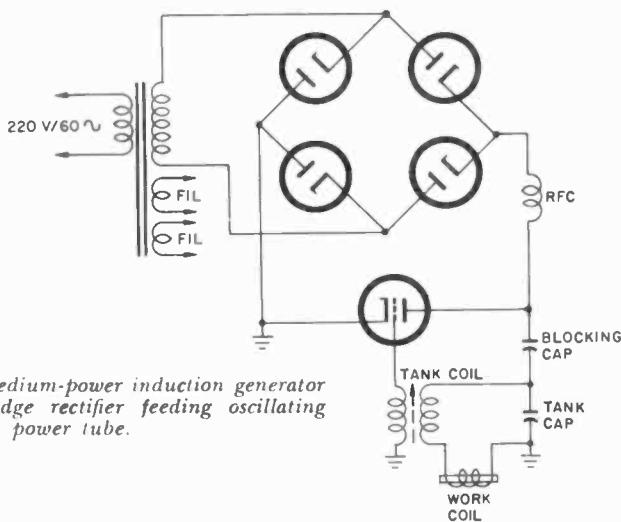

Fig. 305. *Simple medium-power induction generator has unfiltered bridge rectifier feeding oscillating power tube.*

a typical induction-heating generator of moderate power. Notice that there is a power supply with a full-wave bridge rectifier but no filter. In communications, we would not want to tolerate 60-cycle modulation (or, in this case, 120 cycles) of the generated rf, but in heating, it is of no concern.

As you can see, the oscillator is a simple one with a tuned plate load and a feedback coil, while the work coil is part of the plate tank circuit. In some cases, the work coil makes up the entire plate inductance.

Since the work coil directly surrounds the heated object, the coil will become quite hot itself, if only from the radiated heat

from the work piece. For this reason, the work coils almost always consist of tubing, with cooling water circulated inside of them, or of a coil with a special copper cooling tube welded parallel to the coil proper. This makes the connections of the water-cooling system and the tank somewhat complicated. Since the bore of these tubes is not large, and the cooling efficiency depends on the amount of water that can be sent through them, the opening must be kept clear of deposits. For this reason, such an installation will often include a water softener, or a large supply of distilled cooling water which is cooled and reused. Such a system is often a completely closed one to avoid contamination of the cooling water. This type of cooling requires insulated cooling supply lines, and part of the maintenance procedure is to see that these lines are in good condition.

Problems with this type of generator revolve generally around the failure of the tubes, either the rectifiers or the oscillator. Such troubles are easy to locate. When the ac voltage on the rectifier plates is adequate but the dc is sagging, the rectifiers are due for replacement. When the dc voltage is adequate but the oscillator fails to produce sufficient current, the tube may be ready for replacement. Most generators have meters in both the plate and grid circuits, and poor operation shows up immediately on these meters. Of course, other sources of similar trouble must be eliminated for, example, poor connections to the work coil, etc.

Remember when "poking around" in this type of generator that you are probably dealing with potentials up to about 10,000 volts, so be *extra* careful and take all the necessary precautions. Check points are generally brought out to external measurement terminals in any case, so that you need not get into the "hot" generator at all.

Since the work coil is always external to the generator, the circuit of Fig. 305 is a preferred one because it avoids high-voltage dc on the work coil. This does not mean that it is safe to touch the coil with the generator on. Very bad rf burns could be the result. Also, metal objects such a wristwatches, rings or tools should not be brought within the field of the generator — they would promptly heat, and perhaps melt. Nor is it wise to put test instruments in the vicinity of a "hot" coil; the plastic case may survive but the "works" may end up as a molten lump of metal inside the case.

The essential part of the generator, the work coil, may not look

much like a coil at all. Fig. 306 on this and the following page show some typical work coils for induction generators. These coils are shaped and sized to accomplish a precise heating job, whether this be an even, or local, heating problem. Notice the cooling tubes provided to keep the coil itself from becoming red-hot. Fig. 307 shows such an induction generator in operation for the hardening of automotive transmission parts. In the automotive industry, such generators are extremely common.

For higher powers, two or more oscillator tubes are often wired in parallel. The power supply then is likely to become a three-phase job. In this way, powers of hundreds of kilowatts can be obtained. The three-phase power supply is typical of one we will discuss under dielectric generators.
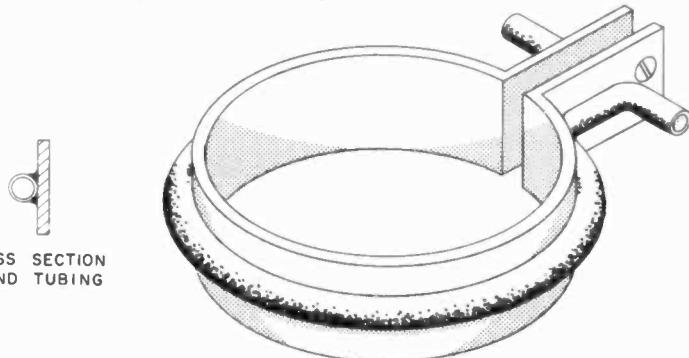
CROSS SECTION
ROUND TUBING

SINGLE-TURN COIL WITH COOLING TUBE SOLDERED TO OUTSIDE

CROSS SECTION

TO WATER
CONNECTIONS
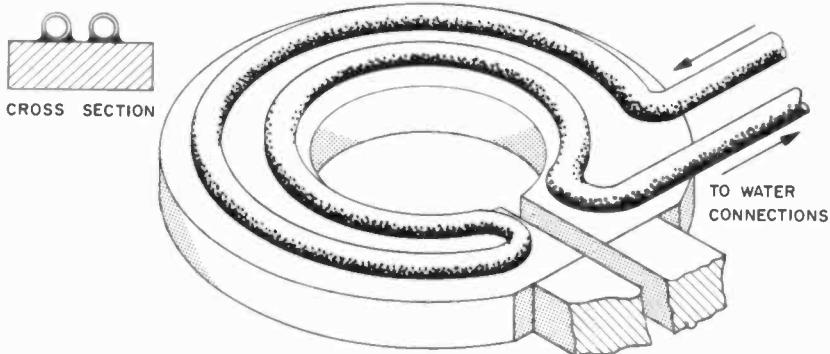
FLAT SINGLE-TURN COIL WITH REVERSED LOOP OF COOLING TUBE SOLDERED TO INSURE ADEQUATE COOLING

Fig. 306-a. *As generator power increases, cooling problems also increase.*
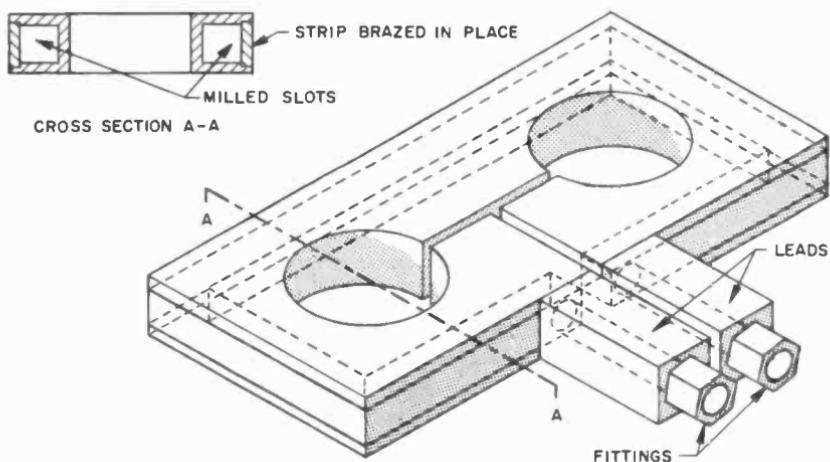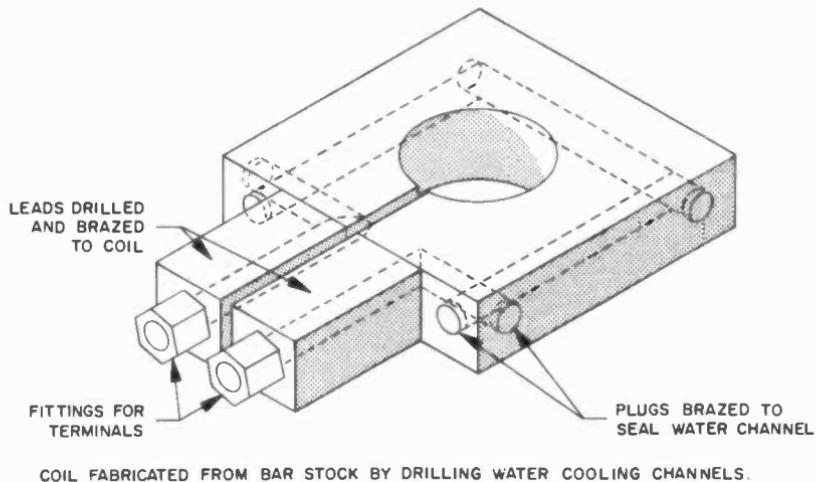
LEADS DRILLED AND BRAZED TO COIL

FITTINGS FOR TERMINALS

PLUGS BRAZED TO SEAL WATER CHANNEL

COIL FABRICATED FROM BAR STOCK BY DRILLING WATER COOLING CHANNELS.

STRIP BRAZED IN PLACE

MILLED SLOTS

CROSS SECTION A-A

LEADS

FITTINGS

COIL FABRICATED FROM BAR STOCK BY MILLING WATER COOLING CHANNELS.

Fig. 306-b. *Water-cooled coils of this type require considerable machine-tool work.*

When checking the meters on the equipment, it is well to remember that too little plate current shows lack of emission. Too little grid current would show either low emission, poor tuning or other maladjustment in the circuit. Too much grid current with low cathode current might indicate that the tube has become gassy.

These tubes are often so large that special setups have to be made to test them. It is, therefore, generally necessary to judge

the condition of the tubes in the actual working circuit. Tubes should last up to 2,000 hours of operation. Beyond that not much can be expected, although many tubes will last longer. At 1,500 hours, replacement of the tube should be considered.

If the equipment is used intermittently, it will be better to arrange for the filaments to be kept hot. A large tube (or even

Fig. 307. *A 25-kw induction heater is used to harden valve stems.* (General Electric Co.)

a small one) will be damaged more easily and show more wear from being turned on and off many times than from proper use. Remember also that most equipment using large tubes has a delay timer which prevents the plate voltage from being applied to the plate before the filament or cathode is properly heated, since this could seriously damage the cathode. Many of these large tubes (as well as the work coils) are water-cooled and proper maintenance of the cooling system is absolutely essential.

Repair of large induction generators is usually not difficult, for, in essence, these are very simple devices.

Dielectric generators

Dielectric generators are essentially similar to induction generators with one important difference. In the former the work is placed in the tank *capacitance* while in the latter it is placed in the tank *inductance*. With the work inside the capacitor which is part of the tuned circuit, the chances are that as the work heats

up, there will be a considerable change in the frequency of the generator. Fortunately this is of little importance in dielectric heating except that a drastic change of capacitance may require that we change the timing of the generator, and leave it on longer or shorter for a particular kind of work. This timing is always established by experiment in any case and, once it has been set for a particular type of work, it can usually remain at that adjustment.

Basically, there are two kinds of dielectric generators, the *direct*-loaded type, in which the electrodes are actually a part of the tank circuit, and the *impedance*-matched type. In the latter we take the energy out as we would in any tank circuit by a matched separate tank, with the work piece, the electrodes and the coupling coil tuned to the generator frequency.

The impedance-matched generator has some advantages. In the first place, it avoids the possibility of having dielectric breakdown of the work damage the generator, since the matching coil has only a few turns and, in effect, constitutes a current transformer. Second, it is easier to remove the electrodes from the generator and operate them at a remote point. And, third, it affords a simple way of adjusting the output power of the generator by changing the coupling of the two coils.

Fig. 308 shows a typical direct-loaded generator and Fig. 309 a typical impedance-matched type. Note again the absence of any filter capacitors. However, the generator will be supplied with a filtering system on the primary or secondary side of the transformer for the purpose of removing any high-frequency energy from the power-line connection. Otherwise, the power line would act as a radiator and could cause a great deal of interference. The FCC has set up strict rules about this, as we shall see.

Dielectric generators come in many shapes and sizes, and for many purposes. Fig. 310 shows a generator inside a bag-sealing machine used to seal plastic bags such as are used for peanuts, etc. Fig. 311 shows a machine specially designed to seal seams on plastic swimming pools on the job. In this case, it has to be an impedance-matched type, since the electrodes are remote from the generator. Similar generators are used in furniture shops to dry glued joints. Where formerly a chair would have to remain clamped for as long as 24 hours after gluing, now the glue can be made to set in minutes, thereby greatly increasing the production of all kinds of wood products.
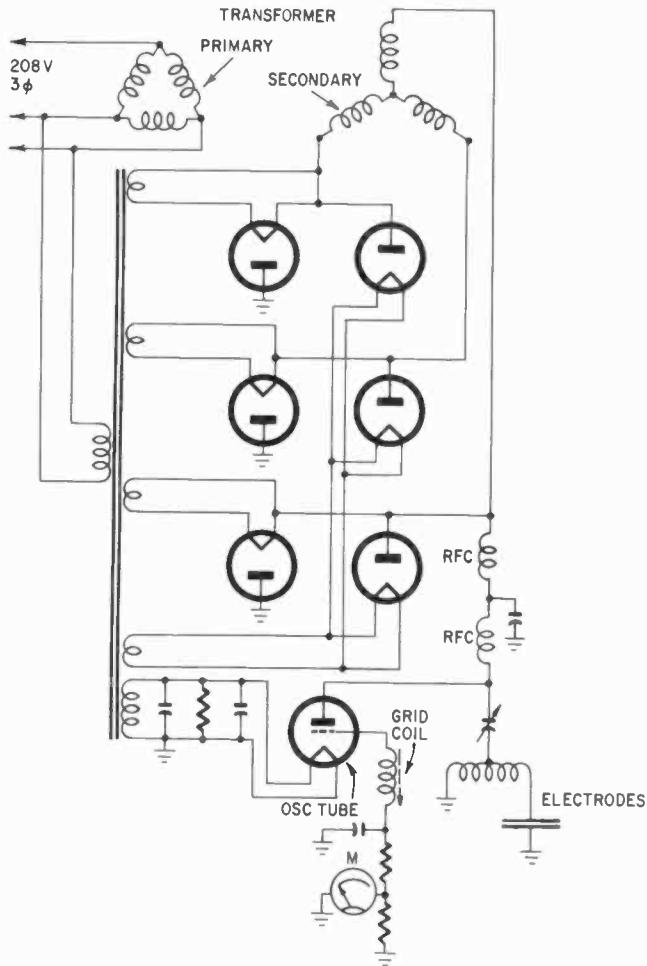
Fig. 308. *Simplified schematic of a typical direct-loaded dielectric generator has dc supplied by a three-phase full-wave rectifier.*

Sometimes a generator will include a small fluorescent tube which will light when the generator is on, due to ionization of the mercury vapor in the tube when exposed to the field of the generator. This is a positive indication that the generator is on, and a signal to the operator to keep his hands out.

A similar indicator can be made by the technician. Fig. 312 shows a simple one consisting of a small neon bulb on a rod, and a battery. The small battery is not quite sufficient to fire the tube
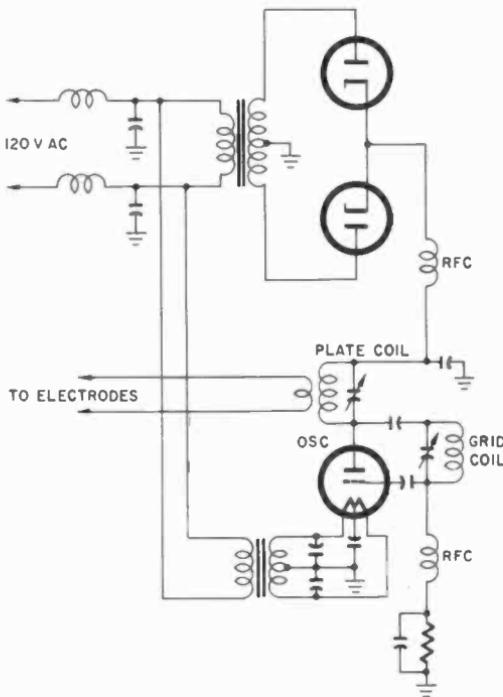
Fig. 309. *Simplified schematic of a typical impedance-matched dielectric generator.*

but, as soon as the tube is moved into the field of a generator or transmitter, the resulting ionization will light the bulb and the battery will intensify the glow. This makes it a very sensitive probe for detecting stray fields, and is strongly recommended when checking a dielectric or induction-heating installation, since exposure to an intense field can be dangerous.

The electrodes that are provided with the generators may vary considerably in shape and size. Fig. 313 shows several unusual shapes in use. To heat large areas such as are encountered in the lamination of plywood sheets or plastic on plywood, large electrodes are needed. To avoid excessive capacitance from such large electrodes, they are broken into strips, separated by about their own width. This will do an adequate heating job, particularly if the strips on the opposite side of the work alternate in location.

Ordinary dielectric-heating generators have been used in food preparation. One example is the hot-dog cooking arrangement in a vending machine, shown in closeup in Fig. 314. The hot dog is
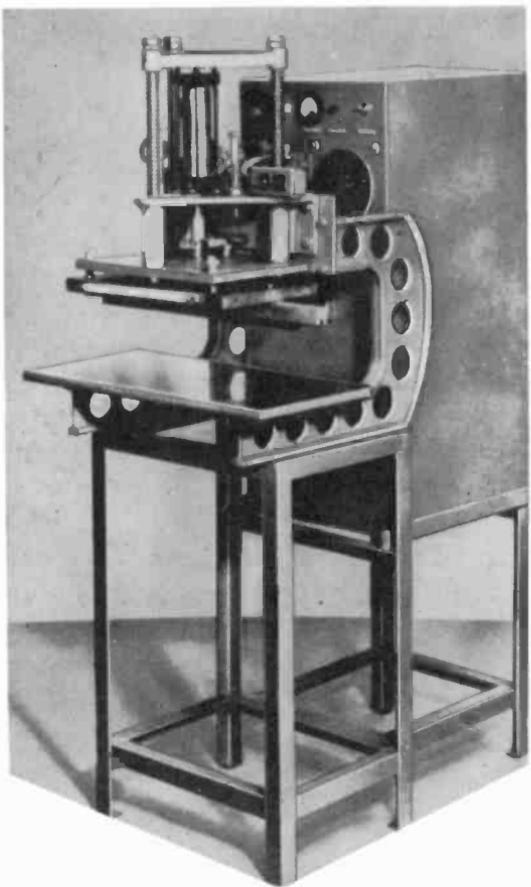
Fig. 310. *The working surfaces of most dielectric generators are designed for specific jobs. This one seals plastic bags.*

actually passed through the coil of the push-pull generator, but the effect is the same as in dielectric heating. However, this is an unusual installation and you will probably not encounter too many of this type.

The repair and maintenance of dielectric generators is similar to that of induction generators. Values of tube currents at the proper voltages are your most important indicators of the proper functioning of the generator. In the case of impedance-matched generators, tuning is very important. This will sometimes be adjustable from the outside, and in other cases will require the movement of taps on the coil inside the generator.

Dielectric generators are used for producing mass quantities

of identical or very similar products, and the final criterion of how well the generator is doing its job is the shape and condition of the end products.
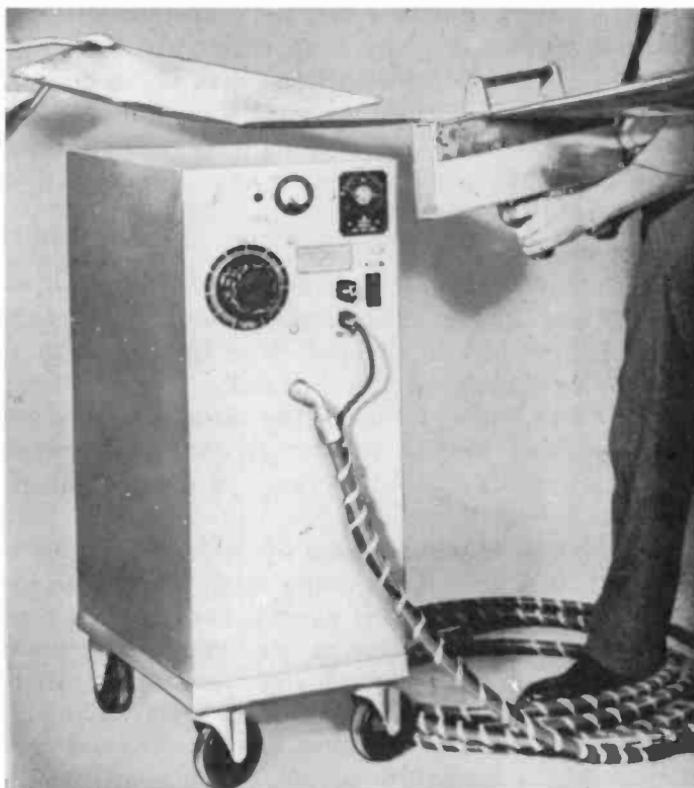

Fig. 311. *This impedance-matched generator uses a long cable to take the work head to the job.*

Microwave cooking

Radar cooking is a process similar to those we have just discussed, except that a much higher frequency is used. In radar cooking, we deal with a frequency of 2450 mc — the 10-cm region. The power in these areas must be generated by special tubes, and mostly the manufacturers use magnetrons. Klystrons have been used in some commercial installations.

The principles of microwave cooking are actually somewhat in question. Some of the effects are due to dielectric and some to induction heating. No electrodes are used. The material, in this case usually meat of some kind, is placed in front of a waveguide, and

a rotating vane is used to make sure all of the material is exposed to the same amount of radiation. In this way, both the electrostatic and magnetic fields come into play. Where the material, such as some of the fats, is an insulator, there will be dielectric effect. Where it is a conductor, there will be induction effects. There are borderline regions in which both effects will show up. However, there is the possibility that there may be other factors involved, for example, resonance of some sort. Although it is not yet fully understood, microwave cooking is very effective; a portion of meat which would take many hours to cook ordinarily can be cooked in minutes by microwave.

Ultrasonic generators

Although the principles of ultrasonic generation have long been familiar and applied to a limited extent, their application has jumped enormously in the past 5 or 10 years with the development of new kinds of efficient and relatively inexpensive transducers. Thus, where formerly the ultrasonic generator was mostly used in depth finders and similar low-power applications, now there is a rapidly expanding range of application of ultrasonic devices.

Ultrasonics is now so widespread a whole book could be written on the subject. It is used for cleaning small parts, washing without soap or detergent, thickness gaging, flaw detection, medical diagnosis, agitation, homogenization, machining of extremely hard parts, dental drills, remote controls and many, many other applications. We will discuss only the principles involved and the generators needed to provide the ultrasonic power, and from this you will be able to recognize the necessary service equipment and procedures to be used in maintenance and repair. Necessarily our account will be limited.

Basic transducers

There are in ultrasonics three basic kinds of transducers. The third, a new material, is used only for low power applications. The principal power transducer until recently was the magnetostrictive type. This depends on the principle that a magnetized metal rod, when subjected to a varying magnetic field in *addition* to the magnetizing force, will undergo contraction and expansion in length due to the changes in magnetic field strength. Conversely, such a rod will also respond to ultrasonic waves striking it by creating (when magnetized) a voltage in a coil surrounding it in proportion to the ultrasonic signal impinging upon it.

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The frequency at which a magnetostrictive transducer rod will vibrate is related to its dimensions (length and diameter) and to the material of which it is made. Thus a rod made from a cobalt alloy has different characteristics from a nickel rod (it will change
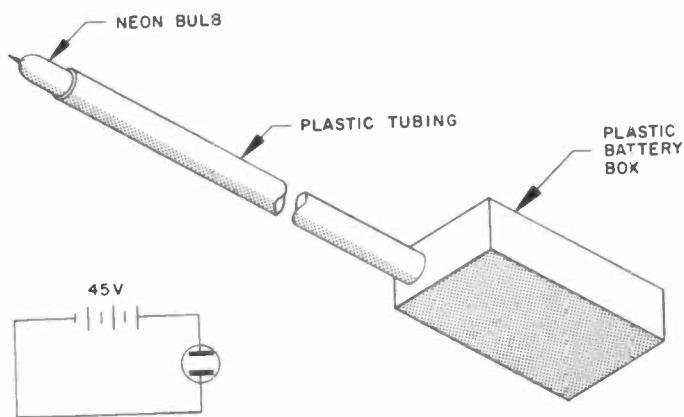

Fig. 312. *High-frequency field "sniffer" uses battery to make it more sensitive.*

length *much* more) but is more difficult to produce. In general, magnetostrictive transducers are not particularly efficient, and this has been one of the factors holding back development. In addition, due to the dimension tie-in, magnetostrictive transducers are limited in usable frequencies to the near-audio range, from about 20 kc to 50 kc, whereas other kinds now can be used practically, up to several megacycles and, in some special laboratory applications, have been operated successfully up to as high as 10,000 *megacycles (sound* waves!!)

Quartz crystals of a special cut have also long been popular. However, a quartz crystal which will transmit sufficient physical energy must be relatively large (or a number of them must be used in parallel) and is economically unfeasible due to the prohibitive cost of quartz crystals of this type.

Fig. 315 shows different ways in which the various kinds of crystal cuts will distort when electrical fields are applied. Transverse shear is obtained from a 0° X-cut of Rochelle salts, and a 45° X-cut gives double transverse expansion (shown exaggerated in Fig. 315). The 0° and 45° Z-cuts of ammonium dihydrogen phosphate, a modern synthetic transducer, give the
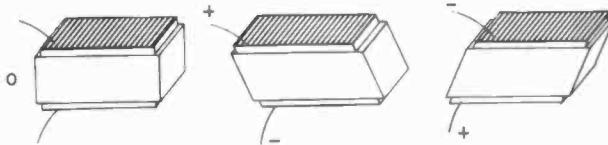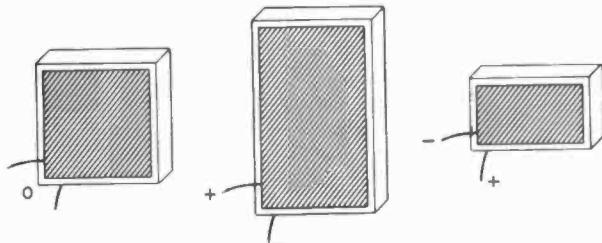
(A) THICKNESS SHEAR
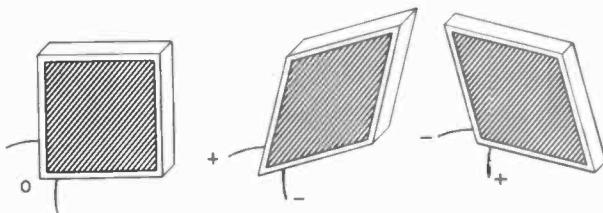
(B) FACE SHEAR
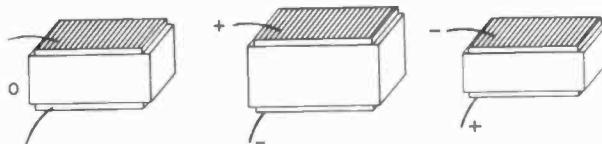
(C) THICKNESS EXPANSION

(D) TRANSVERSE EXPANSION

Fig. 315. *Piezo-electric crystals distort when subjected to a dielectric field. This change of shape is dependent upon the crystal type, cut and field polarity.*
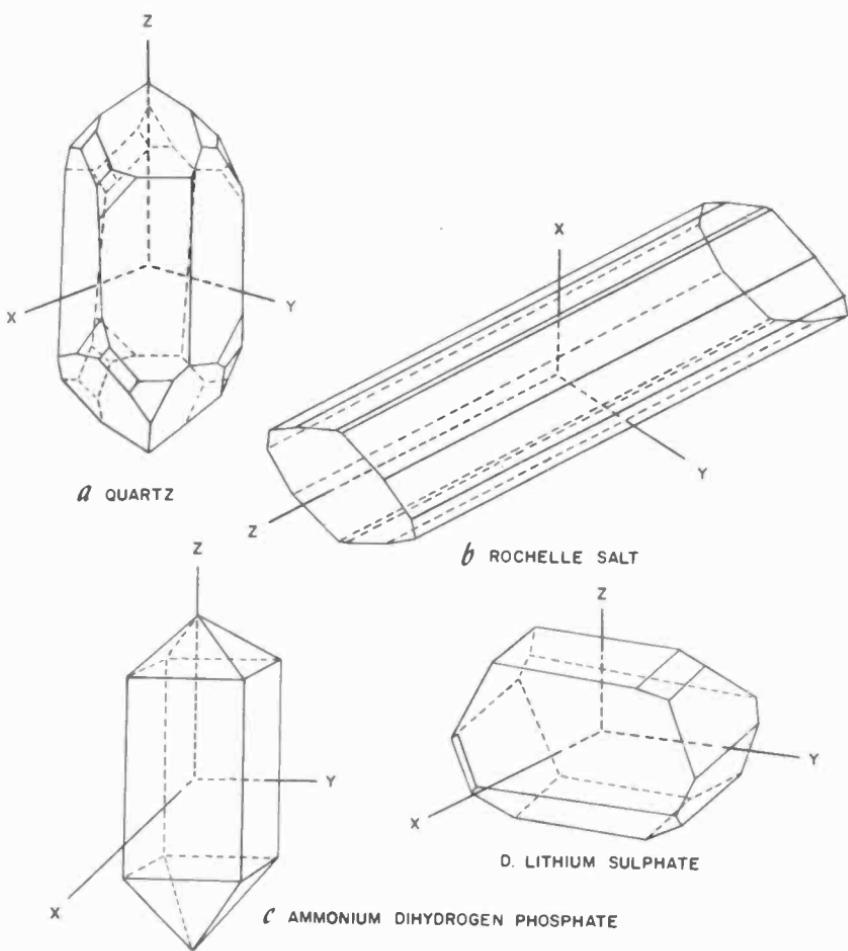
Fig. 316. *The principal transducer crystal materials and their crystallographic axes.*

In gaging or in detecting flaws in solid materials, the transducer is brought into direct contact with the material. In this case, the transducer is often used both as a transmitter and receiver, and a change in echo signal can be recorded and interpreted as some flaw.

What kind of generator is needed for such ultrasonic applications? It depends a great deal on the application since frequency and power requirements vary widely. Most cleaning generators

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for small parts do not need more than several hundred watts of power, but some larger installations run into several kilowatts. Frequencies also vary, but most cleaning operations are carried out between 25 and 50 kc although in some cases it may be as high as 1 mc. The value depends on the manufacturer and his experience with that particular application. Some operations can be carried out at several frequencies, whereas others are effective only at a particular one.
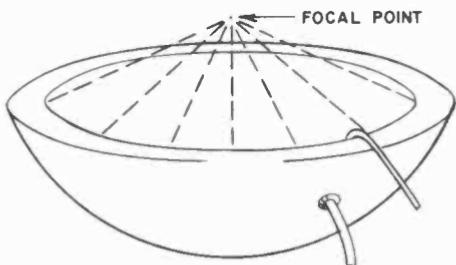
FOCUSED ULTRASONIC ELEMENT

Fig. 317. *Work placed in the focus will receive maximum ultrasonic energy.*

One typical generator is shown in Fig. 318. This is a relatively low-power unit such as might be used for an ultrasonic soldering tool. In this particular example, a special magnetic coil, coupled to the magnetostrictive transducer through a metal bar, provides the necessary feedback for oscillation. More often the feedback coil is wound on the transducer itself. However, here a special condition exists in which the frequency of the generator can take place in multiples and submultiples of the transducer's natural frequency, depending on the coupling between the work and the transducer. This allows the automatic adjustment of the system to the natural frequency of the entire system of transducer and bit. This frequency changes with the great variation in temperature and external loading by the soldering bit, which is attached to the transducer laminations. In this example, the transducer laminations are made from a cobalt alloy.

Ceramic transducers are not frequency selective as the crystal types are. Usually the ceramic type is operated well below its natural frequency or well above it, depending on size.

There is little basic difference between this type of generator, which can be made for the range from 50 kc to 1 mc or more, and the familiar class-C power amplifier in transmitters.

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Measurements

Gaging and measurements are a little different. The power requirements are much less. When the moving molecules in a dense piece of matter reach the end of that material and find a vacuum or just air, few of them find gas molecules to push so they bounce back against other molecules in the solid and start a wave back from the boundary layer. If we adjust the frequency of the original wave so the time it takes for it to travel out and back is exactly half a cycle or a multiple of it, we have a 180° phase shift for regeneration. Any deviation from this precise dimension would immediately show up as an improper phase shift. The diagram in Fig. 319 shows the basic circuit of this kind of gaging apparatus.
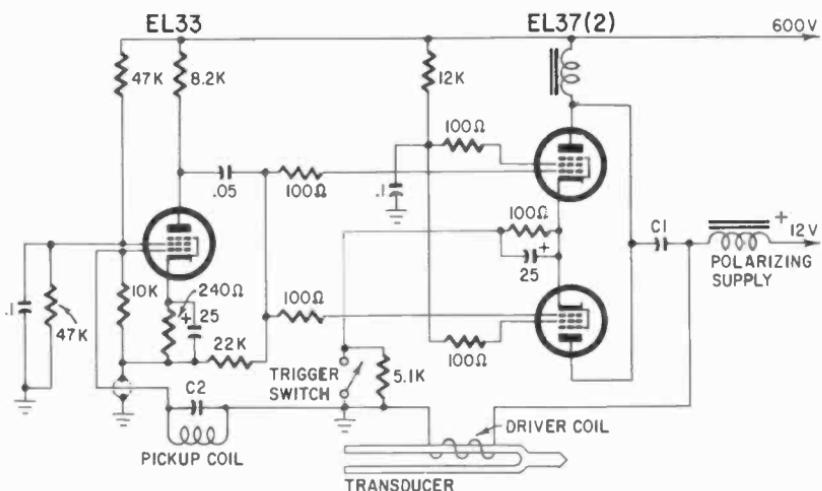

Fig. 318. *Generator for ultrasonic soldering tool.*
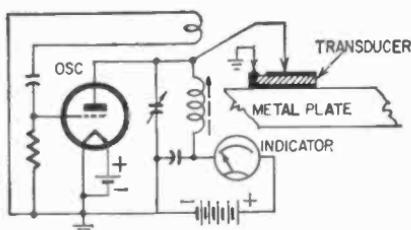
Fig. 319. *Basic circuit for an ultrasonic thickness gage.*

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FCC rules, which apply to all industrial heating equipment, are also applicable to ultrasonic generators. Fortunately, the latter are much easier to shield, since only the crystal need be outside the case and works just as effectively inside a shielded case of its own.

Miscellaneous generators

There are a number of other applications of electronic generators and oscillators, but they do not present any new aspects of electronics so much as they illustrate new uses of the medium. Low power oscillators are used in instrumentation and telemetering, control systems and high-frequency welding, to mention just a few.

Basically all rf generators operate on the same principles. The two criteria for oscillation, a gain of more than one and in-phase feedback, are valid in all cases.

4 * preventing interference

I n all industrial generator installations, careful attention must be paid to the possibility of creating radio interference, not only as a matter of good public relations, but also because of strict regulation by the FCC. The FCC rules for industrial generators are contained in Part 18, "Industrial, Medical and Scientific Uses of Radio."

Part 18 sets aside four frequencies for the operation of industrial heating installations without a license: 13.553 to 13.566, 26.960 to 27.280, 40.660 to 40.700, and 2400 to 2500 mc; (2.4 to 2.5 gigacycles) other frequencies may be used however, provided no interference is radiated.

Even in the assigned frequency bands, harmonic radiation must be carefully suppressed so that not more than 10 μv per meter signal can be detected 1 mile from the equipment. "Per meter" means a signal which can be picked up on an antenna 1 meter (a little over 3 feet) long. This figure also applies to equipment which operates at other than the assigned frequencies, but here the fundamental must also be suppressed to that extent. Furthermore, the same 10-μv-per-meter limitation applies at a distance of 50 feet from the power line to the equipment. This is to prevent the power line from acting as a radiator (antenna) for those frequencies.

All equipment must be grounded, and this often reduces radiation too, particularly if the equipment is housed in a metal cabinet. However, more drastic shielding is often necessary. In some cases,

the entire room may have to be shielded, an expensive operation.

Shielding has its own particular requirements. For example, if the shielding material is a mesh, care must be taken to use a small enough mesh. Any openings greater than a quarter-wavelength would be like no shielding at all.

Doors and windows must be covered with the shielding material, and here particular attention must be paid to bonding the various sections. Usually a bonding strap is used every foot or so. At the hinge side of a door, flexible braid is used; for the other side of the door, a pressure contact must be made.

If commercial equipment is installed, the manufacturer usually contracts to install the generators in accordance with all applicable FCC requirements, and guarantees the installation will not generate objectionable interference.

Rf heating interference can be detected first of all at close range with a probe, and secondly with a shortwave receiver. If, during the tests, the equipment is turned on and off in a particular pattern, it will not be difficult to find the 120-cycle modulated signal
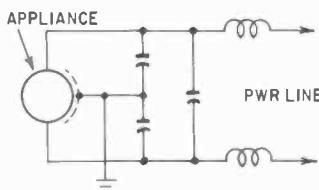

Fig. 401. *A filter of this type will remove the more stubborn types of interference.*

and identify it. Equipment manufacturers often maintain completely equipped detector trucks which can check with sensitive calibrated equipment for all interference over the required distances. For most purposes, a sensitive communications receiver with adequate frequency coverage can give a reasonable indication of whatever interference may be generated. Since these frequencies are close to some TV intermediate frequencies, this is where most of the trouble is found.

Although its monitoring stations continuously check the various frequencies used, the FCC usually does not take action until a complaint is received. The FCC has considerable power, and by legal action can shut down factories if the owners are uncooperative about correcting violations.

Interference sources

Many types of industrial equipment can create interference, even a simple motor or generator commutator. Part of industrial electronic servicing is the elimination of such interference, no matter what its origin.

Generally, interference is transmitted over and radiated by power lines and is quite easily controlled, once it is located. One simple way to locate a source of interference is to switch off one device after another in a plant, to determine if it is the trouble-maker. It is best to wait until night when the plant is shut down, or on weekends, and turn on one machine after another until the offending equipment is located.

Fluorescent, mercury-vapor or cold-cathode lights are notorious sources of radio interference. Any kind of a gas-discharge device, such as a thyratron, is next on the list of suspects. Consider all devices which may continuously or intermittently create sparks — switches, thermostats, commutators, rotary converters, vibrators or even loose connections in any equipment. Static charges on belts
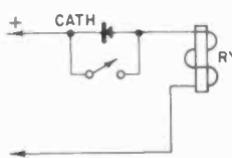

Fig. 402. *Rectifier will reduce switch contact burning when the coil field collapses.*

and pulleys may be as responsible as electronic precipitation equipment, which electrostatically removes dust from the air or soot from smoke. Any prime mover such as an internal combustion engine may be causing interference with its spark plugs.

If these simple methods fail to locate the trouble, try using a receiver with a loop antenna. The interference may not be located within the plant but be generated by something else nearby. The swiftest way to demolish accusations of interference is to locate its true source. With a loop-equipped receiver, converge on the suspected location from several directions or take "bearings" on it from a circle around the area. This should quickly locate or even pinpoint the interference source. For example, high-voltage insulators in substations as well as on power poles, when dusty or wet, may create a great deal of noise in radios. If power

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line equipment is responsible, it must be serviced by the utility company.

The simplest interference filter is a capacitor across the terminals of the offending device, which effectively bypasses the rf to ground through the powerline. Such very simple filters have, however, one serious disadvantage. With a particular inductive load and a particular size capacitor, the interference may be *increased* because the circuit may become resonant to the fundamental or some harmonic of the main interference frequency.

In that case, more effective means such as the filter shown in Fig. 401 must be used. Here inductors as well as capacitors have been used. The inductors can be rf chokes wound from wire heavy enough to carry the load current, and the capacitors should be at least .05 μf and the proper peak-to-peak voltage rating.

In a 120-volt ac circuit, the capacitors must have a working-volts rating of at least 250; in a 220-volt circuit, at least 380. Coils must also be properly insulated for the voltage, and the entire
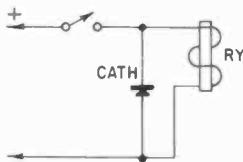

Fig. 403. *Rectifier across coil shorts the counter-emf generated by collapsing field around coil.*

assembly housed in a metal box or cabinet which meets safety codes. The filter of Fig. 401 can be doubled and tripled to make it more effective, but in the majority of cases the single section is adequate.

Relays are another possible source of a great deal of interference. When the circuit to a relay coil is broken, the voltage across the coil tends to rise sharply due to the field remaining around the coil. This voltage appears across the contacts which open the circuit, and thus will cause arcing. This can be suppressed usually by shunting the contacts with a capacitor but, again, the capacitor, if not of exactly the right size, may make matters worse. Too large or too small a unit may make the arcing worse.

A rectifier across the contacts will be more effective (Fig. 402). Since the voltage built up by the collapsing magnetic field of the coil is opposite to the normal flow of current, this generated

current will flow through the rectifier when the contacts are opened, but the normal coil-energizing current can not.

Another method is to shunt the coil itself with the rectifier (Fig. 403). To the voltage generated by the coil, the rectifier will look like a virtual dead short, and the field will not build up sufficient voltage to arc across.

A capacitor across the coil has a similar effect. But, to be really effective, the capacitor must be very large and then the relay operation will be slowed, since, to attract the armature the capacitor must be charged. To break the contact, the capacitor must be discharged first, as the energy stored in it will continue to hold the armature. Thus a large capacitor across a relay coil can be used only when the speed of the relay is not critical.

One of the worst offenders in causing radio interference is the fluorescent lamp and its cousins the cold-cathode and mercury-vapor lamps. During an ac cycle, the gas-discharge lamp, which includes the fluorescent lamp, is not on continuously. When the voltage across it drops low enough, the lamp will extinguish; when the voltage gets high enough again, it will arc across to light. However, our slowly reacting eyes, helped by the persistence of
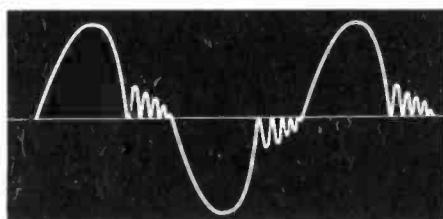

Fig. 404. *Waveform generated by repeated extinction and striking of arc within the fluorescent lamp is at frequency much higher than that provided by the power line.*

the fluorescent powders (coating on the inside of the glass that continues to glow between cycles) makes the lamp appear to stay on.

Fig. 404 shows the waveform which occurs at the terminals of the fluorescent lamp. When the voltage drops low enough, the lamp will extinguish. But because the load across the ballast is now reduced, for a very short instant the voltage will rise again. Thus the lamp may "strike" again and become conducting. But the voltage is still falling, and the lamp goes out again. And so, in rapid succession, at the start and end of each cycle, the lamp will

"flicker" on and off very rapidly a few times. This is equivalent to radiating a very high frequency, and is a serious cause of radio interference.

Although filters can be constructed to remove any such rf from the power line to the lamp, it is almost impossible to build a shield around the lamp that will not let the arc in the lamp itself "broadcast" the rf. For this reason you will find few fluorescent lamps in communications installations as they must be contained in a special, very expensive fixture.

To remove rf from the power line, we can use the method shown in Fig. 405. Here only capacitors have been used but, if the interference is serious enough to warrant it, chokes may have to be added. Cold-cathode and the so-called "instant-start" fluorescent
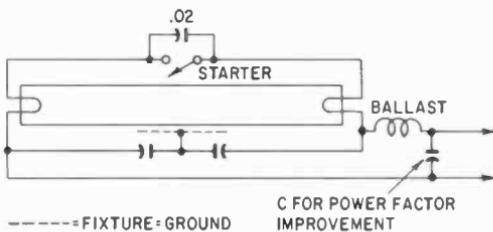

Fig. 405. *Capacitor across switch reduces one type of interference while the capacitors grounded to fixture remove most of the hash.*

lamps as well as the "slim-line" types do not use a heated cathode to start, and must therefore be lighted with much higher voltages. Remember that the capacitors must also be suitable for such high voltages. For 8-foot slim-line lamps, the open-circuit voltage may be as much as 1,500 rms and require 2,500-volt capacitors. For cold-cathode lamps, the voltage may run more than 5,000 volts, open-circuit.

Since such high voltages are always obtained from transformers, the easiest method is to insert a line filter in the transformer primary circuit. Even with this all the wiring between the lamps and the transformer secondary windings still radiate considerable interference. In one church in California, radiation was so severe that television reception for several miles around was impossible when the church lights were on. Needless to say, corrective action was taken quickly.

If the wires from the fixture to the lamps are properly enclosed in a grounded metal conduit, interference is minimized. But this

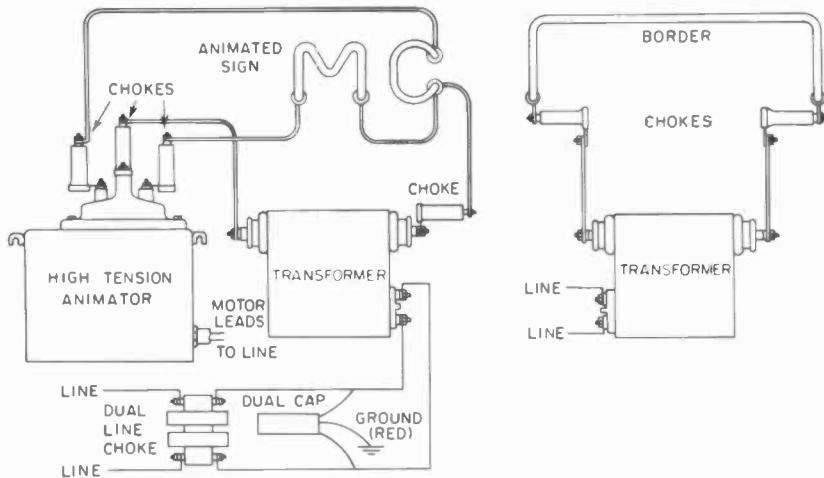# LOW TENSION NEON SIGN FILTER
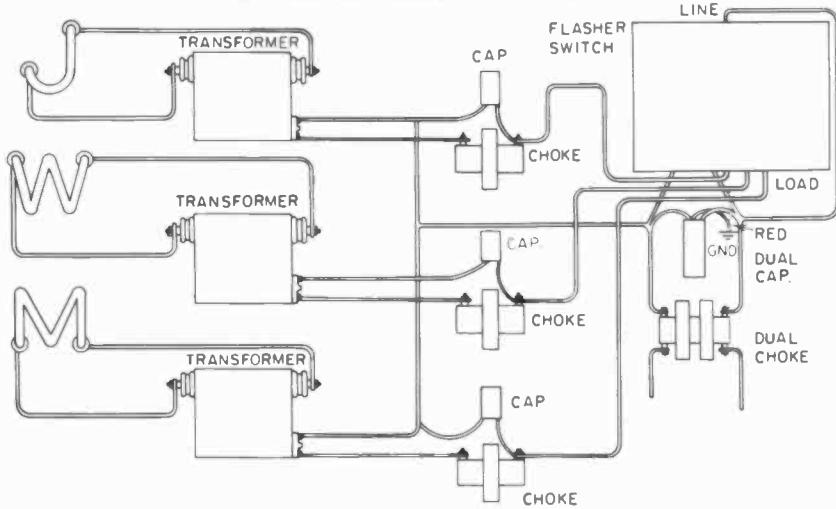
HIGH TENSION NEON FILTERS

Fig. 406. *Filters for neon signs help reduce interference from that source.*

does not eliminate the problem of interference from the lamps themselves. There is really no easy answer to that problem, except to use special fixtures.

Neon signs are another source of radio interference. Their voltages are even higher, often going up to 30 kv, that makes the use of capacitors impractical. Fig. 406 shows two methods of reducing radio interference. These are only partial remedies; the lamps themselves are also radiators. Sometimes, in addition, rf filters in the primary of the transformer may help. If the tubes are actually mounted inside letters or figures made of sheet metal, as they are in many signs today, the interference even from the tubes themselves will be considerably reduced if all the sheet metal is properly grounded.

While not a problem in fluorescent lamps, the connections to neon lamps are apt to cause interference through corona discharge at the voltage peaks. Corona is the electrical discharge of energy resulting from ionization of the surrounding air. It will take place from any sharp point which is at a high voltage potential. It is not necessary for this high voltage to be in the vicinity of a ground point. Poor connections with sharp wire ends sticking out and sharp burrs or edges on the connectors are likely corona discharge points. By soldering connections and making them smooth, such radiation can be prevented. Covering the joint can help, but will not always be effective.

Giving the parts a very high polish will be of some help. Remember that, wherever you deal with very high voltages, shiny polished parts will be less prone to corona discharge than dull dirty parts.

Also remember, particularly in outdoor installations, that, although the equipment may function perfectly one day, it may be an irritating source of interference the next high humidity day. Humidity is a contributing factor in corona discharge.

Where equipment that must be tested is likely to cause interference to neighboring communications equipment and a filter will not do the job completely or, vice versa, where communications equipment must be tested, adjusted and calibrated in an area where there is a great deal of unpreventable interference, shielded rooms (or screen rooms) must be considered. These are small frame rooms completely covered by copper mesh or copper plate. Effective shielding from rf is accomplished only when all the joints are carefully made, and the entire cage is well grounded. If the ground connections are too long, the cage and the ground

wires themselves become excellent radiators of rf energy. Since many antennas are short wires, some of them grounded at their bases, it is not surprising that in vhf and uhf operations a ground wire of a quarter wavelength or more, makes everything an excellent radiator. Ground leads must, therefore, be very short to effectively ground a shielded room.

Often the shielding must be in several layers, for example, screened inside and out. The two layers must be connected together at many points, but care must be taken that these connections are not some submultiple of one of the major frequencies used in the room. Doors and windows must also be shielded. Particularly at the door, great care must be taken to bond the shields at the hinge side and to provide some adequate pressure contact at the opening edge. With the door open, the room is of little value. The mesh must have holes no larger than a quarter-wavelength; so, for radar frequencies, which go all the way up to millimeter waves, solid copper plate is the only answer for adequate shielding.

Interference to communications equipment may not necessarily originate in industrial machinery. Quite a lot of it can be generated by the communications equipment itself. Improperly designed or adjusted TV and radio receivers can broadcast a great deal of interference from their oscillators and even from their high-voltage supplies.

Ordinary switches, if used frequently enough, can also be guilty. For example, in industry, footswitches are often used for repetitive operations (to keep the operator's hands free). The switching operation takes place many times per minute, and are prime sources of interference of the "clacking" type. Switches inadequate for the voltages they are expected to break will, of course, be more likely to cause interference, since they will create more arcs.

Secondary radiation sources are sometimes very difficult to locate. For example, it may seem that everything possible to prevent or reduce radiation from a specific source has been done, yet there may be some serious radiation left which does not change, no matter what is done to filter or ground the original source. This may mean secondary radiation. Any isolated or even poorly grounded metal cable, structural member or pipe near a source of radiation may, in effect, become an antenna, inductively or capacitively coupled to the source, and it may then reradiate interference. This can usually be prevented by properly bonding or grounding such cables, pipes or structures.

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And finally, there is a source of interference which is quite common and almost as commonly unsuspected — drive belts. These, because they operate on friction and because they are usually made from an insulating material, are generally capable of building up tremendous charges of static electricity — which they radiate as corona. This is such a serious problem, that when explosion hazards exist in a plant, special precautions must be taken.

One is to conduct the electricity off the belt with metal brushes which touch the belt in several places and which are properly grounded, but this is not always effective and requires a lot of maintenance of the brushes. Conductive coatings can be used on the belt to discharge the electricity automatically through the metal pulleys and the machinery grounds. Even this is not always permanent because the conducting coatings dry out, become ineffectual in a few weeks and must be constantly renewed. One remedy used for many years is to coat the belts with a graphite powder. This is a dirty job, and it reduces the ability of the belt to transmit power, since graphite is also a lubricant. Metal belts are another answer, but not applicable where high speeds are involved, and they are expensive.

Every industrial service technician must be thoroughly familiar with safety and building codes. Whenever you are working on an installation which involves the presence of any employees, you are automatically supervised by state and local authorities with respect to the safety and health of such employees. Thus any installation or alteration in an industrial plant must satisfy the codes laid down by these agencies. Generally speaking, you will be safe if your work meets the requirements of the National Electric Safety Code. A copy of this code can be obtained from any office of the National Board of Fire Underwriters.

But this is not always enough. Many local codes are considerably more stringent than the national code, and they must be adhered to in all cases. Particular attention must be paid to shock hazard and grounding of equipment. If by installing a filter, for example, you create in some way the possibility that the equipment might be isolated from ground, your installation will not satisfy any code. This applies to all equipment, including communications equipment and even low-voltage installations. Types and sizes of wires which may be used are specified in the codes, and methods of wiring are carefully spelled out.

5 *

<div style="text-align: right">

counting
and
counters

</div>

O F all the control functions in industry, counting is by far the most prevalent and, in a sense, the most important. Counting is applied wherever there is a repetitive process, whether it be manufacturing or only processing and packing. Thus jelly beans are counted into the bags in which they are sold, and so are steel balls for ball bearings. This counting may be a very crude approximation; for example, when the objects are simply weighed and their weight made a certain number of times the weight of a single jelly bean or other object. But more often than not, the counting is a precise procedure. Gallons of oil leaving a refinery are counted, nuts and bolts produced by automatic screw machines are counted and, very important, *time* is counted. How these counting procedures are used in industrial applications will be the substance of the next chapter. In this chapter we will review the methods and instruments used in counting.

Principles of counting

Since the reader has been counting since he was a child, it may seem superfluous to tell him the principles of counting. This may be true enough when we talk about counting in the system which is most familiar; counting by tens or in the decimal system. Many types of counters can do this, particularly the mechanical counters which operate by a series of toothed wheels with numbers on them. Although these counters are very widely used in industry, they have very serious limitations. The worst one is that they can be used for counting only up to a certain speed, which is the limit

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of their mechanical endurance. Beyond this, the mechanical counter would simply refuse to count accurately or, would literally fly apart. Electronic means of counting must then take over, and there are a number of decimal electronic counters which we will discuss presently. But first we must talk about another method of counting. This is counting in the *binary* system, or counting by *powers of 2*. The reason for its popularity is that it effects important savings in electronic circuitry, as you will see.

First, let us take a brief look at what binary counting is. Binary counting is quite old. It was invented long ago by a German philosopher named Leibnitz, who hoped to use it to convert the Emperor of China to Christianity. He did not succeed, and the story does not tell why. Binary counting is extremely important in the industrial picture because of the rapidly expanding applications of digital computers which utilize the binary principle.

Binary math is figured on the base 2 rather than 10. In the decimal system, we have units, hundreds, thousands, etc. all multiples by 10. In the decimal system we can write any number as a *power* of 10. For example, $100 = 10^2$ and $1,000 = 10^3$ and so on. Or take a complicated number like 13,271: $13,271 = 1 \times 10^4 + 3 \times 10^3 + 2 \times 10^2 + 7 \times 10^1 + 1 \times 10^0$. Let's check: $10,000 + 3,000 + 200 + 70 + 1$, sure enough adds up to 13,271.

We have used only one little trick here: $10^0 = 1$. Now this is also obvious, for we know that

$$\frac{100}{100} = 1 \text{ and thus } \frac{10^2}{10^2} = 1.$$

And we can write

$$\frac{1}{10^2}$$

as 10^{-2}. Then $100/100 = 1 = 10^{(2-2)} = 10^0$.

And just one more basic idea, since we will be using it again and again: why is $10^{(2-2)}$ the same as 100/100?

Let us start by taking another set: $1,000/100 = 10$ or $10^3/10^2 = 10^1$ and we see that the *exponentials* in division are *subtracted* and in multiplication they are added.

The powers of 10 are familiar from daily use: as 1, 10, 100, 1,000, 10,000, 100,000, etc. But the *powers* of 2 are not so familiar when the figures get large (Table 5-1). Notice how fast we get up into large figures.

TABLE 5-1

0	1
1	2
2	4
3	8
4	16
5	32
6	64
7	128
8	256
9	512
10	1,024
11	2,048
12	4,096
13	8,192
14	16,384
15	32,768
16	65,536
17	131,072
18	262,144
19	524,288
20	1,048,576

in other words, $2^3 = 8$ and $2^4 = 16$ etc.

Of course you could easily have constructed this table yourself, since each figure is just twice the preceding one!

Now we can express the number used in the preceding example in the *binary* system. Thus: $13,271 = 2^{13} + 2^{12} + (no\ 2^{11}) + (no\ 2^{10}) + 2^9 + 2^8 + 2^7 + 2^6 + (no\ 2^5) + 2^4 + (no\ 2^3) + 2^2 + 2^1 + 2^0$. We simply take the largest power of 2 that "goes into" the number, mark it down and subtract it. Then we look at the next power of 2 and, if we *cannot* subtract, we write *(no)* and go on to the next power we can subtract, mark *it* down and so on. Each time we *subtract* we mark it down, and each time we *cannot* subtract we mark it down as *(no . . .)*.

For 13,271 we have in effect said: yes, yes, no, no, yes, no, yes, no, yes, yes, no, no, yes, yes. Now if we write, for simplification, for the times we said yes 1 and for the times we said no a 0, then we have a very simple notation indeed: $13,271 = 11001111010111$. And this is a handy notation, and we could say, equally well that 1 stands for a *closed* switch or relay contact and 0 for an open one.

In spite of the simplicity and apparent monotony of this notation, we can simply and very quickly carry out arithmetical computations with this method. And, in effect, this is *all* that is done by the *most complex* computer—simple arithmetic operations.

In effect, all a computer does is add or subtract. As you may remember from your grade school days, long division is simply a matter of subtracting, and multiplication primarily a matter of addition. Leibnitz, the philosopher, wrote down all the necessary

mathematical operations in a simple table, and we will show this table, but first let's see how and why the operations go the way they do, and let us carry out some of them. Suppose we have a 1, which means that we *do* have *that* power of 2, say 2^2. If we put under it another number which also had (1) it will also be $2^2 = 4$. Now we add $4 + 4 = 8$. But $2^2 + 2^2 = 2^3$, which is not 2^4 but 2^3, the *next higher power of 2,* and nothing else.

Thus if we have a 1 and add a 1, we get the next COLUMN notation of 1 0 (it is pronounced one–oh) because we have now the next higher power of 2 and we have used all the powers of 2 we started with. Leibnitz put this in his table as: $1 + 1 = 10$, which does not seem to make sense, until you realize that we just shift our "yes" notation one column to the left.

Try it with another power: $2^3 = 8$, so $2^3 + 2^3 = 8 + 8 = 16 = 2^4$ See? It works with any of them.

Similarly, when we subtract, we shift to the right, thus: $10 - 1 = 1$ or rather, as we should write, 01. If we have a "yes" in the column of 2^4, this as we have seen is 2 times 2^3. So if we take 2^3 from *that* column when there isn't any (we had 1 0), we must borrow from the 2^4 column. This means we have nothing left there (0), and we are left with 1 times 2^3, thus $10 - 1 = 01$.

You can work out the same thing for $11 - 1$ (or as we *could* write $11 - 01$), and this equals 10. And $10 + 01 = 11$. Thus we get painlessly through most of Leibnitz' table of operations:

$$0 + 0 = 0 \qquad 0 \times 0 = 0$$
$$1 + 0 = 1 \qquad 0 \times 1 = 0$$
$$1 + 1 = 10 \qquad 1 \times 1 = 1$$

This, it says in fine print, is *all you need to know to work in binary math!*

Let's see if it is true.

For example, the simple addition $35 + 11 = 46$

$$35 = 2^5 + 0 + 0 + 0 + 2^1 + 2^0 \text{ or} \qquad 100011$$
$$11 = 2^3 + 0 + 2^1 + 2^0 \qquad\qquad +\ 1011$$
$$\overline{\qquad\qquad 101110}$$

Now read with us from right to left: $1 + 1$ is 10, so the first digit from the right is 0 and we carry a 1. Now again $1 + 1 = 10$, so our second digit would be also an 0, except that we *carried* a 1 so it becomes 1, for $0 + 1 = 1$. Then: $0 + 1$ (which we carried this time) $= 1$ and our third digit from the right is again a 1. Next $1 + 0 = 1$ and our fourth digit from the right is also a 1. Then $0 + 0$ (which we did not write!) $= 0$ and $1 + 0$ (which we did not write) $= 1$ so our number is one oh one one one oh, or 101110.

Subtraction goes the same way when we "talk it out":

$$\begin{array}{r} 30 \\ -11 \\ \hline 19 \end{array} \quad \text{which we write} \quad \begin{array}{r} 11110 \\ -\ 1011 \\ \hline 10011 \end{array}$$

Let's see if it is right. $19 = 2^4 + 0 + 0 + 2^1 + 2^0 = 16 + 2 + 1$

Now, using Leibnitz' table, let's try multiplication:

Multiply 11×3 or, as we "skilled mathematicians" can now write it:

$$\begin{array}{r} 1011 \\ \times 11 \\ \hline 1011 \\ 1011 \\ \hline 100001 \end{array}$$

(remember Leibnitz' table)

Add!

or $2^5 + 0 + 0 + 0 + 0 + 2^0 = 32 + 1 = 33$

And so on to division (remember that $10 - 01 = 01$):

Take: $55 \div 11 = 5$

```
1011 | 110111            (2⁵ + 2⁴ + 0 + 2² + 2¹ + 2⁰)
     | 1011
       ────
       0010

       0101
       0000
       ────
        101

       1011
       1011
       ────
       0000      (no remainder!)
```

and the answer $101 = 2^2 + 0 + 2^0 = 4 + 1 = 5$

You have now gone through the basic arithmetic operations in binary math. Not difficult, is it? Of course, you can develop skill only with practice, but fortunately you won't need it. That's what computers are for. You can also see why we can use flip-flops, for they conduct either on one side or the other: yes or no, 1 or 0. Or, as Berkeley showed so nicely in his simple computer series in late 1950 and early 1951[1], we can do it with relays. Call a relay contact closed 1 and a contact open 0, or a coil energized 1 and a coil de-energized 0. There you have it.

Economy? Well, to show a number like 13,271 in lamps on a binary computer panel we need 14 lamps, thus 11001111010111. To show the same thing in the decimal system, we need this:

[1] "World's Smallest Electronic Brain" series, Edmund C. Berkeley and Robert A. Jensen, RADIO-ELECTRONICS Magazine, October 1950 to October 1951.
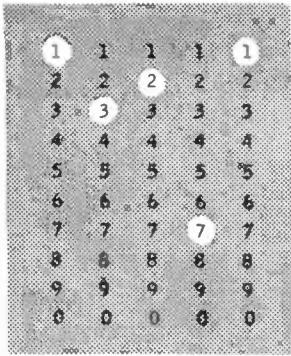
A total of 50 lamps,
almost four times as many!!

This is only an illustration. There is much more involved besides the so-called readout lamps, and the economy shown there is duplicated in other circuitry. The flip-flop is an excellent circuit for distinguishing between the 1 and 0 conditions. In it a tube will alternately conduct and not conduct; thus, the switching operation or "counting" can take place very rapidly, as fast as 10,000,000 times a second, and the parts are not subject to mechanical wear. For this reason the majority of industrial electronic counters up to now have been based on the flip-flop circuit. Although beam switching tubes are rapidly taking their place, flip-flop counters still predominate and you should understand their operation.

Fig. 501 shows the basic flip-flop circuit or bi-stable multivibrator. This is a well known circuit in the electronics field, and any good reference book can give a detailed explanation of its functioning. Briefly, it is this: Upon a positive signal on its grid or a negative signal on its plate, a nonconducting tube will suddenly be made conducting and, through the feedback coupling capacitor, the opposite member of the team is switched from conducting to nonconducting. Therefore, the flip-flop changes state for each pulse, and returns to its original state every second pulse.

Now then, if we were to cascade flip-flops—put several of them one after the other, with the pulses for the following ones to be produced by the preceding ones—you can see that the first flip-flop or binary as it is called would return to its original state every 2 pulses, the next one every 4 pulses, then 16, 32 and so on. This is a true binary counter and in this form is used in counting radioactive particles. The answer need not necessarily come out in the decimal system, since we are usually satisfied if we can simply count the particles very rapidly and then, by a simple arithmetical operation—division by 8, 16, 32, 64, etc.—arrive at the true number of particles which have passed through our counter.

Fig. 502 shows such a straight binary counter, and you will notice that the coupling between the binaries is made through diodes which apply negative pulses simultaneously to the two plates of the next binary. Only the binary tube which is nonconducting is affected by these pulses, making the binary change state. Sometimes it is sufficient simply to differentiate the signal supplied by the drop in voltage across a plate resistor by means of a very small capacitor of the tube just starting to conduct, and we then do not need the coupling diodes. In fact, most industrial
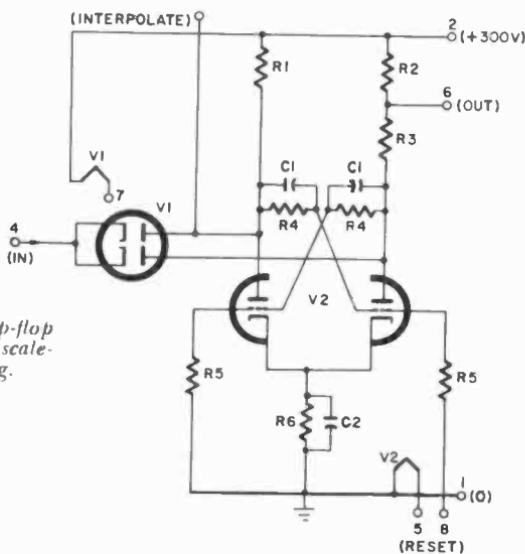
Fig. 501. *Basic flip-flop circuit is used for scale-of-two counting.*

counters use such a differentiation network and no coupling diodes.

Because the decimal system is commonly understood and used, binary counting can be inconvenient and clumsy. How can we use the same flip-flops for counting in tens? Many ways have been devised, but we will show several here which have become quite popular.

Nothing that happens in the flip-flops can be observed from the outside of the tubes, unless we provide some sort of indicator. In Fig. 502, small neon lamps indicate whether a tube in the binary is conducting or nonconducting. This is useful information, but it still allows us to count only in 2's, 4's, 8's, etc. But let us construct a table which shows the state of the binaries after a certain number of pulses (Table 5-2).

In this table 1 means conducting, 0 means cut off. The left figure is the left triode and the right figure is right triode in the binary.

TABLE 5-2

Pulse	I	II	III	IV
			Binary	
0 (reset)	10	10	10	10
1	01	10	10	10
2	10	01	10	10
3	01	01	10	10
4	10	10	01	10
5	01	10	01	10
6	10	01	01	10
7	01	01	01	10
8	10	10	10	01
9	01	10	10	01
10	10	01	10'	01
11	01	01	10	01
12	10	10	01	01
13	01	10	01	01
14	10	01	01	01
15	01	01	01	01
16	10	10	10	10

Notice that it takes the first binary two pulses to return to its *original state*, and the last binary 16 (at the input). If you observe this table carefully, you will discover that, although these "states" may have the same situation on one, two and sometimes even three binaries, with the state of only three binaries we can show the entire state of the counter—if we include the binary which is *different* for that count. For example, count 4 and count 12 look very similar, but notice that the fourth binary in count 12 has a different state. Thus if we make sure that in count 12 we can always identify the state of binary IV, we can always distinguish it from count 4. Now if we were limited in our binaries, we could even distinguish the states of all of them, and thus the count up to 16, by remembering all the lamp combinations. But that is too much trouble so we design a circuit in which *four* binaries indicate each count, using, say, 10 lamps. This is shown in Fig. 503.

This happens to be the circuit of a *decade* counter, and we will go into its other features. Notice first of all that there are 10 lamps, and that each of these lamps is controlled through voltage dividers by *four* binaries. Thus the state of the first, second and fourth binaries control the condition of lamp 0, and also lamp 1; the first, second and third control the condition of lamps 2 and 3, and so on.

This decade shows how to use four flip-flops to count to only 10, not to 16. How is this done? Notice that from the third to the second binary there is a feedback loop. And from the fourth to
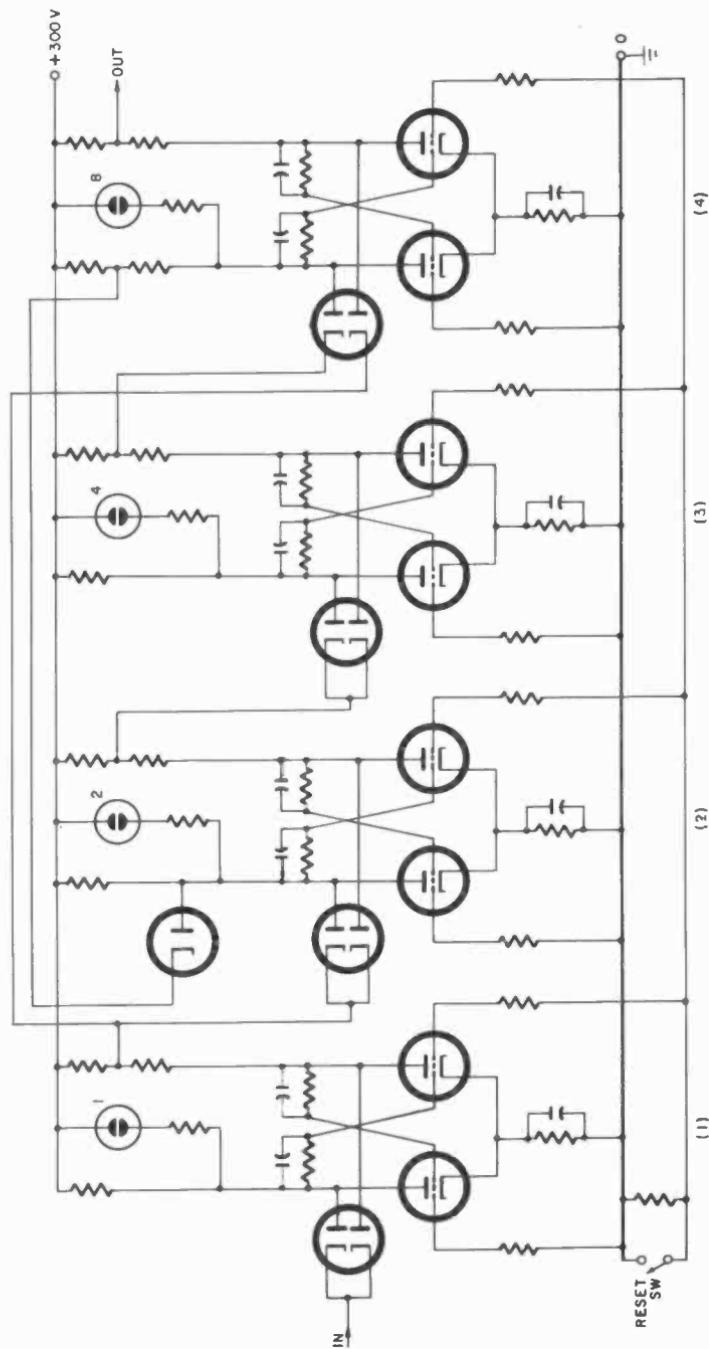
Fig. 502. Four scale-of-two flip-flops will count to sixteen.

the third there is another feedback loop. These loops, since they are connected to the grids of the tubes to which the feedback signal is applied, will carry a positive triggering signal when the flip-flop tube from which they originate becomes nonconducting. Let us construct another simple table to show what happens through these feedback signals. For convenience, we will repeat Table 5-2 in Table 5-3, to show the difference.

TABLE 5-3

Pulse	I	II	III	IV	I	II	III	IV
0	10	10	10	10	10	10	10	10
1	01	10	10	10	01	10	10	10
2	10	01	10	10	10	01	10	10
3	01	01	10	10	01	01 F.B.	10	10
4	10	10	01	10	10	(10)01◄	01	10 (looks like 6)
5	01	10	01	10	01	01	01 F.B.	10 (looks like 7)
6	10	01	01	10	10	10	(10)01◄	01
7	01	01	01	10	01	10	01	01 (looks like 13)
8	10	10	10	01	10	01	01	01
9	01	10	10	01	01	01	01	01 (looks like 15)
10	10	01	10	01	10	10	10	10
11	01	01	10	01	01			
12	10	10	01	01	10			
13	01	10	01	01	01			
14	10	01	01	01	10			
15	01	01	01	01	01			
16	10	10	10	10	10			

Look at the right half of Table 5-3 and see what happens. On count 4, binary II tries to change, but binary III also changes and, through the feedback loop, *prevents* II from changing state. The effect is that, when this pulse has occurred, the state of the flip-flops *looks as if* we had received six pulses instead of four. To our eyes it does not really matter what happened inside the tube; all we can see are the neon indicators which tell where we are in counting. And if we can fool the decade and make it look as if it had had 6 pulses, but we call this 4, then we need add only 6 more to get 10.

Now go two more steps. The same situation occurs when binary IV is finally tripped after what *seems to it* to be 8 pulses (but *actually* is only 6) and its feedback loop *prevents* III from changing state. Here we have a situation in which we have actually received only 6 pulses, but it looks *as if* we might have received 12 instead. Add 4 pulses, and we will have the same *indicator* lamp situation *as if* we had had 16 pulses, but we have only had 10, and so this circuit counts every 10 pulses, a decade.

Compare all the lamp combinations. *Actual* count 7 in the decade looks the same as *actual* count 13 in the binary type
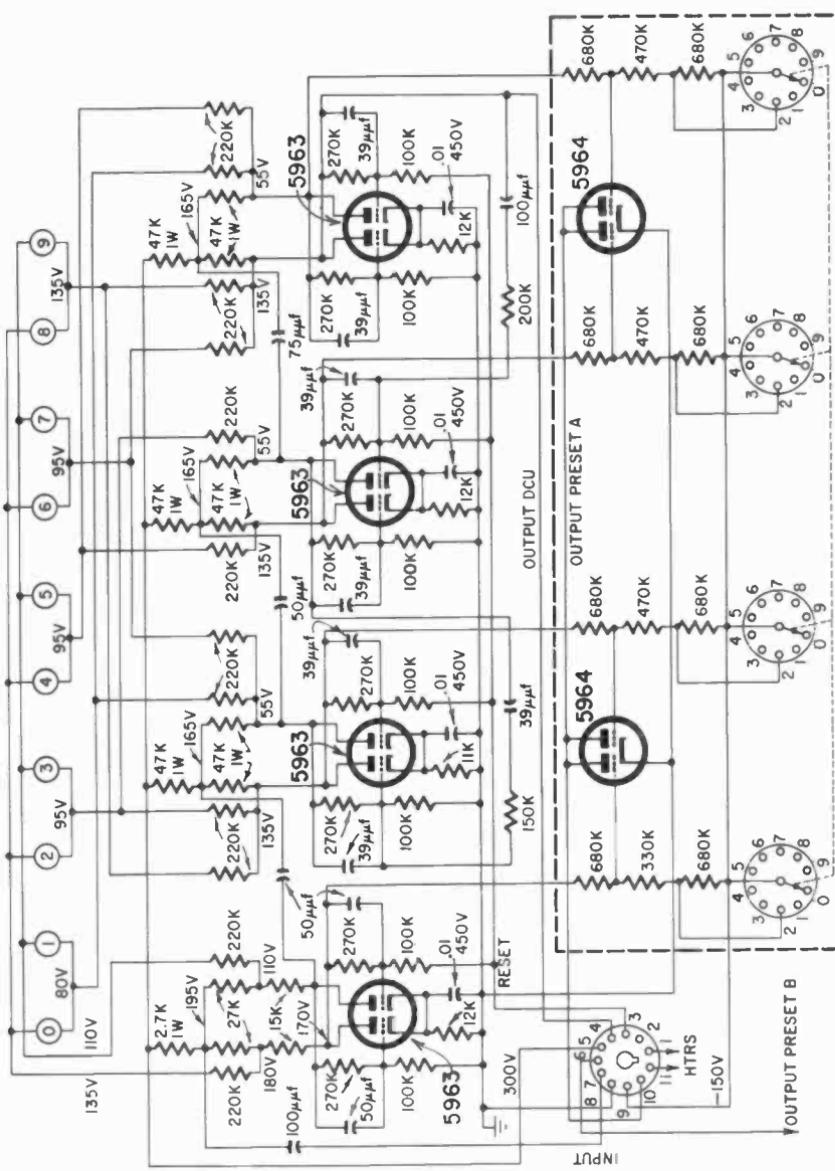
Fig 503. In this counter decade each neon indicator lamp is controlled by the state of four binaries.

counter. Since we control our indicators with four binaries, and we can write on the face of the neon lamps any number we please, when we number them from 0 to 9, and circuit them as shown in Fig. 503, we have a decade, counting to 10, and for all the world indicating only *10 distinct states*.

If we use several of these decades, one for the units, one for the hundreds, one for the thousands, and so on, we have a complete decimal counter. One form of such a counter is shown in Fig. 504.

Fig. 504. *One form of counter is called a time interval meter.* (Beckman Div. Berkley Inst.)

(Fig. 503 has another circuit at the bottom with two tubes and a switch, which we shall discuss later.)

Fig. 505 shows another way to count by tens in flip-flops. Here, there is only one feedback loop, from binary IV to binary II. What happens is that the counter first accepts 16 pulses and goes through 16 changes of state. But on the 16th pulse, the feedback loop resets binary II, and, as a result, the state of the flip-flops on count 16 is exactly the same as on count 6. Thus the decade is accomplished by similar changes of state and, when the next pulses arrive, pulse 17 looks like 11, etc. This has one disadvantage: unless the counter is reset properly to begin with we could lose

the first six counts. However, a signal from a reset button (not shown) will do the same as the feedback from binary IV, and thus we can always start with what is actually 0, but looks in binary terms like 6, and thus count to 10 each time.

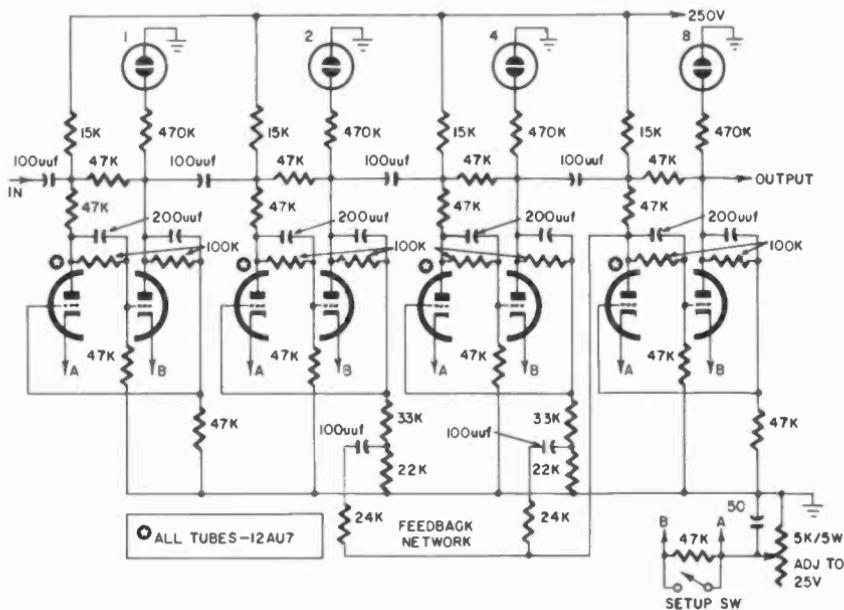There are many other ways of doing the same thing, even

Fig. 505. *A scale of 16 can be made to indicate tens by using feedback.*

without feedback loops, but the two methods discussed are the simplest and therefore the most popular. Your understanding of them will enable you to cope with any others.

We are accustomed to using vacuum tubes in counters, but they are not the only kind of device used. Fig. 506 shows a similar decade using transistors, and Fig. 507 a specially developed p n p n switching device which can obviously simplify such switching circuits. This is undoubtedly not the limit, and by the time this volume comes off the press, you can expect that new ways of making decades will have been invented. But, in essence, they will still be flip-flops, no matter how we simplify the components and circuits, and the principles of feedback for *apparent* counts, as we have shown them will still have to be applied.

Notice that in Fig. 506 a special bias circuit had to be used to develop sufficient voltage to make the neon indicators glow.

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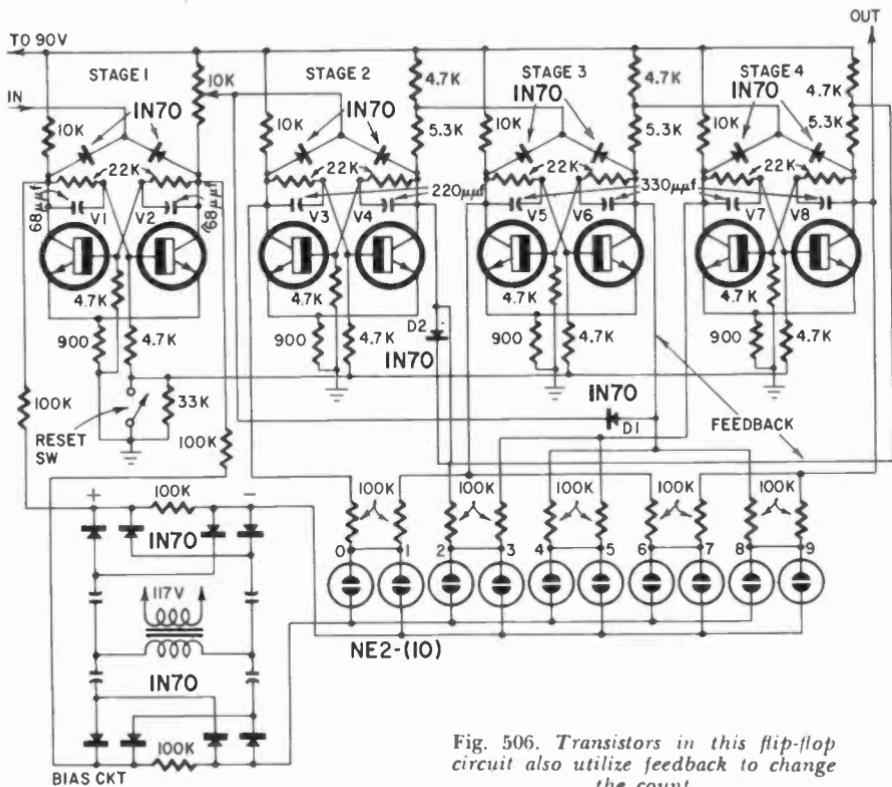
Fig. 506. *Transistors in this flip-flop circuit also utilize feedback to change the count.*

With later model indicators this was simplified. For example, the Amperex 6977, an indicator tube specially developed for transistor circuits, is a subminiature triode with a specially-coated fluorescent anode which glows blue-green when a positive signal is applied to the grid, as in the "magic-eye" tube.

Some transistor counters use special low-drain filament type lamps for indicators. In principle, all these work the same, but the neon tubes (and the 6977) have the advantage that they present virtually no drain to the transistor circuits.

Now for the extra circuits shown in Fig. 503. Here,, at the bottom, there are two twin triodes, so-called coincidence tubes. These tubes are simply biased in such a way, with all four plates tied together, that no signal is produced on the plates unless *three* of the four tubes simultaneously have a signal on the grid. Hence the name coincidence tubes. Which three will have the signal is determined by the setting of the switches. As with the indicator

lamps, here, too, the binaries can determine any "state" of the counter. Thus we can produce with the two coincidence tubes a signal at any desired count of this decade. If we have such coincidence circuits on other decades also and require that all the signals from several decade coincidence circuits must again come at the same time (in another set of coincidence tubes), we can see that the switches can be used to *set up any count number* we wish. This signal produced through all these coincidence circuits can then be used to trip some device on a machine, say a packing machine, which will momentarily stop the machine. It can also reset the counter itself, and then start it over again.

Here we have what is called a predetermined or preset counter, a very useful instrument. For example, we can decide that we want exactly 317 jelly beans in a bag. We will set this counter for 317, and at that count the counter will give a signal, cutting off the supply of beans, sealing the bag, placing a new bag under the spout and start to fill the next one. Of course, all this will take additional controls, but the counter gives the start (or stop, if you will) signal for such a sequence.
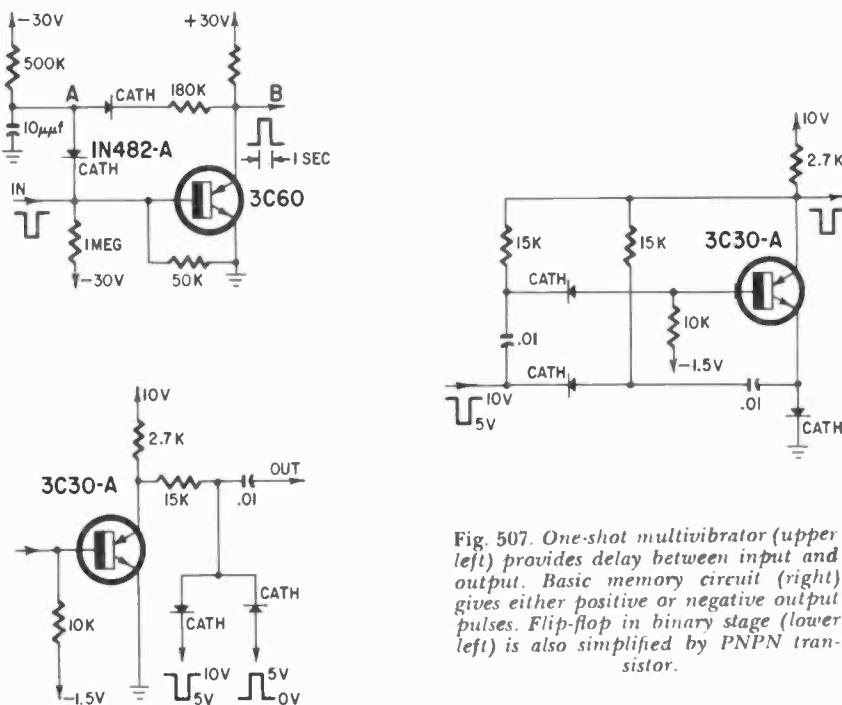
Fig. 507. *One-shot multivibrator (upper left) provides delay between input and output. Basic memory circuit (right) gives either positive or negative output pulses. Flip-flop in binary stage (lower left) is also simplified by PNPN transistor.*

Other accessories to the electronic decade type of counters will be discussed in the next chapter under applications. The electronic counter can be a very versatile instrument.

Shift-register counters and beam switching

So far we have discussed binary counters which can count by tens. Actually these are sly designs which count by two's and are only made to look as if they count by tens. However, that is all right so long as the end count comes out correctly. But there are also ways to count directly in groups of ten, without going through
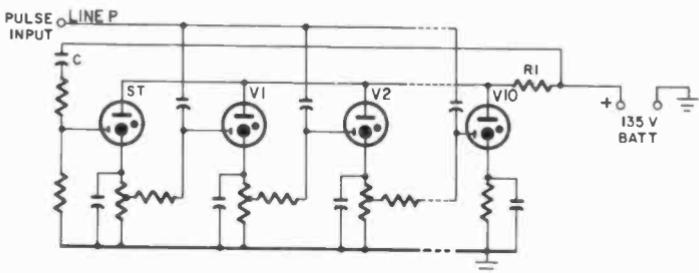
Fig. 508. *Three-electrode type cold-cathode tubes can be used for slow speed counting.*

the process of feeding back flip-flops. Some of these ways are quite old, and some quite slow. First, we can of course do this sort of thing with relays, in a chain of ten, provided we make sure that when we pulse such a circuit, the second pulse turns on No. 2 relay, turns off No. 1, etc., and we count up the scale this way. This kind of a circuit is interesting, and is used in telephone work; we will discuss it briefly under relays in another chapter.

The simplest method is shown in Fig. 508. This is a chain of cold-cathode tubes on which the bias is so arranged that the tubes are *almost* ready to fire. To obtain bias for tube V1, a starting tube ST is included. When a positive pulse arrives on line P, tube V1 will fire but, since none of the other tubes is conducting, no other tube has sufficient bias to be *almost* conducting while tube V1 (with ST conducting) has the little extra bias needed. When the second pulse arrives, V2 is *almost* ready to conduct because of the voltage generated in its cathode circuit by the conducting V1, applied to the "starting" electrode of V2, and V2 will fire. But since all the tubes have a common plate resistor R1, when V2 fires, the voltage drop will be too great to maintain *two* of the tubes in fired condition. Storage in the capacitor in the cathode

circuit of V1 holds this cathode momentarily at a high positive voltage and, when the anode voltage drops, this tube will be extinguished while V2 will remain fired. And so on up the line, until the last of 10 tubes has fired, when a reset pulse is required to fire ST again.

This simple kind of circuit is called a shift register. It is a limited circuit. The values of the cathode capacitors are critical and so is the shape and size of the pulse. Besides, these tubes take a certain amount of time to de-ionize (one reason for the critical cathode capacitor) and the speed of the circuit is quite limited.
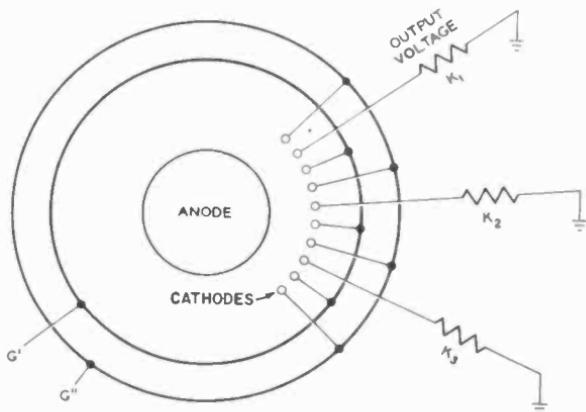
Fig. 509. *Schematic of the Dekatron tube made for counting.*

A more sophisticated version of such a shift register is embodied in a single tube, also a gas tube and known as a Dekatron. The 6476, shown in Fig. 509, has an anode, 10 cathodes and 2 sets of "ring cathodes" which are auxiliary aids for shifting.

Here is how this tube works: two pulses, (or actually a double pulse) is required for each "step." The auxiliary cathode rings are called G' and G". One cathode in the tube will always be glowing, and the gas in the tube partially ionized. Because the ionization is most dense near the glowing cathode, the striking voltage to the two cathodes adjacent to the glowing one will be lowest. The cathode voltage on the glowing one will, of course, be lower, due to the drop across resistor K. If the glowing cathode is K1, and we make ring G" strongly positive, then a pulse arriving on G' will tend to shift the glow from K1 and onto G'. But G' is not maintained at the proper voltage for striking, and thus the glow will

shift to the nearest possible point, which would be K2 (G″ still being positive). If we produce a pulse almost simultaneously on both G′ and G″, this action will automatically take place.

Fig. 510 shows a 6476 Dekatron with its driving circuit, a cathode-coupled multivibrator. Here, momentarily, the auxiliary cathode marked G1 will be lowered on arrival of an input pulse, and the cathode marked K1 immediately raised, as a result of the multivibrator change of state. This provides the necessary double
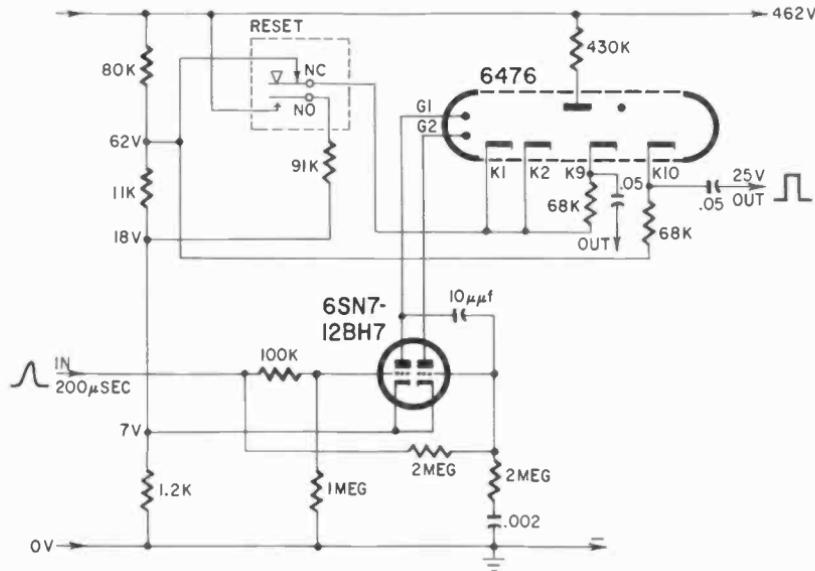

Fig. 510. *Driver circuit for Dekatron is simpler than flip-flop decade circuitry.*

pulse, one negative and one positive, to shift the glow, and the tube in effect counts the pulses. The reset circuit shown in Fig. 510 momentarily lowers the No. 1 cathode so much, with respect to the others, that the glow will jump to this cathode. This can, of course, be done electronically with a large negative pulse.

Several Dekatrons like this one can make a decimal counter but, because of de-ionization time required, the speed of such a counter is limited. The very best that has been achieved with this type of tube is 100 kc, but most other tubes operate nearer to a 20-kc maximum. There are ways to get around this limitation to some extent, as we shall see in the next chapter.

A later development in switching tubes, one which is much faster and actually no more complicated in circuitry, is the so-

called magnetron beam-switching tube. It is, in effect, a slightly large miniature tube with many, many pins, and a ring magnet surrounding the glass envelope. Inside the tube (Fig. 511), a central cathode is surrounded by 10 sets of elements, each set consisting of a spade, a target and a grid rod. Grids are tied together in two groups, but spades and targets are all brought out individually.
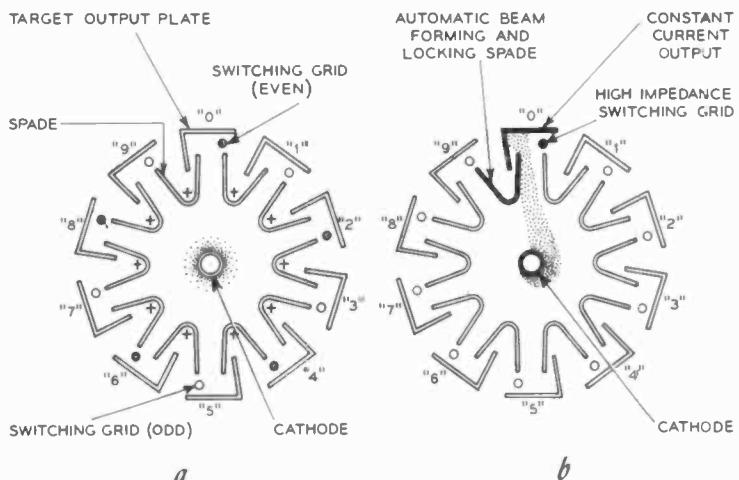

TARGET OUTPUT PLATE

SWITCHING GRID (EVEN)

SPADE

AUTOMATIC BEAM FORMING AND LOCKING SPADE

CONSTANT CURRENT OUTPUT

HIGH IMPEDANCE SWITCHING GRID

SWITCHING GRID (ODD) CATHODE

CATHODE

a   b

Fig. 511. *During the CLEAR condition (a) there is no current flow. Electron beam indicates zero. Design causes beam to switch to the next highest number.*

In a previous chapter we discussed magnetrons briefly. In the cutoff state, the electrons spin around the cathode in a circle (because of the magnetic field forces) following the equipotential force lines. This also takes place in a beam-switching tube when all the spades and targets are at equal potentials. In the magnetron, we disturb this state of spinning equilibrium by *lowering* the voltage on one plate, which then causes electrons to travel to *that* plate. In the beam-switching tube, we do the same thing. With a pulse, we lower the voltage on one spade and, as we do this, a "beam" of electrons will form to that particular spade and will lock in on its associated target.

The output voltage from the target is the useful output of the tube, which can be used to light a neon indicator tube or to control circuits with sensitive relays. In the latter case, the relay coil would take the place of the target resistor. If a beam has formed on a target and spade, we can remove the beam by making the

associated grid strongly negative. But the beam cannot simply be interrupted. When we make it impossible for the beam to go to the present spade, with the grid cut off, because of the shape of the spades the beam will jump to the next spade in line. Notice in Fig. 511 that the "next" spade is physically closer to the previous spade-and-target-held-beam than the one before that, and the natural place for the beam to go is to this next spade. This is what happens when we switch with the grid rods. Alternate pulses
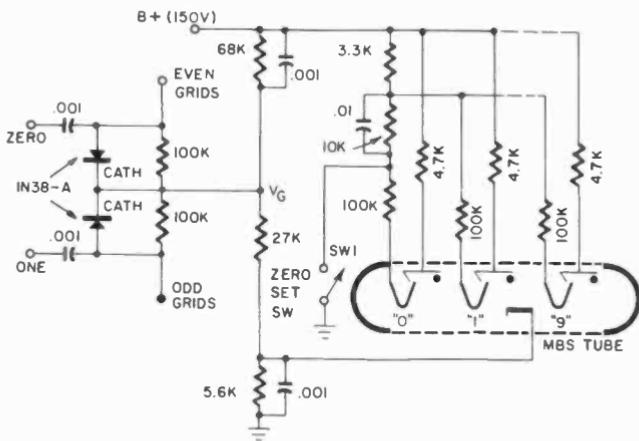

Fig. 512. *Schematic of basic beam switching drive circuit.*

must be obtained for even and odd grids, as shown in the basic circuit of Fig. 512. If we tie all the spade circuits together and then leave the grids at a constant potential, we can also switch by applying a positive pulse to the connected spades. After all, making the anode more positive, as far as the grid is concerned, is equivalent to making the grid more negative, if the stream from the cathode remains the same. Or to put it differently, if we make the lowered spade more positive, it will no longer make such a "dent" in the equipotential lines, and the beam will tend to jump to the next spade in line.

Odd and even pulses for the grids are most readily obtained from our well known flip-flop circuit, and this is the way the tube is most often controlled. The schematic is shown in Fig. 513. The next beam-switching tube in line would then receive a starting pulse from this one, and thus we can use tubes for units, tens, hundreds, thousands, etc. and so make up a complete decimal counter. If the counting must take place very fast, we will not
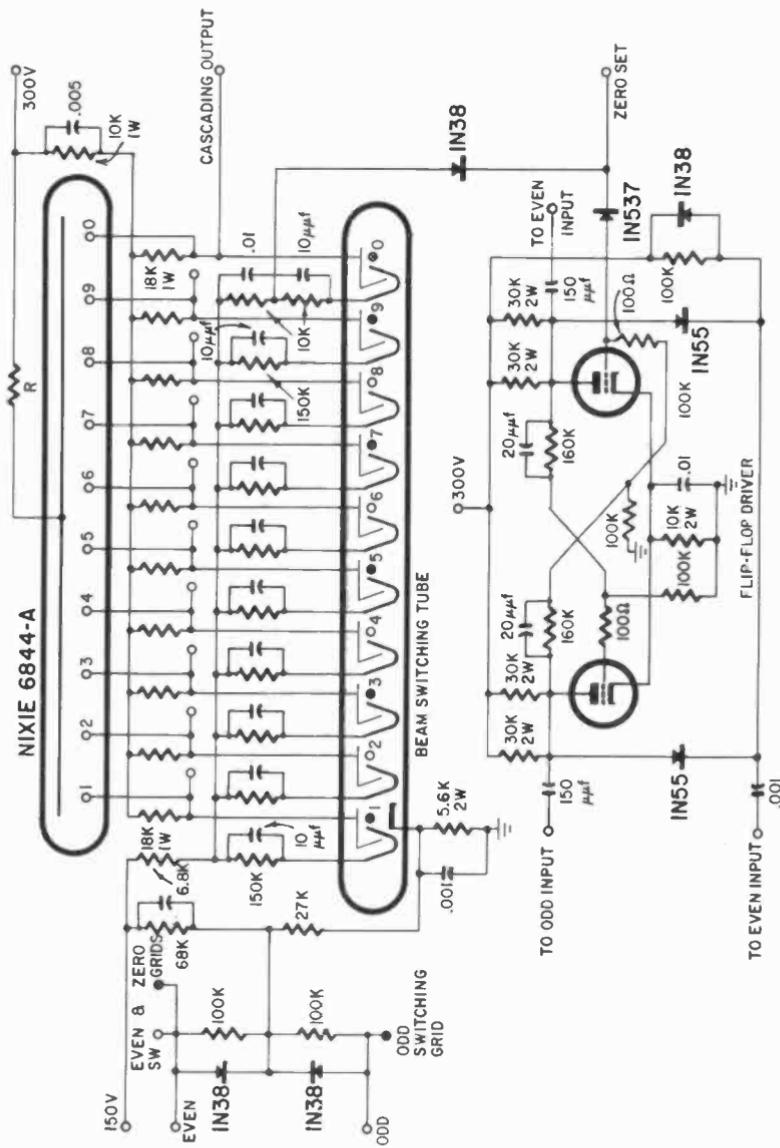
Fig. 513. One beam switching tube and one display tube make a simple and compact counter decade.

depend on the pulse from the beam-switching tube directly but, instead, make sure the pulse is large enough and brief enough by interposing a multivibrator between the tubes.

The Dekatron and the beam-switching tubes obviously lend themselves as well to circuitry with coincidence gates, and we can again make up preset counters which can control various industrial processes.
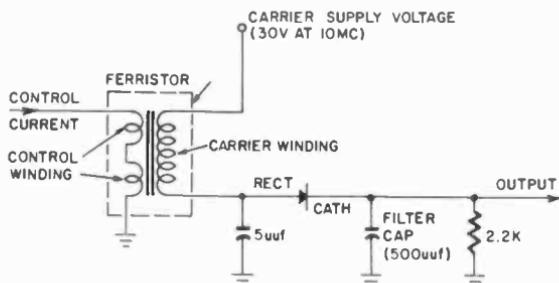

Fig. 514. *Basic ferromagnetic amplifier. High-frequency ac is used for a carrier.*

In effect, the beam-switching tubes and Dekatrons are used as current distributors or nonmechanical switches in many ways, something which was difficult to do with flip-flops, and hence these tubes have a decided advantage. They are as fast as reliable flip-flops, and they certainly require less parts per decade. They are also relatively expensive, but if we consider, as part of the cost of an instrument, all the labor needed to connect the circuits, then beam-switching tubes can provide a considerable saving in spite of their somewhat higher cost.

Other static switches

Next we will look at other forms of static switching, those not using vacuum tubes or transistors. The term *static* here means only that we use no moving parts, so here transistors and tubes are considered static switches.

The static switches we will now consider are those using magnetic principles. Certain magnetic materials have peculiar characteristics with respect to their magnetism. Two distinct kinds of devices are used, and both depend on magnetic properties. These magnetic devices usually consist of small toroidal cores of a particular material, with several windings on them. The characteristic upon which we depend is that the course of magnetization in these cores takes place in a manner that will permit linear control of an alternating current in one winding with a small dc variation in the other, on the same general principle as a magnetic amplifier.

The basic circuit is simplicity itself. In Fig. 514, a carrier current is applied to one winding. This can be an ac as high as 10 megacycles per second. Through the other winding we can apply a direct variation of voltage or current, and the current in the secondary will vary with this primary current, which may be very small. If the carrier voltage which results is rectified, this will vary

Fig. 515. *Basic feedback circuit. Proper component values will make this a bistable circuit.*
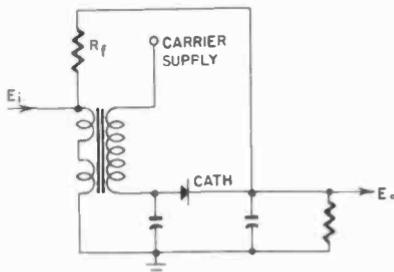
with the primary or control current. (See Chapter 8 for more details about magnetic amplifiers and static switching.)

As in any magnetic device, when we make the control current great enough, the core will saturate, and then we cannot further increase the carrier current passed. This is a characteristic which we can use to make a bi-stable circuit. If we feed back a portion of the secondary current into the control winding and carefully adjust the value so that as the primary, and thus the secondary, current increases, this portion becomes sufficient to keep the core saturated. A pulse applied to the primary, if large enough, will lock the core in that magnetic condition. It would then take a negative pulse to unlock the core, after which the core will lock oppositely magnetized. This feedback loop is shown in Fig. 515. The pulse which demagnetizes the core and starts the reverse magnetization must be rather large, and notice that the unit must have alternate negative and positive pulses.

Many variations of this circuit can be built with ferromagnetic units but, although they are common in digital computers, they are not really marketed in electronic counters as yet, again because of certain limitations. One circuit which can be developed from this is a free-running multivibrator in which the entire control current is obtained from the secondary. In Fig. 516 the primary current is fed back through a capacitor. Once the capacitor is charged. no more current will pass, and the unit will demagnetize until the capacitor is sufficiently discharged to start the cycle all over

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again. The size of the capacitor and the resistor will determine the timing of the circuit.

Many similar circuits can be built, but they are not yet common in industry. However, it may well be that these ferromagnetic devices present the best solution for the various kinds of atomic reactor control functions of the future.
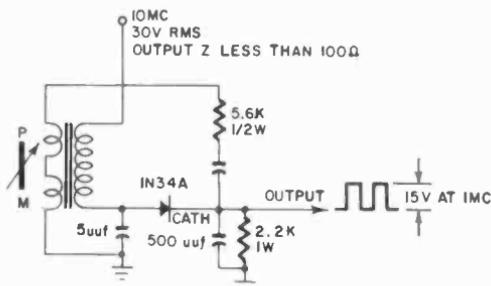

Fig. 516. *Pulse feedback makes a freerunning multivibrator of the basic ferristor circuit.*

Another way in which the ferromagnetic elements are used is called *ferroresonance*. In this, the secondary of the unit is circuited in series with a capacitor, and the control current varies the reactance of the core and secondary. When resonance is reached (Fig. 517), the current through the secondary is greatest

Fig. 517. *Basic ferroresonant circuit is bistable because of its negative resistance qualities.*
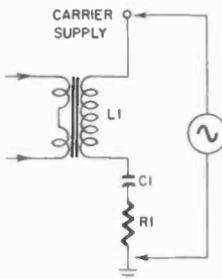
and, with the proper values in the circuit, this can be a saturation current. This then is a ferroresonant point. The core will be maintained at saturation. However, although a trigger can start the swing toward saturation, it is not possible to desaturate the core with a pulse, at least not directly through the control winding. To achieve this the voltage of the carrier must be lowered, which is analogous to extinguishing a thyratron.

This type of ferromagnetic circuit has two stable states, saturated and nonsaturated. These states can be used to make flip-flop type circuits for counters.

6 * counter use and maintenance

A FTER our review of counter circuits in the previous chapter it, may be well to reiterate that it does not cover all types of counting devices. For example, a recent transistor development, the Unijunction transistor, which is suitable for switching duties, will eventually make interesting and reliable counters. At this time, however, unijunction transistors are still expensive enough to receive a great deal of competition from vacuum-tube counters. Then there is also the so-called "avalanche" transistor which employs a barrier layer of radioactive material and can switch so fast that we have no way of measuring the transition time from one state to another. And there are other, much slower but nevertheless promising devices such as the electrolytic switch in which the application of a dc polarizing potential makes the electrolyte conducting to alternating current, while the removal of the dc potential increases the resistance enormously. It is somewhat analogous to ferromagnetic switching devices.

There will continue to be advances in other directions. Transistor microcircuit developments have led to the manufacture of transistor flip-flops which can literally fit into the eye of a needle. If such circuits become plentiful and inexpensive through mass production, spectacular developments can be anticipated in the field of electronic counters.

But no matter what the developments are in counters, the techniques for using them will change but little, since there are certain fundamental limitations on digital devices.

Simple counting

The most obvious use of counters, of course, is in simple counting. No matter what is being counted, the objects must in some way produce electric pulses which can activate the counter. These can be created by interrupting a light beam to a photocell, by switches being closed momentarily, by the objects, by sounds picked up by microphones and amplified to the proper input voltage or by variations in some form of transducer such as a piezoelectric ceramic crystal, due to pressure changes, puffs of air or exhaust gas, or mechanical motions; by special pulse generators designed for the purpose (as in tachometers), and by many other means. But, in essence, they all amount to one method. Mechanical forces, motions of objects or operations are counted by transforming them into electrical pulses. Notice that in all cases motion is involved. We can count stationary objects, but in that case the "counter transducer" must be moved, at least in one direction and possibly in two or even three directions.
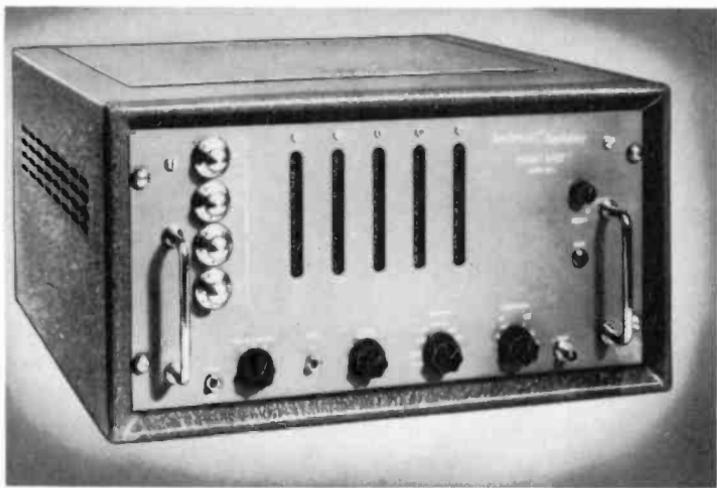
Fig. 601. *Anything that can be converted to usable pulses can be counted on the Events Per Unit Time (EPUT) meter.* (Beckman, Inc.)

Simple counting is useful when we want to determine the number of items produced; or the number of operations a machine has carried out, in order that required maintenance schedules may be set up; or how many cars have passed into a parking lot to get an estimate of the business done in a shopping center, and so on. A variation of 5% or 10% in the reading in such cases will prob-

ably not be alarming. But suppose that we are concerned with much greater accuracy—that we want to know much more precisely the number of items passing a given point in a specified period. In the first place, we will need to limit the time span to a very precise period. This can be accomplished by the use of (EPUT), Events Per Unit Time counters which have many useful applications (see Fig. 601).

Applications for EPUT counters

Some counters have the time-measuring device built in whereas in others, it is an external accessory. Whichever is used, the timing device simply turns the counter off at the end of a specified interval after the starting signal. The timing device is often a crystal-controlled oscillator, followed by multivibrator frequency dividers. Fig. 602 shows a block diagram of such a timing chain, and Fig. 603, a typical multivibrator divider which divides by 10.

The great advantage of this system is the tremendous accuracy obtained. It is quite easy to obtain an accuracy of 1 part in 1,000,000 with a temperature stabilized, crystal-controlled oscillator. This .0001% accuracy is, of course, maintained through the divider chains. Thus, with a time span of 1 second, we can get an
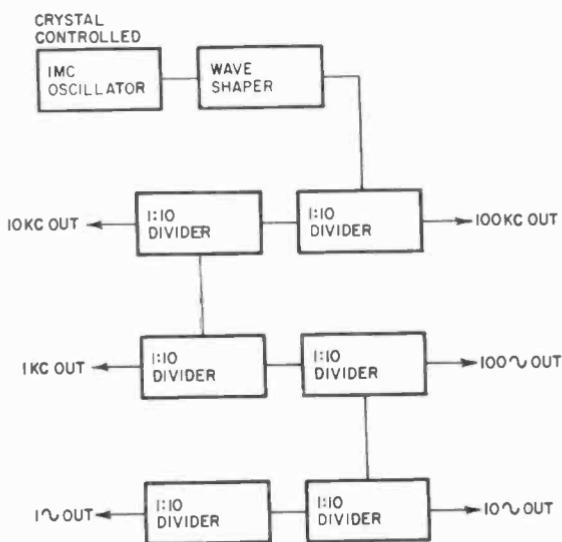
Fig. 602. *Frequency-divider chain also reduces the possible error by the amount the frequency is reduced.*

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accuracy of 1 miscrosecond and, if we were counting 1 million events in this second, could obtain an accuracy with ± 1 count.

This means that with such a time-period accuracy the electronic counter becomes an excellent frequency meter, which is one of the most useful applications of the EPUT-type counter, Specially-made counters for this purpose can count up to 10 megacycles directly and can repeat their count each second, each 1/10 second or
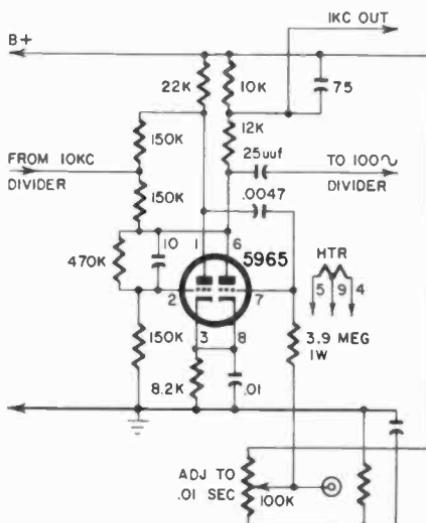

Fig. 603. *Typical frequency-divider stage can be used in many timing devices.*

even faster. Thus it is possible to keep almost continuous track of frequency as fast as or faster than can be read on the indicators.

This counting rate can be extended almost indefinitely with an addition to the counter of a *heterodyning* device, which is illustrated in Fig. 604. This consists simply of a very accurate oscillator, which puts out a pulse form usable by the counter, and a mixer. The frequency to be measured is mixed with the oscillator frequency, and the resulting *beat* is counted. Thus if we have a 1-mc counter and an oscillator which produces 15-mc waves very accurately, we will be able to count from 14 to 16 mc, with an accuracy only limited by the precision of the heterodyning oscillator and the timing oscillator and dividers in the counter. Such EPUT counters are beginning to offer serious competition to other types of frequency meters in industry and laboratory. The photo in Fig. 604 shows an amplifier and converter combination designed for this work.

Another immediate application suggests itself: tachometers. If we have a wheel with holes or a flywheel with a bright spot, either of which can periodically pass or reflect a light beam into a photocell as the wheel rotates, and if we count the number of pulses a second or minute, we have an accurate indication of the number of revolutions in that time. This is illustrated in Fig. 605.

There are many similar applications in which events per unit time are of consequence. If the number of units produced in a
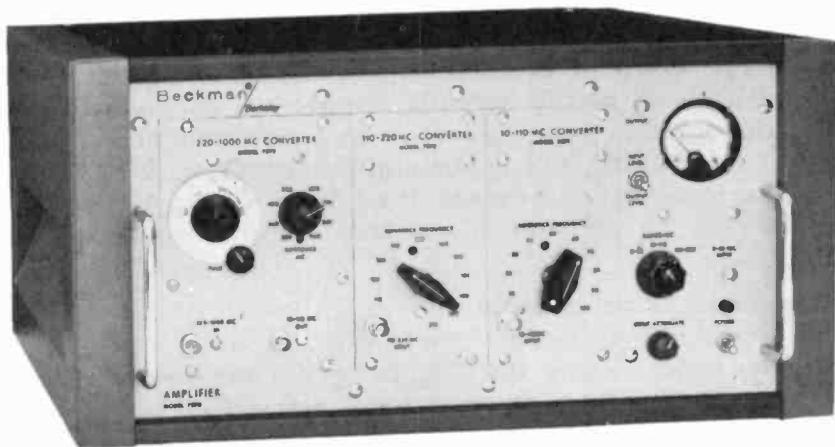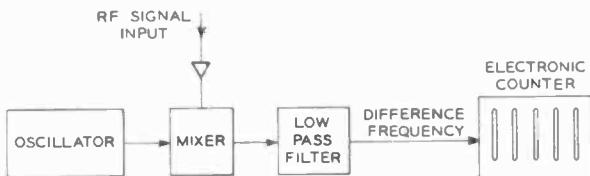
Fig. 604. *It is necessary to hetrodyne a high frequency that is not within the frequency range of a counter. Stable oscillators can be included in the same case.* (Beckman, Inc.)

given time is known, simple multiplication will determine the total production from an average of several such samples.

If a flowing liquid has a small quantity of low-grade radioactive material added, we can, by calibrating and by counting the pulses which flow past a Geiger counter, measure the exact rate of flow of the liquid. With a low-energy radioactive source behind a ribbon of metal coming out of a rolling mill, we can, by keeping track of the count of pulses, determine the exact thickness of the material and regulate for uniformity.

ELECTRONIC
COUNTER

REFLECTING SPOT
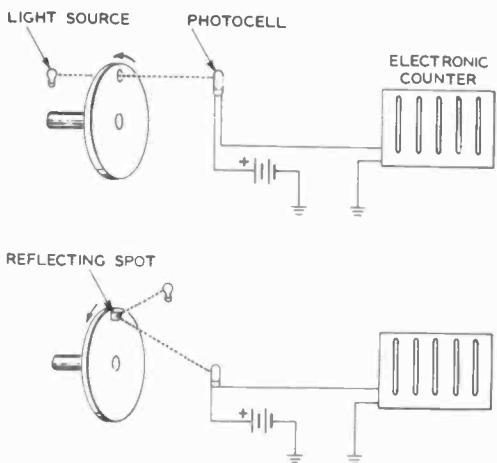
Fig. 605. *Pulses of light can be converted into rpm with a counter.*

All these applications are concerned with the number of pulses counted per unit time, and the reader can probably think of many others. However, we can make use of this idea in another way which is almost equally versatile. Suppose we already know the number of pulses from our source, say a very accurate oscillator. Then, by counting, we can establish the time lapse, from the beginning to the end of the count. If we design a setup in which one event turns on the counter and another turns it off, we have something new.

The time-interval counter

The time-interval counter is a digital counter made' up of decades, and has a gate which can be opened and closed. The gate is controlled not by an internal timing mechanism, but by an external signal. The input of the counter is then connected to an accurate oscillator, which we will call the "clock" oscillator. The counter will thus show the exact time that the gate is open, and provide an accurate count of the time lapse between opening and closing. Special time-interval counters have the "clock" built in, and in this case there is usually a choice of clock pulse from 1 mc down to 1/100 second or less. The principle is illustrated in Fig. 606.

Such a counter can measure any lapsed time between two electrical events which fall within the capability of its count. Some of the applications of the time-interval counter are in pulse-generator calibration, relay timing, timing of photographic shutters, ballistic measurements, etc.

Fig. 607 shows the calibration of a relay, while Fig. 608 illustrates a ballistic measurement. The start pulse in the latter is obtained from the first photocell, while the stop pulse is generated
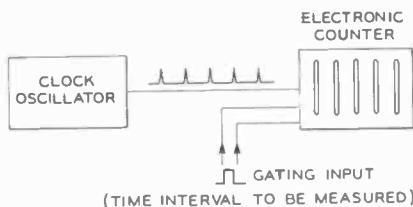

Fig. 606. *When the clock oscillator frequency is a known value, it is easy to compute the duration of the gate pulse.*

when the projectile interrupts the beam to the second photocell. Similar arangements can be used for timing sporting events. The transducers need not be photocells. Fig. 609 shows another way of deriving the stop and start pulses for ballistic measurements. Here a thin sheet of paper supports a fine wire grid and, when the projectile pierces the paper, the circuit is broken, starting the count. When the projectile pierces the second paper, the stop pulse is generated.

Fig. 610 illustrates the measurement of shutter timing. As indicated in the curve, the leading edge and trailing edge resulting from the rise and fall of the current in the photocell are sharply differentiated to provide the necessary on and off pulses.

There are numerous other applications for time-interval meas-
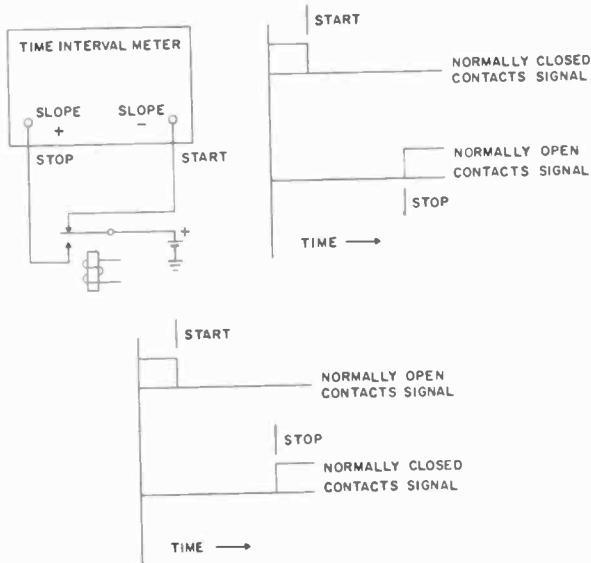
Fig. 607. *Simple circuit measures relay transition time.*

urement; those shown are only a few examples. Timing is important in everything, from missile countdown to the heating cycle
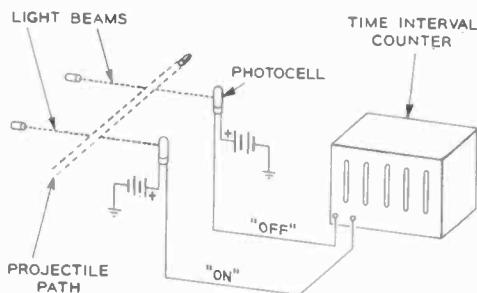

Fig. 608. *The speeds of large projectiles are easily measured with photocells.*

of a dielectric generator. Although you probably wouldn't use the electronic counter for the first, in the second case it would be used to check the accuracy of the standard timer.

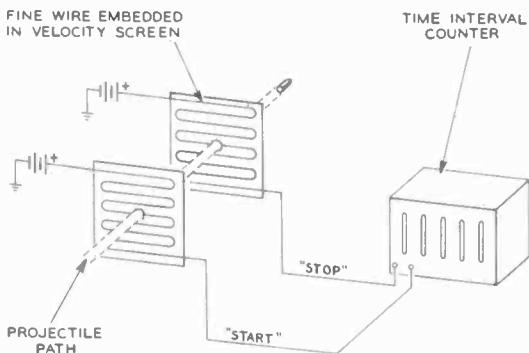The time-interval counter is as important an instrument for

Fig. 609. *This nonelectronic circuit is simpler but requires repair or replacement of the velocity screen after each test.*

service work as the EPUT counter, and many electronic counters perform both functions. For the EPUT, a timing pulse from an accurate clock is needed, plus a gate which can be opened and closed, whereas the time-interval counter needs a gate which can be opened and a clock pulse which is counted. In essence the requirements are the same, and thus easily incorporated in a single counter.
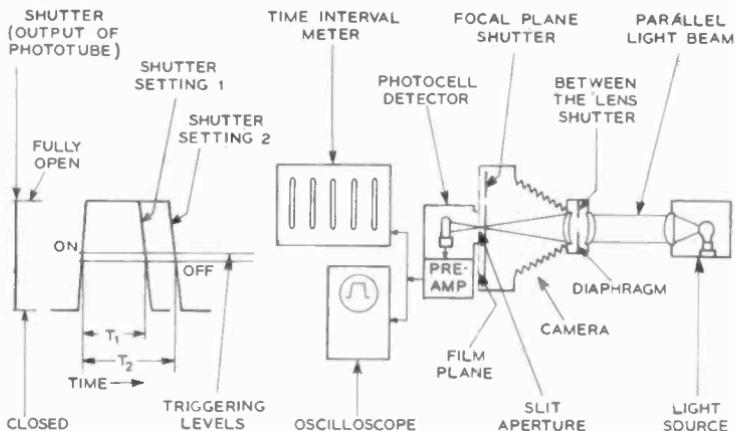
Fig. 610. *A photocell connected to a time-interval meter will check camera shutter speed.*

More common than either the EPUT or the time-interval counter is the preset counter. A preset counter is not shut off by an external clock (like a time-interval meter) or an internal clock (like the EPUT), but by its own operation. In Chapter V we mentioned briefly how presetting can be arranged with coincidence circuits, and gave a simple example of counting jelly beans before a bag of them is sealed. There are numerous more sophisticated, applications of the preset counter in industry. A preset counter can be used, for example, as an accurate timer, using a clock pulse. If the device, which starts the count, starts a clock oscillator, and the counter is preset for a certain number of counts, the counter will shut down after receiving the preset number of pulses from this oscillator.

Preset counters are useful in applications in which counting is irregular. A simple example would be the irradiation of a product to a certain precise level. An actual count from the output of a Geiger counter would give very close control over the amount of radiation.

An electronic counter can even be used to measure liquids if the proper kind of transducer is used with it. The magnetic flow meter in Fig. 611 is such a transducer. In this sensor, the liquid flows through the pipe and rotates a turbine, which contains a magnet, making the vanes magnetic also. As the vanes pass the coil, they create pulses in this coil, which are fed into the input of an electronic counter. The manufacturer of this transducer also

makes counters to go with it, one of which is shown in Fig. 612.

Its ability to measure time, frequency and events accurately makes an electronic counter an almost universal instrument in a sense. Automation will make use of more of them for various operations.
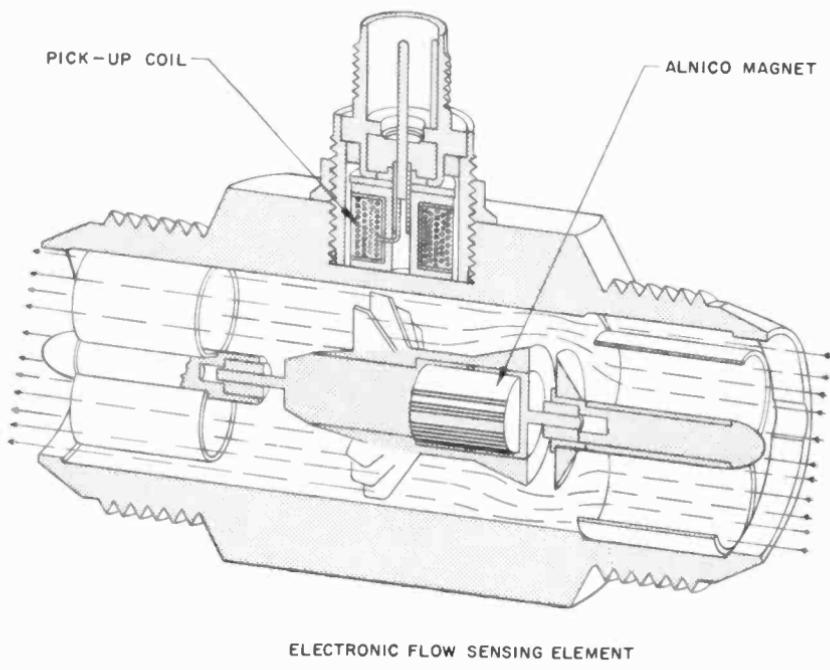
PICK–UP COIL

ALNICO MAGNET

ELECTRONIC FLOW SENSING ELEMENT

Fig. 611. *Magnetic flowmeter generates pulses which can be counted as a measure of liquid flow. Sensor must be calibrated for temperature and viscosity of liquid.*

Readout of counters

Anyone concerned with the maintenance of counters must be familiar with readout devices which display the count.

The count can be displayed by small neon tubes, and this is a very popular approach because it is inexpensive. But it does require relatively close reading, since the neon tubes are small and not very bright. For a bench type instrument, neon tubes are fine. But for displaying at a distance, something more easily read is needed.

One of these readout devices is the Nixie tube, made by Burroughs. It is, in effect, 10 neon tubes in one. Each Nixie contains 10 cathodes, shaped like letters and superimposed one upon the other in such a way that, if any one cathode is "hot," its shape can

be easily seen. The Nixie is strictly a readout device, doing no counting itself.

Incidentally, the Nixie tubes are also made with letters instead of numerals, which makes them suitable for spelling out words, but this is not for counter applications, except where these counter circuits are used in computers designed to give an immediate legible output.

Another system of readout calls for the use of numerals engraved on thin sheets of plastic. The figure shows clearly when the plastic is edge-lighted. Thus a stack of such sheets, each with a numeral, each edge lighted by a different bulb, will show the appropriate numeral as each bulb is switched on. If the plastic is a fluorescent
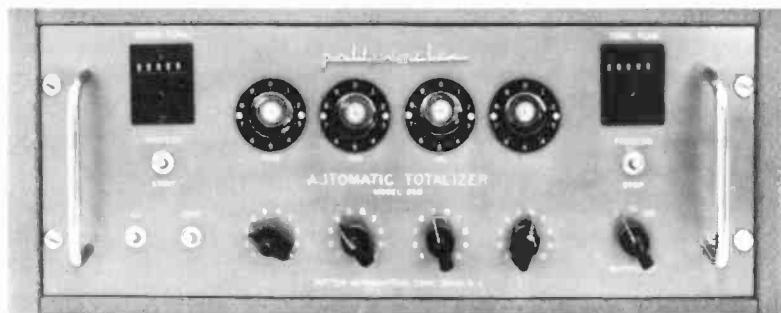
Fig. 612. *A counter of this type indicates the rate of flow as well as total flow. The reset counter is convenient to keep track of small quantities.* (Potter Aeronautical Corp.)

type, the display can be very effective for large numerals, but an inverse relationship exists here: the larger the numeral, the more the brightness of the light will be dispersed and the less clear the numeral will appear (unless several lamps are used).

Another system used for readout is familiar from its use in display of time, temperature, etc. on buildings. The numerals are formed from a group of neon tubes so shaped that any numeral can be made from a limited number of straight sections. A special switching arrangement is required. Fig. 613 shows how numerals can be formed from only seven straight bars. Short neon tubes are used for the bars. Notice that the bars for 8 and 9 are almost the same, with the exception of one bar; that 5, 6, 8 and 9 differ by only one or two bars, etc.

Remembering that it took three flip-flop outputs to show unambiguously the state of a counter, you can easily see how we can use this fact, plus the state of the fourth flip-flop in the counter, to show such numerals.

Other ingenious kinds of readouts have been designed, using similar principles. For example, one development consists of small boxes with optical systems with miniature masks as well as sets of very small lamps. When a mask is lighted from behind it projects, on a small translucent screen, the number to be read out. This system has the advantage that it can be used for other things besides numbers; an entire message can be inscribed on the mask.

Troubleshooting and repair

Besides the customary test instruments used in repairing electronic equipment, two additional items are needed for the repair of electronic counters generally. One is a pulse source accurately calibrated to frequency, or a crystal oscillator of an accurate frequency within the capability of the counter, and with some way of differentiating the waveform from the oscillator. The latter may be accomplished readily by using a very small capacitor and a large resistor. Often the counters will accept the sine wave from the oscillator, and have the pulse-forming circuits built right into the instrument.

The second unusual item needed is an accurate timer which falls within the range of the counter requirements, and one which can turn the counter gate circuits on and off precisely. The uses of these two units are obvious from the preceding discussion.

Electronic counters, like any other complicated piece of equipment, come equipped with a complete service manual. If the counter is a regular item in the equipment under your care, you'd do well to get acquainted with this manual long before the actual need arises, thus saving time on repair when the equipment does break down.

It should be noted that decades never count at the same rate; they differ by a factor of 10. The fastest is the Units counter, and each decade is 1/10 the speed of the previous decade.

When a counter tube begins to deteriorate — if, for example, it has become slightly gassy — it will not be able to count as fast as one in perfect shape.

Fortunately most counters have identical decades. One of the ways in which we can often avoid having to use new parts is to switch decades. Insert perfect ones in the fastest spots, and those which refuse to work at top speed, in the slower ones.

This swapping is also a way of rapidly testing for trouble spots. If a counter still does not work after switching the first and last decades around, chances are that the decades may be all right. But if it works up to the decade which used to be the units one

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and then stops, it is a sure indication that there is trouble in this decade. Follow this procedue to test any of the decades, swap them around to see if the behavior of the counter is any different.

Outright cessation of counting can be caused by faulty coincidence tubes in the models that have them. The coincidence tube (Fig. 503), is normally left connected to the plate circuit of the first tube in each flip-flop. If it becomes gassy, it can effectively absorb the output pulse and stop the whole decade. This is one of the first places to look for failure.

Next, the decade tubes themselves should be tested and replaced if necessary. Weak tubes will not produce sufficient output voltage to pulse the next decade. A replacement tube should operate properly without any special selection. Binaries are usually designed with adequate leeway for this reason.

Power supply voltages are relatively critical and should be checked when the whole set of decades show erratic operation.

With an oscilloscope it is easy to establish whether the input circuit is operating properly. If it is, the trouble in the counter is either in the decades, the power supply circuits or even in the

Fig. 613. *Numerals of this type are displayed by neon tubes or electroluminescent display devices.*

readout. It is quite conceivable that the decades may be working all right but the neon tubes remain dark because of a tube failure. This can be readily established with the aid of a small neon tube of the proper voltage limits. Preferably, if the counter uses neon tubes, an identical tube should be kept for testing the readout circuits. Or, with the counter off, a voltage can be connected across the readout tubes to determine whether they are functioning properly.

Next, make certain that the input pulse has the proper size and shape. Usually the input pulse-forming stages take the form of a Schmitt trigger circuit, which has the happy faculty of always producing the same kind of pulses from any input-signal waveform. The Schmitt trigger circuit is a type of cathode-coupled

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multivibrator, but its operation is a little different than the usual binary. Fig. 614 shows a basic Schmitt trigger. This one uses triodes; often pentodes are used for fast response, but the operation is basically the same.

The circuit (Fig. 614) has two states, as does any bi-stable multivibrator. Assume that the voltage on grid of V1 is such that the tube is cut off. This means V2 is conducting. The plate of V1 will be at supply voltage potential and, through divider R1, R3, R4, the grid of V2 will be at a relatively high voltage. The cathode of this tube, V2, which now operates as a cathode follower, will be at a slightly higher voltage than its grid: of course, the cathode voltage of V1 is the same. If we now raise the input voltage gradually, V1 will start to conduct when we reach a point slightly below the cathode voltage on V1. This will lower the voltage on its plate, and with it the voltage on the grid of V2, which now conducts a little less. If we continue raising the input voltage, V1 will conduct more and more. This also raises the cathode voltage of the two tubes.

At a certain point, the voltage on the grid of V2, which is gradually lowering and the cathode voltage which is gradually
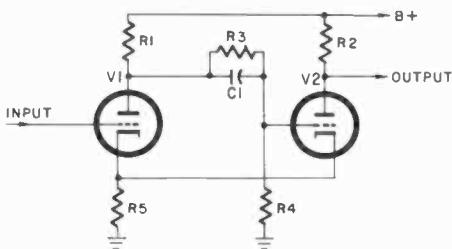
Fig. 614. *Basic Schmitt trigger circuit is used to generate uniform pulses from various input waveforms.*

rising, will reach a point where V2 is cut off. Immediately, the voltage on the cathode of the tubes drops sharply, allowing V1 to conduct heavily. But V2, which normally would be expected also to begin conducting again at this lowered cathode voltage, cannot do so because its grid is held at a lower voltage by the charge stored in capacitor C1.

Thus V1 has taken over conduction, and now the trigger circuit has *changed state*. This would register at the plate of V2, where we take the output, as a sharp rise in voltage. Now when we start lowering the input voltage, we will reverse the process, making

V1 less conducting and raising the grid voltage on V2. At a certain point, we will reach the grid voltage on V2 which will allow this tube to start conducting a little, and it will suddenly take over conduction in the same way. The grid of V1 is held low by the low input voltage and, in spite of the lowered cathode voltage when V1 cuts off, it cannot conduct again. V2 takes over and the circuit is back to its original state.

At the plate of V2 this second change of state registers as a sharp drop in voltage (when V2 conducts again), and thus we have formed a pulse. This pulse will always have the same amplitude and the same rise and fall time (unless we drive the Schmitt with a *very short* pulse). The duration of the pulse will depend only on when these two points, at which the respective tubes started to conduct, are crossed, once on the way up with the input voltage and once on the way down. These two points are known as hysteresis points, for the obvious reason that this circuit acts, to all intents and purposes, as a piece of iron being magnetized in regard to the sudden changes of state and the "lag" in change of state with the change in input voltage.

The pulse length, produced by the Schmitt trigger, is usually adjusted by providing the grids with adjustable bias, so that the hysteresis limits can be accurately preset. Obviously, a very small change in voltage can flip the Schmitt if we set the hysteresis limits close, and this is what makes this such a useful pulse-forming circuit. If the circuit has to be energized with very small voltages, it is generally preceded by a simple amplifier, and sometimes with a cathode follower before that to avoid loading the input circuit.

Counters, in theory, don't present much serious difficulty basically — in practice, they are usually built in as small a space as is feasible and, although the decades are often plug-in devices which can be removed as a unit, the rest of the counter is quite crowded and may present some problems in checking the circuits. An extension cable would help here. In some cases, it might be better to set up a power supply and a spare socket of the proper circuit connections for the external testing of decades. This is strongly recommended if your work will require frequent servicing of a group of counters and will save considerable time.

What has been said about swapping decades is as valid for the various kinds of counter tubes. These, too, can be swapped to find the sick one. Obviously, the units counter here must also do a much faster job, so that, if it slows down through aging (and this

does happen), then it can be used in a slower circuit, with a new one or one of the other tubes taking its place.

When removing and inserting counter tubes, particularly the beam-switching tubes, be very careful not to bend any pins. If you have ever had trouble inserting a seven-pin or nine-pin miniature, you will appreciate what it means to have 26 pins on a tube not much larger. Because of the heavy magnet around the tubes, shocks to the instrument are more likely to unseat the tubes, and this is something to keep well in mind when transporting these instruments.

Outside of such special tricks as swapping decades and the particular care in handling decade tubes, electronic counters should be treated like any other complex electronic instrument. Periodically, the tubes should be checked if the counter is used continuously. Among the most likely thing to go wrong with a counter is that one of the flip-flops will stop changing state; these are the most critical items in the instrument. For the rest, your treatment of the counter will depend on whether you subscribe to the philosophy that it is better to leave equipment alone so long as it is functioning well, or whether you are of the school that believes in preventive maintenance. In general, in the military services and in industry, the leave-it-alone philosophy is gaining favor as the more economical of the two in the long run. And, of course, as with all electronic equipment, cleanliness is the first order of maintenance.

7 * industrial controls

MANY electronic controls used in industry have a relay or contactor as the final link in the chain. These relays come in many shapes, sizes and forms as a glance at Fig. 701 shows. Generally speaking, the relays dealt with in industry will be of moderate size. The majority will be open types mounted in cabinets along with other equipment, and only a few will have special sensitivity and coil ratings or unusual contacts such as one type designed to handle very high voltages.

A relay is any device whose contacts are opened and closed by electrical means (whether this be a coil, a heated bi-metal strip, a meter-movement type of rotating coil, an expanding ceramic element or a motor type of disc) in order to control another circuit. Most prevalent are the coil types, and we need say little about these except that there is a basic difference between the ac and dc forms. One difference is that the ac type must contain some means of avoiding armature chatter, and this usually takes the form of a shorted turn called a "shaded" pole. The shorted turn shifts part of the magnetic field in phase so that, when the main current through the coil goes through zero, there will still be more magnetic field to hold the armature to the core.

Dc and ac relays have different maintenance problems. In dc coils there will be corrosion, due to electrolysis; in ac relays this presents no problem. In ac relays, on the other hand, you will find problems such as shorted turns which can drastically affect the

operation of the relay (since the core will give it the character of a transformer with shorted secondary). Contacts carrying dc are more likely to arc, with resultant uneven burning and pitting. Ac voltage peaks are passed in a fraction of a cycle, but a dc arc continues to build up. In ac relays, the coil current is drastically
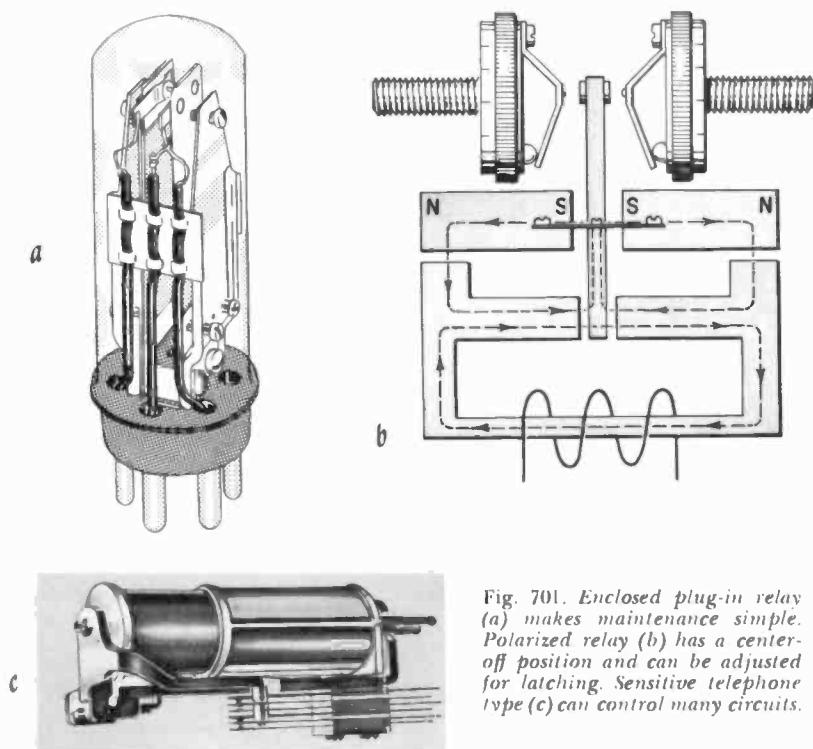
Fig. 701. *Enclosed plug-in relay (a) makes maintenance simple. Polarized relay (b) has a center-off position and can be adjusted for latching. Sensitive telephone type (c) can control many circuits.*

reduced when the armature closes completely while in dc coils it decreases very little. Therefore, dc relays remaining energized for long periods of time show more tendency to heat.

Fig. 702 shows some telephone type relays, which are in a class by themselves, but are likely to be encountered in electronic controls because their flexibility of contact arrangement makes them specially suited to this kind of work. Also the frame configuration of telephone type relays lends itself to the construction of sensitive units with high coil impedances and resultant low current requirements.

Relays in control functions are digital devices, since they have two states, either on or off — there is no halfway point. Also in the

class of digital switching devices are the various stepping switches, some of which are shown in Figs. 703 and 704. Those in Fig. 703 are familiar in telephone circuitry, and some of them contain
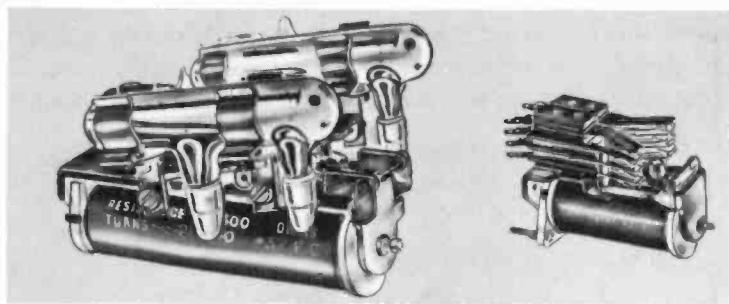
Fig. 702. *Telephone type construction can tilt mercury-tube contacts or operate many dry contacts.*

many hundreds of contacts in banks of 11, 22, 36 or 45. The one at the right is a 10-point switch which has a spring reset mechanism; the other rotates continuously, bringing a new set of rotating contacts onto the stationary contacts every 180°.
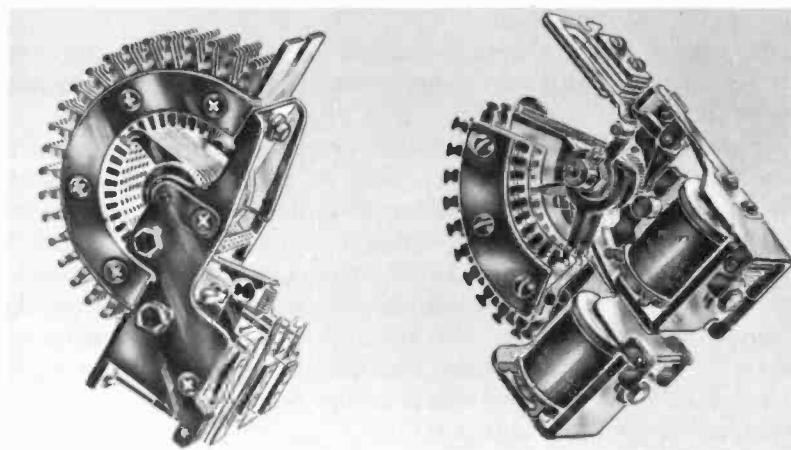
Fig. 703. *Stepping relays are digital since stepping pulses are also digital.*

There are many other versions of these switches, some of them capable of rotating in two directions. One of the oldest and most used of this type is the Strowger switch (Fig. 705 — contact banks

have been shown separately for clarity) which has two motions. The vertical motion selects the appropriate bank of contacts while the horizontal rotary motion selects one contact in that bank. The relays mounted on the frame control these motions, with appropriate timing so that the switch can respond to two sequences of digital signal, one sequence for each motion. After the motions have been completed or, if too much time passes between motion
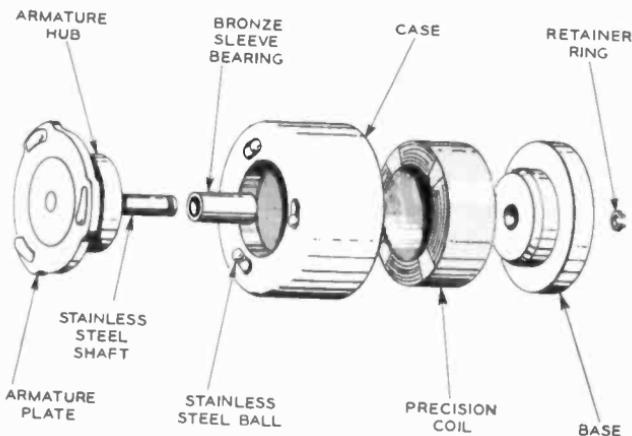
Fig. 704. *Rotary solenoid can be used to drive many rotary switch decks.*

signals, a single pulse allows the switch to step to home position. Strowger switches are useful where more than 100 contact points must be dealt with.

The switch in Fig. 704 is the well known LEDEX type, which uses a rotary solenoid to step points on ordinary rotary switch decks. This allows any combination of available switch sequences, with shorting or nonshorting contacts as desired. The LEDEX solenoid depends on the mechanical motion executed by a linearly moving slug in a coil, and a slanted disc attached to this slug. As the slug is attracted deeper into the coil, the disc, which rolls on steel balls, will tend to rotate because this is the only motion which will allow the slug to travel to the bottom of the coil. The race on which the balls run is slanted.

In the power-generating and transmission business we also have what are called "electronic relays," a version of protective relay used to protect sections of transmission lines.

Relays which are oversized are no longer classified as relays; we then call them "contactors." Basically there is no difference. Contactors which must handle large loads are supplied with a means
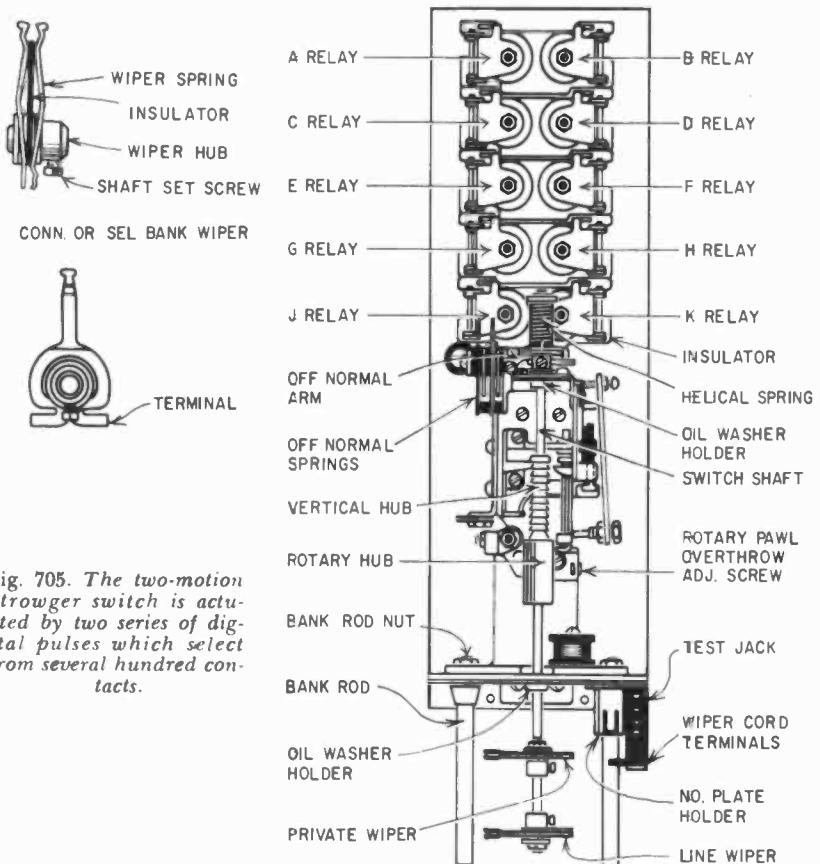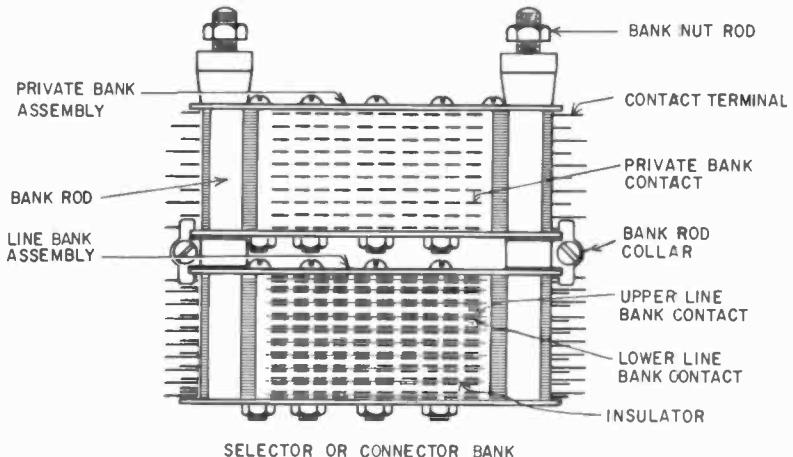
WIPER SPRING
INSULATOR
WIPER HUB
SHAFT SET SCREW
CONN. OR SEL BANK WIPER

TERMINAL

A RELAY
B RELAY
C RELAY
D RELAY
E RELAY
F RELAY
G RELAY
H RELAY
J RELAY
K RELAY
INSULATOR
OFF NORMAL ARM
HELICAL SPRING
OFF NORMAL SPRINGS
OIL WASHER HOLDER
VERTICAL HUB
SWITCH SHAFT
ROTARY HUB
ROTARY PAWL OVERTHROW ADJ. SCREW
BANK ROD NUT
TEST JACK
BANK ROD
WIPER CORD TERMINALS
OIL WASHER HOLDER
NO. PLATE HOLDER
PRIVATE WIPER
LINE WIPER

Fig. 705. *The two-motion Strowger switch is actuated by two series of digital pulses which select from several hundred contacts.*

BANK NUT ROD
PRIVATE BANK ASSEMBLY
CONTACT TERMINAL
PRIVATE BANK CONTACT
BANK ROD
LINE BANK ASSEMBLY
BANK ROD COLLAR
UPPER LINE BANK CONTACT
LOWER LINE BANK CONTACT
INSULATOR

SELECTOR OR CONNECTOR BANK

of extinguishing arcs, and this may take the form of magnetic "blowout" coils. Arc is a stream of ions and such a stream of ions can be affected by a magnetic field.

Another blowout means is a special arc chute which operates
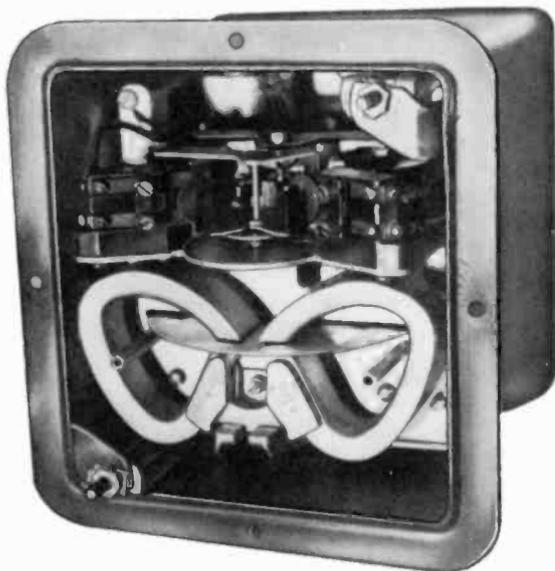
Fig. 706. *Eddy-current disc motor is strong enough to operate contacts in this time-delay device.*

on the principle that the arc heats the air surrounding the contacts and thus tends literally to "blow" out the arc. When the loads which contactors are rated to handle are exceeded, heavy-current switches, called circuit breakers, (electrically or mechanically operated) are used. This is getting pretty well out of the class of electronic controls except where the "sensing means" for determining whether the breaker should be closed or open are electronic.

Relays do not always operate rapidly, and they are, in fact, classified according to how fast they must operate. Thus telephone type relays are slowed down by adding slugs to the core above or below the coil. Such slugs, when mounted at the armature end, will cause delayed *opening* of the relay; at the other end or "heel" of the relay frame they will delay *closing*. Such a copper slug at each end of the central core will make the relay operate slowly on both motions.

Other ways of slowing down relays consist of thermal means, such as separate bi-metallic contacts heated by the same current which will eventually hold the relay energized, or mechanical dashpots with air or oil. All of these are fairly familiar in industry. For example, the Amperex series of time-delay relays (a thermal
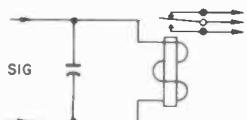
Fig. 707. *Simple time delay is had by paralleling relay coil with large value of capacitance. Charge holds relay closed after voltage is removed.*

type of relay mounted in a tube envelope) can be obtained for many delay times and is often used to protect equipment against operating with unheated filaments (which might rapidly evaporate the filaments when high voltage is applied). Fig. 701-a on page 122 is a relay of this type.

Of much greater interest here are the electronic means of obtaining time delays for relays, and this will be our first look at electronic controls. These will generally be dc relays, in contrast with the inherently delayed relay of Fig. 706 which works on ac
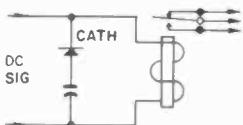
Fig. 708. *Proportional-delay relay circuit. Hold-in depends on reverse-current charging of capacitor. Relay hold-in is proportional to duration of signal.*

on the same principle as your home electric meter, with contacts made by a pusher on the rotating eddy-current disc.

Electronic time delays

The simplest form of electronic time delay is shown in Fig. 707. It consists simply of a large electrolytic capacitor in parallel with the relay coil. Delays of up to a second can be obtained this way. If the applied voltage is always the same and the duration of the applied voltage is either always the same or more than long enough to charge the capacitor fully, this kind of delay can be quite dependable so long as the capacitor does not deteriorate.

To make a distinction between a short timing delay and a long-duration signal, the circuit of Fig. 708 will serve. If the applied voltage is only of very short duration, the relay will drop quite rapidly. If the applied voltage remains on for a considerable time, the capacitor will charge enough to hold the relay for some time after the applied voltage is removed.

A delayed make circuit is shown in Fig. 709. When the switch is first closed, B is at exactly half of the battery voltage but, since it takes time for the capacitor to charge, point A is initially at zero. As the capacitor charges through R1, the potential at B and at the other end of the coil gets progressively more positive but,
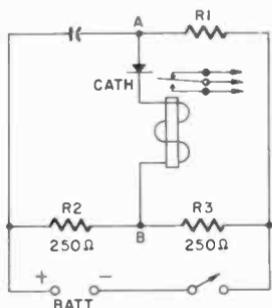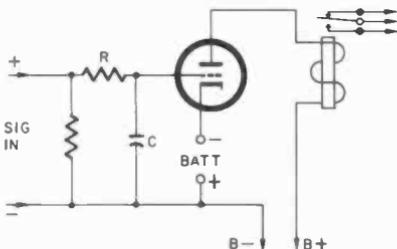
since the cathode of the rectifier is yet more positive than the anode, no current will flow. Only when the capacitor is fully charged will A be more positive than B, and current will suddenly flow through the relay, energizing it. For an adjustable delay, R1 can be made variable. The capacitor should be quite large for long time delays.

Timing by charging capacitors is a relatively old subject to most readers who understand electronics. Thus the circuit of Fig. 710 is quite familiar. In this circuit, the capacitor must be charged by dc until the voltage on it is sufficient to overcome the negative grid bias, whereupon the tube will conduct and energize the relay. This same operation can be made linear in time by using a charging tube (Fig. 711) but the principle is basically the same.

In industry, however, we deal most often with ac, and we would like to save components if we can. Thus, if we can operate a timing relay without first converting all the ac needed into dc, we can save a lot of money when making large quantities. Such an

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operating principle is shown in Fig. 712. Here we "misuse" the triode by operating the grid as an anode when the switch is not on, and in this way charge the capacitor C1 to a potential controlled by R1. The high-ohmic resistance R1 will tend to discharge the
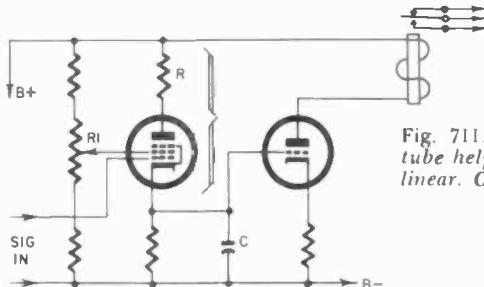

Fig. 711. *Pentode charging tube helps make time delay linear. Charging rate is set by R1.*

capacitor and the time required for this resistor to discharge the capacitor is a function of the potential to which we allow it to be charged: the higher the potential, the longer the time constant. Thus, when the switch is closed, the tube will have a high negative bias imposed on the grid, superimposed on the alternating voltages of the circuit, and not until the potential across C1 has dropped enough to allow the tube to conduct on positive half-cycles will the relay energize. This is a quite simple and common circuit in industrial timers.

Had the switch been incorporated in the bias charging circuit instead, we could then get the opposite effect – the relay would be energized until the switch was closed, and the relay would drop

Fig. 712. *Ac-powered time-delay circuit. Triode is also rectifier to provide bias.*
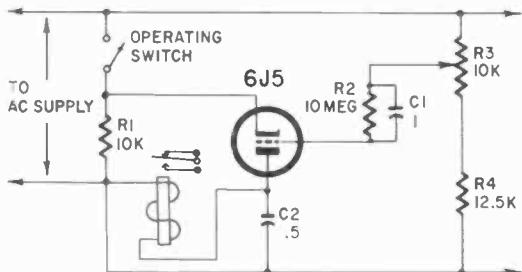
out after a sufficient *charging* time had elapsed. Such circuit variants are also available commercially.

An entirely different principle of time delay involves the use of thermistor beads of sintered material, often a semiconductor material, which have the characteristic that their resistance drops

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sharply as their temperature rises. Thus, in the circuit of Fig. 713, the current through the relay will be insufficient until the thermistor has heated up. Variable time-delay can be had by making the heater current variable, so that it takes more time to heat the
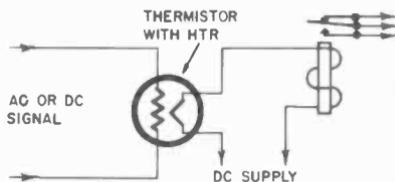

THERMISTOR
WITH HTR

AC OR DC
SIGNAL

DC SUPPLY

Fig. 713. Basic thermistor
time-delay circuit.

thermistor. Complicated electronic circuits can also be built with the thermistor as the regulating element.

Note that no matter what kind of electronic control of time has been discussed, it always involves some process which in itself takes time, such as heating an object, or filling or discharging some kind of reservoir, liquid, gas or what have you.
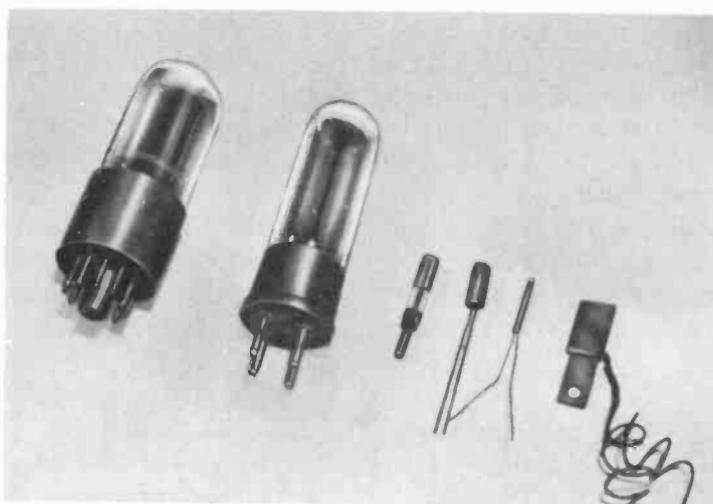
Fig. 714. Photosensitive devices have many forms.

Photoelectric controls

It is possible to go on ad infinitum discussing relays, but there are many other classes of controls to be included. Among these are photoelectric controls. These can also be simple or complex, depending on need, but industry will generally choose only those circuits which have very high reliability. A man's life or safety of limb may well depend on proper functioning.

The simplest means of control would be a photovoltaic cell, generating its own voltage as the result of the impinging light. Such cells are used in photo exposure meters, for example. Until the invention of solar batteries, few voltaic cells gave enough output for reliable control work; consequently, not many applications of solar cells are to be found in industry.

Most of the photoelectric controls we will examine will deal with photoemissive cells, the well known phototubes. These release electrons from a cathode as the result of light impinging on it, and these electrons are in turn attracted to the high voltage applied to the anode.
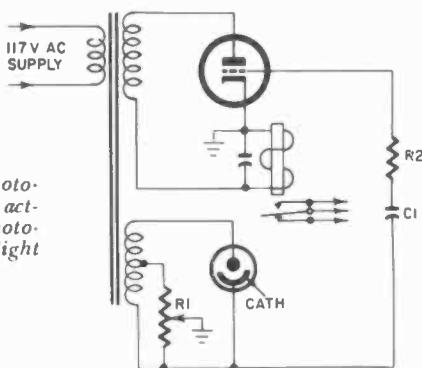
Fig. 715. *Typical ac-powered photo-electric relay circuit. Triode grid, acting as diode plate, charges C1. Photo-tube discharges capacitor when light strikes cathode.*

Also important are photoconductive cells made from certain semiconductor materials which drastically change their resistance when the element is exposed to light. Typical materials used are germanium, silicon and cadmium sulfide. The last is most important because it can respond to a wide range of radiation, from infrared up to X-rays. Cadmium sulfide detectors are also used in industrial installations for X-ray dosage measurement. Fig. 714 shows some phototubes and typical germanium and cadmium sulfide photocells. Note the small size of some of the units.

Industrial circuits in the past have used mostly photoemissive cells. Fig. 715 shows a typical industrial photoelectric circuit, which differs from the usual experimenter's circuit in that it uses ac directly, even on the phototube itself. Here again the unit uses the triode grid to charge a capacitor, and the charge on the capacitor depends on the setting of R1. If light falls on the phototube, it will try to discharge the capacitor on the next positive half-cycle

but does not succeed at once. But, as the phototube keeps discharging and the capacitor gets only a half-cycle to restore what is lost by grid rectification (which is a very slow way of charging), the capacitor will eventually be discharged sufficiently (and the bias will be reduced sufficiently) to allow tube current to flow and the relay to be energized. As long as there is sufficient light to keep the capacitor from recharging enough to reach cutoff bias, the relay will remain energized.

Similar relays may use thyratrons instead of triodes. One such circuit is shown in Fig. 716. Here the grid of the thyratron is, on the positive half-cycles, more negative than the cathode, and the tube remains cut off. When light falls on the phototube and the cell conducts, the grid will be made more positive by the drop across R4, and the thyratron will conduct. As soon as the light is removed, the relay will be de-energized.
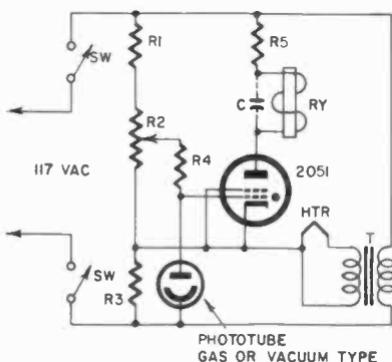
C = 2-8 μf, 250 V.; USED IF NEEDED TO PRE-
VENT RELAY CHATTER
R1, R2
    R1, R2 FOR VACUUM-TYPE PHOTOTUBE:
        R1 = 0 OHMS
        R2 = 5000 OHMS, 4 WATTS
    FOR GAS-TYPE PHOTOTUBE
        R1 = 3000 OHMS, 2 WATTS
        R2 = 2000 OHMS, 1 WATT
R4 = 100 OHMS, 1 WATT
R1 = 1-10 MEGOHMS
R5 = CURRENT-LIMITING RESISTOR
SW = DOUBLE-POLE ON-OFF SWITCH
T = HEATER TRANSFORMER, 6.3 V., 0.6 AMP.
RELAY SHOULD OPERATE ON 25 MA OR LESS

Fig. 716. *Ac-powered thyratron photoelectric relay circuit energizes relay when light hits phototube.*

A similar circuit operating on a *decrease* of light is shown in Fig. 717, and its action is self-explanatory. Quite often in industry photoelectric circuits are used to compare brightness or reflectance of colors. This can be done with the circuit shown in Fig. 718. Because we usually are dealing with very small differences in these cases—in fact, often differences which the human eye cannot detect—a dc circuit is used. Ac circuits with phototubes are fine for on—off action, such as the relay circuits we have shown, but when it comes to sensitive measurement, say with a meter, as the 100-μa meter in Fig. 718, then the use of dc is obviously an advantage.

The meter could, of course, be replaced with a sensitive relay

set to activate other circuits when the meter type relay swings one way or the other. This system is often used to accept or reject products by matching them with a standard. Sometimes fruit is inspected for color this way, and if color or ripeness is an indication
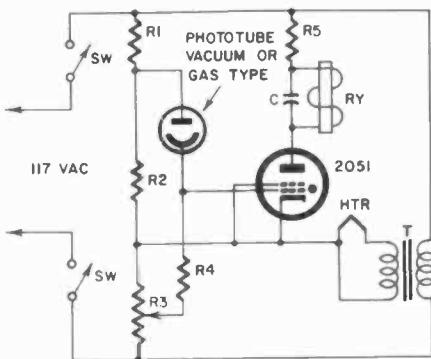

Fig. 717. *Similar to Fig. 716, grid circuit changes cause relay to be energized when light is cut off from phototube.*

of grade, the fruit may be sorted into categories by several circuits, one after another.

Photoelectric relays are frequently used to prevent injury to press operators—the press cannot operate so long as the operator has his arm in the multiple path of a light beam that must reach

Fig. 718. *This comparison circuit measures relative light intensities.*
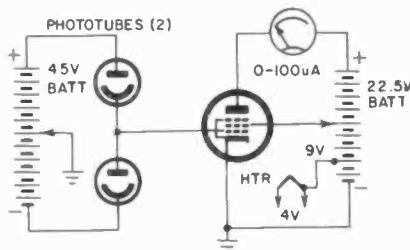
the phototube. Less important but often encountered are the photoelectric door openers in markets and restaurants, department and drug stores, etc. Similarly, phototubes, operated by daylight, turn plant lighting and road lights on and off.

Electric motor controls

In industry polyphase ac motors are preferred when certain

ratings are exceeded, because they are more economical, both in terms of power efficiency as well as in the motor design itself. Thus for a given power rating, the polyphase induction motor, invented by Tesla, requires less iron and less copper than other types, with a resulting decrease in losses in the form of heat. Incidentally, the reason for using 60 cycles stems from the fact that Tesla calculated that at 60 cycles the precise optimum point is achieved in terms of iron losses in motors and generators.

Polyphase induction motors come basically in two types, the squirrel cage with one or more "shorted" windings in the armature and the so-called "wound rotor." The squirrel-cage motor is not intrinsically limited in size; but the motor has one disadvantage which becomes very significant in large motors. The initial surge of starting current in a squirrel-cage motor is as much as ten times the normal operating current. In dealing with a motor larger than 5-hp this becomes a serious factor, though still permissible. Above 100-hp, most utility companies prohibit starting a squirrel-cage induction motor directly across the power line to prevent system damage. In such cases the motor is started at about 65% of normal line voltage, and, draws much less current. Resistors can be used for this purpose, but these waste power. Generally it is more efficient to use an autotransformer for starting.

Now when we get up into several hundreds of horsepower, there is theoretically no reason why the same system could not be used. In practice the currents become so large that autotransformers become too bulky, and very expensive. For this reason, wound-rotor polyphase induction motors are used at these higher ratings and they possess the advantages of positive control of starting current as well as speed by controlling the current in the wound-rotor (field) windings.

Wound-rotor ac motors in small sizes would be very expensive. Therefore, when accurate speed control is required at lower power ratings dc motors are used instead. In dc motors the motor speed is controlled by varying the armature current or the field current or both.

There are many other ways to control speed in machinery, other than by actually controlling the motors, but they universally have the disadvantage that the control must be gradual. For example, a number of excellent variable-speed controls use variable-depth V-pulleys, which are very reliable and do control a wide range of speeds, but to change the speed from one extreme to another takes some time, whereas electrically it can be done very rapidly.

In many applications, motors in industry must have very rapid, continuously controlled variable speeds. Such applications are generally found in factories dealing with continuous processes such as steel rolling mills and paper, textile and wire mills, and in many other industrial conveyor systems, to mention a few. Electronic controls have solved many of their long standing problems, enabling an enormous speedup of many such processes.

Electronics, through the use of rectifiers, provides us with a ready means to control dc motors or the direct current in the field
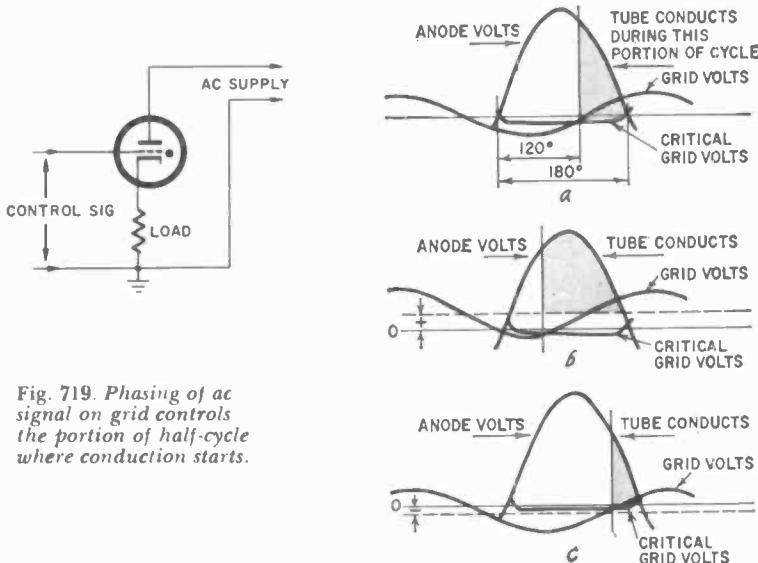
Fig. 719. *Phasing of ac signal on grid controls the portion of half-cycle where conduction starts.*

winding of large ac motors. By controlling the amount of current a rectifier passes, we have immediate control over the *average* direct current fed to the load. A number of devices can be used for this control, depending on the size of the current dealt with. For the smaller loads, high-vacuum tubes can be used, but these have the disadvantage that the current through them must pass through a relatively high internal resistance. Even many tubes in parallel and with specially low internal resistance would have prohibitive total resistance for large currents. In such cases, thyratrons, handling up to several hundreds of amps, are utilized. Above these capacities we turn to ignitrons, a similar device operating on a somewhat different principle. Finally, for extremely heavy currents, mercury-pool rectifiers are employed. However, these are not often controlled electronically as are thyratrons and

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ignitrons. In certain industries, such as the aluminum industry, complicated and ingenious controls are used for mercury-pool rectifiers, but these are beyond the scope of this volume.

Let us turn next to thyratron control circuits, the principle of which is illustrated in Fig. 719. As the voltage on the plate goes through its positive excursion, the point at which the tube con-
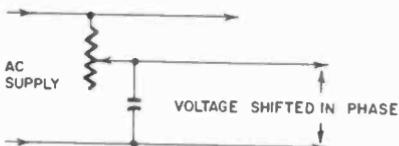

Fig. 720. *Simple variable phase-shift network uses capacitor and variable resistor.*

ducts depends entirely on the voltage on the grid. We can control this in two ways, by voltage and by phase. Voltage control would require dc on the grid. For this reason ac phase-shift is more generally used to control thyratrons.

There are various methods of controlling the phase of the grid voltage. One is to use a capacitor and resistor in series across the
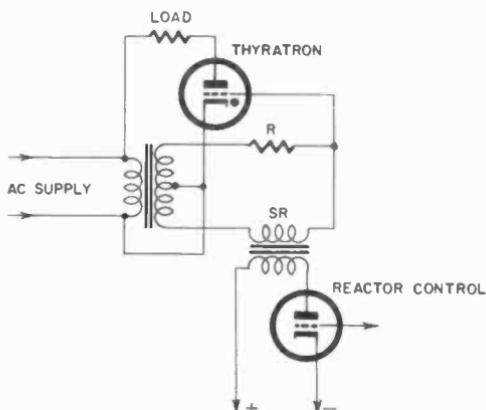
Fig. 721. *This circuit uses a saturable reactor to control phase shift of signal applied to thyratron grid.*

ac supply and to tap off the phase-shifted voltage at their junction point. If the impedances of the capacitor and resistor are exactly the same, we will get exactly 90° of phase shift. Theoretically, this circuit could give us a shift of 180°. Practically it is much less for. as the resistor is made smaller, the voltage across it is also reduced until it becomes zero. In fact one of the major disadvantages of the method is that it does not produce a constant voltage. Variation of the capacitance in the circuit has the same effect (Fig. 720).

Another way to do the job is to replace the capacitance with an inductance and, if we use a saturable reactor as in Fig. 721,

we have a ready means of varying the inductance. (Details of saturable reactor functions are discussed in Chapter 8.) Here again we still have the problem of varying control voltage, but we do have an extremely rapid means of control.

And, finally, if three-phase voltages are available, another way to obtain phase shift is with a selsyn in which the three-phase field can be made to induce a voltage of any phase on the secondary, which can be rotated either by hand or by motor.

Since the R-C method is the least expensive, we cure this system of its major fault, by using two sets, in the quadrature circuit of Fig. 722, which now shifts the phase one half in each section and has a constant voltage output.

Controlling phase with a resistor would require manual or electrical control of a dual potentiometer or rheostat, and this would soon wear out. To make the system more durable (and more convenient), a system with a constant phase shift, combined with a variable dc voltage for control, is used. The circuit is shown in Fig. 723 and the waveforms at the thyratron show

Fig. 722. *Phase-shifted voltage output from this dual circuit is quite constant.*
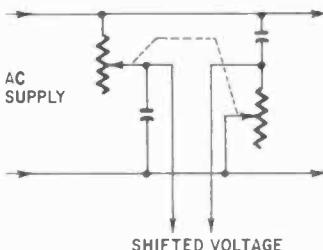
clearly what is happening. The top of Fig. 724 shows the normal course of waveforms with phase-shift control, and at the bottom, with fixed phase shift and variable dc voltage. As far as firing the thyratron is concerned there is no difference in effect.

Another feature of both phase-shift and voltage control of thyratrons shows up clearly in Fig. 724. The curve representing the grid voltage crosses the cutoff line at a very obtuse angle. This means that, with a slight variation in thyratron characteristics, the actual firing point might vary quite a bit. To obtain firing accuracy we must employ a means to sharpen this firing-point definitely. This we can do with a peaking transformer. A peaking transformer is one which has a great deal more current forced through the primary than is needed for the load. When the current reaches positive or negative peaks, this will saturate the core.

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A voltage will then be obtained from this transformer only when the core is changing from one state of saturation to another. The resultant secondary current is sharply peaked (Fig. 725). A very inefficient transfromer, true, but a useful one for our purposes.

How we use this transformer in thyratron control is shown in Fig. 726. When the switch is opened, the capacitor in the cathode will gradually discharge. When the cathode voltage becomes low enough, the peak superimposed on the control voltage will fire the thyratron at a precise point. This is a very practical and very common means of controlling thyratrons and ignitrons.

A typical control circuit for thyratrons or ignitrons is shown in simplified form in Fig. 727. The cathode of the thyratron and its grid are connected by three transformers in series. T1 is a peaking transformer which obtains its primary current from a phase-shift
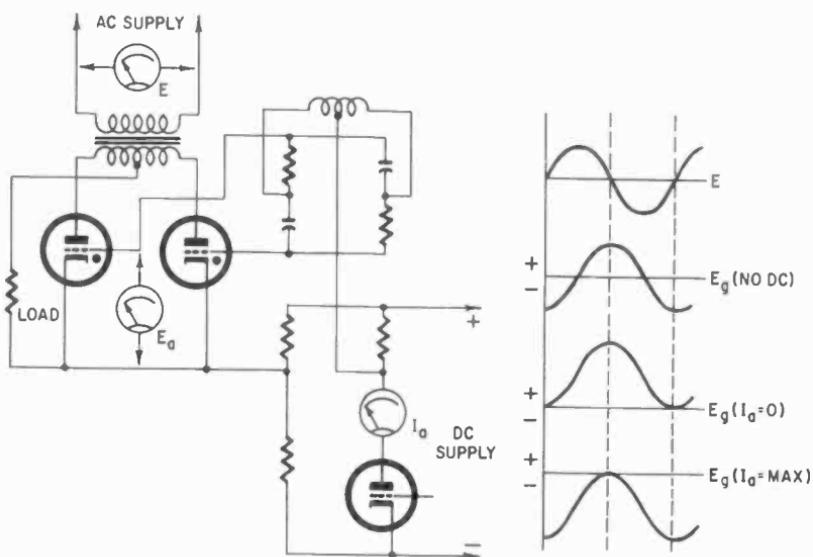

Fig. 723. *This thyratron circuit has a fixed phase shift and a variable dc bias controlled by the vacuum tube. Waveforms show effect of bias variations and relation to thyratron plate voltage.*

network. The primary of T3 is out-of-phase and prevents firing of the thyratron, and the primary of T2 is in-phase (with anode voltage) and tends to help fire the thyratron. When the signal for firing is transmitted, the secondary of T2 will overcome the voltage on T3, and the combination of the difference and the peak from T1 will accurately fire the thyratron.

These circuits, and some others like them, form the basis of control through thyratrons or similar gas tubes. The output of the circuits used with the thyratron is a pulsating dc. If it is possible to use these circuits with three-phase primary current and fire
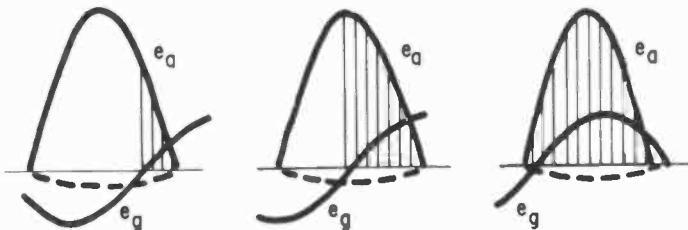
CONTROL BY PHASE SHIFT OF CONSTANT VOLTAGE VECTOR
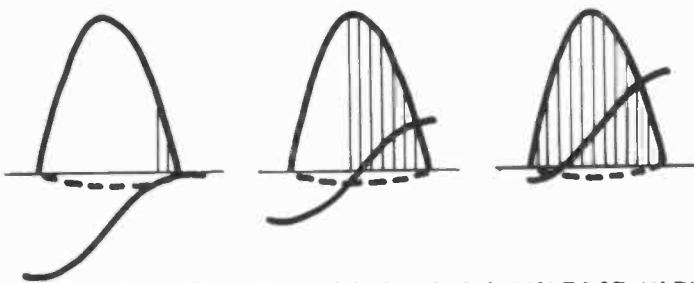
CONTROL BY FIXED VECTOR & D C VOLTAGE VARIATION

Fig. 724. *Comparing pure phase-shift and combination phase-shift voltage firing of thyratrons. Note that in both cases the grid voltage curve passes the firing point at a very obtuse angle.*

three thyratrons in sequence as the phase becomes appropriate, we will smooth out the dc a great deal.

With this controlled dc, we can regulate the speed of dc motors or the field current for ac wound-rotor motors. We can also use them to control the dc control current for saturable reactors and magnetic amplifiers (Chapter 8).

A typical thyratron speed regulator circuit, the GE Thymotrol, is shown in Fig. 728. Both the armature and field current of the dc motor are controlled, each by a set of full-wave thyratron rectifiers, V1 through V4. Note in the diagram that the primaries and secondaries of various transformers are well separated, as was explained in Chapter 2. This is a more convenient notation to obtain *functional* progress through the diagram. The grids of V1, V4 and V2, V3 are controlled by the saturable-reactor phase-shifting circuits SRA and SRF, respectively. V1 and V4 are controlled

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by T3, the primary of which (T3p) is in bridge SRA, and of V2 and V3, by the secondary of T4. Increased current in the saturable reactors will *increase* armature and field currents.

In addition to the phase shift, which is controlled by vacuum tubes, there is compensation for the IR drop in the armature, which would vary with the load and would thus vary the current in the armature. The armature saturable-reactor control winding
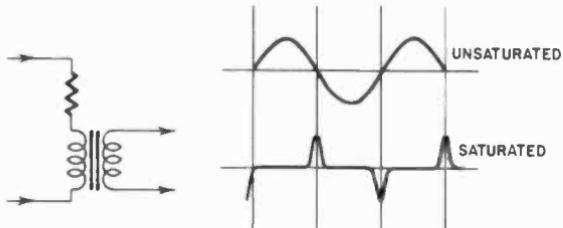

Fig. 725. *A peaking transformer is saturated and produces secondary voltages only when changing from one state of saturation to the other. The low impedance of the saturated transformer requires a series current-limiting resistor.*

is controlled by tube VD. VA is a full-wave rectifier to supply dc to the vacuum-tube circuits, and VG and VB are regulator tubes.

The grid of VD is fed from the voltage divider R2, R3, R4. R2 is the common plate resistor for VE and VC. VE is normally cut off, and tube VC controls the armature current. The cathode of
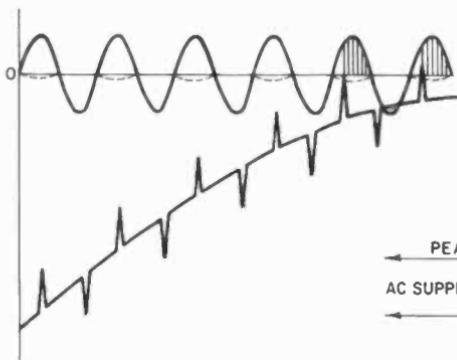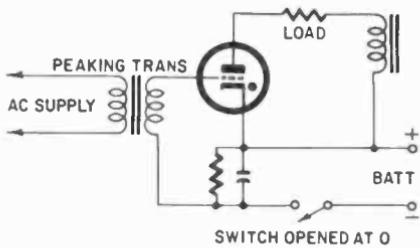

Fig. 726. *This schematic shows peaking transformer uses dc bias for more accurate firing of thyratron. Waveform indicates grid voltage action.*

LOAD

PEAKING TRANS

AC SUPPLY

BATT

SWITCH OPENED AT O

VC is set at a predetermined voltage by R1, across the regulated 75 volts supply. The grid is connected to an adjustable point on the divider R5, R6, R7, fed from the supply to the armature.

When this voltage rises, the grid will rise with it, increasing the current through VC. This lowers the voltage at the plate and at the grid of VD, reducing the current through VD and the control winding of the saturable reactor, thus lowering the supply current to the motor.

The setting of R1 and R6 will determine the armature current. However, the armature current is not an accurate indication
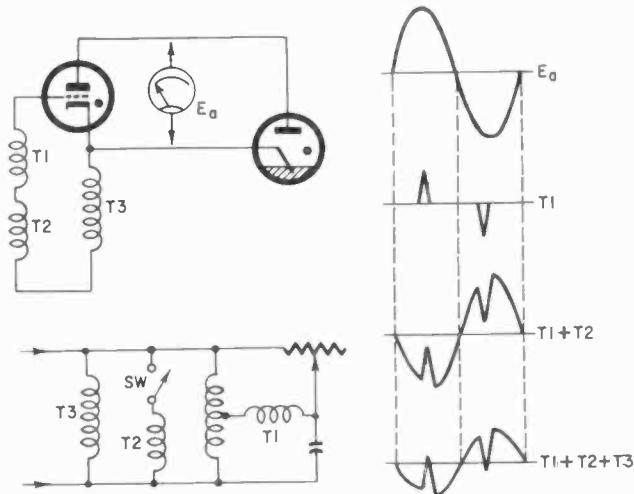

Fig. 727. *Waveforms on the right result when in-phase and out-of-phase voltages are used with peaking transformer to fire an ignitron very precisely.*

of speed, for the voltage (IR) drop in the armature will also depend on the load. The greater the load, the greater the current supplied by the control to try to maintain constant speed, and thus the greater the drop. This must be compensated for. In the circuit to the armature-control thyratrons there are two current transformer windings T2p. The secondary of this transformer is a center-tapped winding. T2s and rectifier VF (full wave) feed the divider R8, R9, R10, which has a voltage impressed on it proportional to the armature current. The arm on potentiometer R10 affects the voltage to the grid of VC, and the voltage on this arm is substracted from the voltage supplied to this grid by R6. Thus the compensation is applied to the armature control. The setting of R10 depends on the armature resistance, and is set only once for a particular motor.

The voltage across R9 is tapped off on R8 and applied to the grid of VE. Normally this grid is very much negative with re-

spect to the cathode but, when the armature voltage rises high enough, this will change and VE will conduct. This lowers its anode voltage and the grid voltage of VD, again lowering the armature voltage. Thus VE, when fired, limits the current to the motor. This is simply a protective feature to avoid damaging the motor and the armature thyratrons, for example, when the load becomes excessive.

Control of the field current is similar but carried out by VDD, VEE and VCC, which take the place of the similarly designated tubes in the armature control. R1, which sets the motor armature current, and R11, which sets the field current, are on a common shaft, allowing presetting of the motor control over the range of speed permitted by the motor design.

Fig. 728 is a simplified schematic—there are other parts to this control but, since they are not essential to understanding the control operation, they have been omitted. This control as shown is a *constant-speed* device. Not shown, but ordinarily present, are the motor contactors, reversing contactors, if any, and contactor control circuits, protective devices, etc. A similar control could be arranged to produce a variable speed in response to a demand from some source in the process, simply by varying the voltages on the points connected to the arms of R1 and R11 and the grid voltages on the control tubes.

Thyratron controls are used quite extensively in industry. Thyratrons and ignitrons have been used for motor controls for over 30 years. Today there is a serious challenge to the unique position of the thyratron—the controlled semiconductor rectifier. These are still so new that no extensive industrial examples are available. The basic function of the controlled rectifier was described in Chapter 2. Because this rectifier behaves like a thyratron, it too can be controlled by phase shift or by dc control voltages. The controlled rectifier however, has, so many other applications besides motor control, that a more detailed discussion will be found in Chapter 9, which deals with various static control systems.

Servos

A servo is another means of controlling machinery. The old ball type governor used on Watt's steam engine was a servo in a sense. As the engine speed decreased, the weights would tend to fall down from their orbit, and the motion would open a valve, called the governor valve, which then applied more steam to the engine, recovering speed in this way.
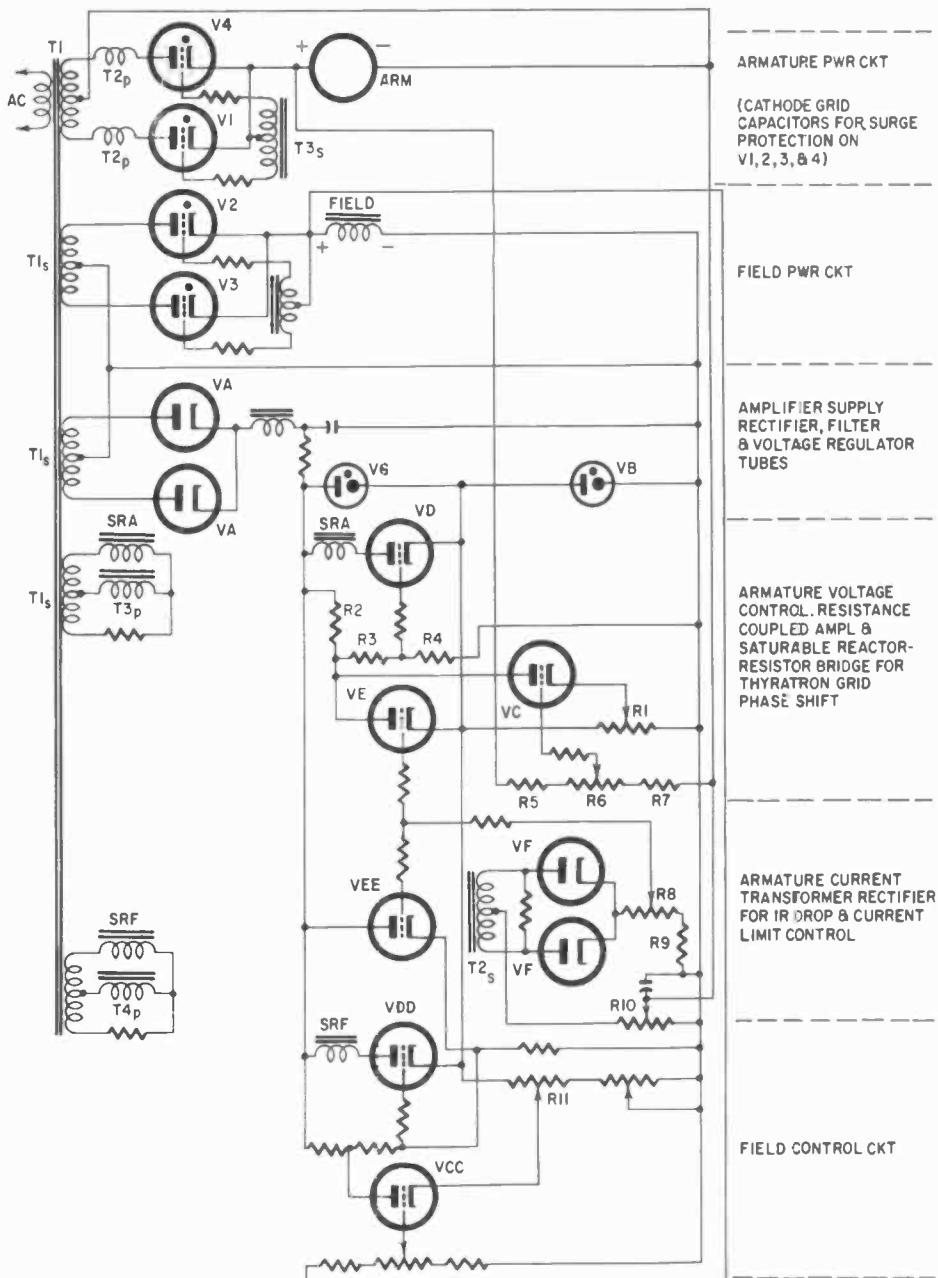
V4

T1

T2p

AC

V1

T2p

T3s

+ − ARM

ARMATURE PWR CKT

(CATHODE GRID
CAPACITORS FOR SURGE
PROTECTION ON
V1, 2, 3, & 4)

V2

FIELD

+ −

T1s

V3

FIELD PWR CKT

T3s

VA

AMPLIFIER SUPPLY
RECTIFIER, FILTER
& VOLTAGE REGULATOR
TUBES

T1s

V6

VB

VA

SRA

VD

SRA

T1s

T3p

ARMATURE VOLTAGE
CONTROL. RESISTANCE
COUPLED AMPL &
SATURABLE REACTOR-
RESISTOR BRIDGE FOR
THYRATRON GRID
PHASE SHIFT

R2

R3 R4

VE

VC

R1

R5 R6 R7

VF

VEE

R8

R9

ARMATURE CURRENT
TRANSFORMER RECTIFIER
FOR IR DROP & CURRENT
LIMIT CONTROL

SRF

T2s VF

R10

T4p

VDD

SRF

R11

FIELD CONTROL CKT

VCC

Fig. 728. *Simplified schematic of G-E Thymotrol constant-speed motor control. See text for explanation.*

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A room thermostat is another good basic example of a servo system.

What then are the elements of a servo system? First, there is the sensor, which tells what the actual conditions are (the thermostat bulb). Then there must be some kind of a standard or set to compare this with, to tell whether the condition is satisfactory. On the thermostat this is the gadget you set for the desired temperature, and which is actually a normally closed switch that is opened by the thermostat bulb. Next comes the means to control the process. In the thermostat, this would be the solenoid which operates the valve for gas or oil to the furnace. And then the process itself, which is the furnace, producing heat and changing actual conditions. When the thermostat determines that these correspond to the set condition, the furnace is no longer needed, temporarily, and will be cut off.

The most important part of the system is not too obvious in this example—the feedback loop. This in our case is the warm air produced by the furnace. Fig. 729 illustrates the principal components of a servo system. Often the feedback loop is more complicated, for the sensor may work in a mode different from the process. For example, in the case of a motor rotating a machine part, the signal which must be returned to the sensor is an electrical one (unless we use mechanical linkage, as in the governor). In some way, then, the position of the machine part must be translated into an electrical signal. This is the role of the translator (transducer), which can be a potentiometer with a dc voltage on it, but which often gets rather involved.

A typical industrial servo system could be the control of a motor through a tachometer generator. If, in the Thymotrol system discussed earlier, we provide the control grids of the tubes controlling the thyratrons with a dc signal proportional to the speed of the motor, we have made a typical servo system out of the control. Note that we keep saying a servo *system*. The lone word *servo* may mean something else. If a switch is used to control a small motor remotely, to open a valve, then the motor is a servo motor even without feedback. The system is a servo system in a sense but, because it has no feedback, it is called an "open-loop system." This misnomer is simply a convenience, used by engineers in discussing *control* systems—an open loop is no longer a loop.

Servo systems can take many forms—vacuum tubes and thyratrons, controlled rectifiers, magnetic amplifiers, saturable reactors, etc. All kinds of transducers are used to generate the feedback

signal, including mechanical linkages or some sensor appropriate to the process. For example, the magnetically read flowmeter mentioned in Chapter 6 could very well be used as the transducer in a system to control the flow of a liquid. Integrating the pulses from the flowmeter would give a voltage signal for control.

Servo systems will crop up again when we discuss industrial recorders in Chapter 10, for many of these are prime examples of servo systems used to control the recording pens. In such follow up
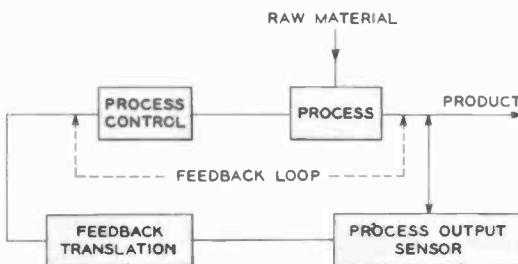

Fig. 729. *Block diagram shows principal components of a servo system.*

systems the input to the system is operated by the output to follow some condition. For example, when you look at any moving object, you will try to keep your eyes focused on it. This requires turning the head. The signals to your brain for turning the head are obtained from the eyes. This is a follow-up system. If we shine a light beam on two photocells and if we arrange their circuit so that the output will tend to equalize the light on the two cells by rotating or moving them in some way, then, when we move the light, the cells will tend to "follow" this light. Circuits for comparison of photoelectric-cell output such as we showed earlier in the chapter could be used for this.

A follow-up system need not necessarily use photoelectric cells although it often does. It can use mechanical motion, pressure or even a gyro such as the automatic pilot on planes and boats, and need not be physically linked to the actual controlling element.

Summary

We have tried to give you a brief but as wide as possible a look at industrial controls. Many circuits can be made with relays, even complicated counting circuits and very complex control systems. However, modern industrial practice is getting away from mechanical control devices, for obvious reasons, and are substituting more durable and reliable static controls as discussed in the next two chapters.

Once many industrial engineers had the attitude that "if it can be done mechanically, don't do it electrically." This was understandable when he had to deal with relays only. Next came the trend of "if you can do it with relays, don't use vacuum tubes," and this too persisted for a time, based on the early lack of reliability in the vacuum tube. Now we have a different situation which promises greater reliability and durability through static control.

8 ∗ static control systems

M ost of the industrial controls discussed thus far have utilized electron tubes. In recent years transistors have also been used in industrial electronic controls to an increasing extent as their reliability has improved. The situation in regard to transistors is somewhat similar to that which existed some years ago when electron tubes were first introduced.

There is a natural reluctance on the part of industry to switch to something entirely new and often untried, due to the prohibitive costs of production-line failures. For example, failure of an electronic thickness gage on a rolling mill would mean that in a span of a few minutes many tons of sheet steel would be produced which were off standard and would have to be rejected. A more serious example would be the failure of an electronic flaw detector to spot a flaw in a steel beam designed to be the main supporting member of a large bridge. We can leave it to your imagination to visualize the cost of such failures.

Despite increasing applications of transistors in industrial controls, electron tubes will continue to play a major role due to the availability of reliable tubes either specially selected from a production batch, or with extra supporting elements. Also, the new ceramic tubes developed for high temperature requirements in space technology have the kind of ruggedness and reliability which will tend to make them desirable in industrial circuits.

However, mechanically-operated relays and switches do present

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a serious maintenance problem, and for this reason very serious efforts have been made to replace them with non-moving or static switching devices. These operate on magnetic principles but have no moving parts except for the final output unit (a relay, contactor or circuit breaker) which controls the machinery.

Principles of magnetic amplifiers

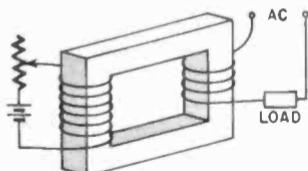The magnetic amplifier originally stemmed from a saturable reactor (Fig. 801). In this case, the core, made from a material

Fig. 801. *Basic saturable reactor.*

which is easily saturated, is magnetized by a control winding, while the load current passes through a heavier winding consisting of a few turns. When the core is not magnetized, the load current must provide the field for the coil on each half-cycle, which takes a certain amount of energy, and the core and coil have a considerable inductive impedance to the current because of this. If the core is now magnetized with dc, one half of the cycle need not build up the field, and the apparent inductive reactance will be considerably less. Thus by controlling the direct current in the control winding, we can, in this manner, control the alternating current in the load winding.

One application of saturable reactors is for lighting control, particularly for dimming fluorescent lamps, where resistor dimming is impractical. But for electronic control, a saturable reactor would be a rather impractical device because the field created by the load coil would reflect in the primary, and the device would act as a stepup transformer and would thus create rather high voltages in the control winding.

Therefore, in designing a magnetic amplifier, the core is constructed as shown in Fig. 802 where the magnetic fields of the two load coils on the two outside legs of the core cancel each other in the center leg. With the control winding on the center leg of this core, it is then possible to saturate the entire core, but in this case the control winding will no longer be affected by the load windings. This is the basic form of the magnetic amplifier, in which,

with a small dc control current, it is possible to control relatively large amounts of ac.

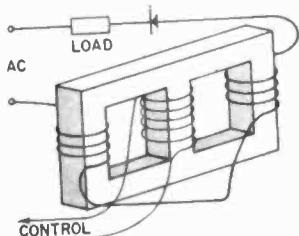If the core were built from ordinary magnetic materials, the

Fig. 802. *Basic magnetic amplifier. Ac fields cancel in central core section.*

device would not be very efficient, because such material is not easily saturated. But if the material used has a very steep B-H curve (B — flux density; H — magnetizing force — Fig. 803), then we obtain a very high amplification, analogous to a vacuum tube with very high transconductance.

This basic magnetic amplifier has been represented symbolically in Fig. 804-a. With an ac load, we would, however, have control

Fig. 803. *Iron-core magnetization curve.*
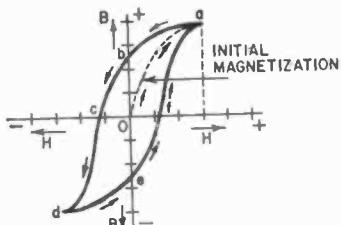
only during the half-cycle in which the load and the control currents work together toward saturation; during the other half-cycle we would have virtually no control But, if we insert two rectifiers into the load circuit, we will always have the load and the control currents working together (Fig. 804-b). For even greater efficiency, a full-wave bridge rectifier may be used (Fig. 804-c) .

Feedback improves the performance of a magnetic amplifier just as it does vacuum-tube devices. In this case we are striving for more gain, and therefore, positive feedback is used. Since we are operating with dc, we need not concern ourselves with such problems as oscillation. Fig. 805 shows a magnetic amplifier with feedback; its basic function is self-explanatory. As we increase the control current, we increase the current in the secondary or load

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winding and the current in the feedback winding, which in turn aids the control winding.

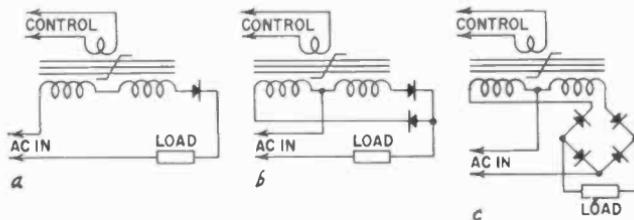Fig. 805 is designated as a shunt feedback system since the

Fig. 804. *Basic magnetic-amplifier circuits with half-wave (a), full-wave (b), and bridge rectifier (c) circuits to provide dc.*

feedback winding is in parallel with the load. With a different kind of winding (fewer turns of heavy wire), series feedback may be provided in the circuit in series with the load (Fig. 806). Gains up to 1,000,000 can be achieved in this way.

Further refinements can be had by adding circuits which control the winding that saturates the core. These can be vacuum tubes, thyratrons or transistors. If it becomes necessary to match unusual control signals to this dc control winding, such as signals from very high impedance sources, a cathode-follower circuit may be used for matching purposes. Or some kind of balanced circuit in which the control current is applied to two magnetic amplifiers in accordance with the received signal, which could be either a
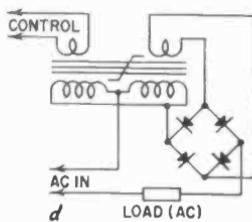
Fig. 805. *Bridge-rectifier magnetic amplifier with shunt feedback and ac load.*

rising or positive signal, or a falling or negative signal. To control the magnetic amplifiers properly in such a circuit, with the balance point at zero, some form of bridge circuit must be used with vacuum tubes or thyratrons for the other two legs of the bridge, since the current through them is readily controlled.

Magnetic amplifiers have been used to amplify audio signals, using a high-frequency carrier (Fig. 807), but these devices are

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mostly laboratory oddities. In audio circuits, we seldom need the power levels of which magnetic amplifiers are capable, nor do we need their extremely high reliability.

However, magnetic amplifiers are used extensively in direct control of motors. Complete servo systems using only magnetic amplifiers are now commercially available, and they have a definite

Fig. 806. *Bridge-rectifier magnetic amplifier with series feedback and dc load.*
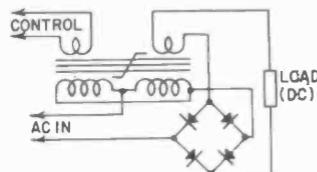
advantage where extreme shock and vibration are to be expected. There is very little in a magnetic amplifier that can be damaged by extremes of acceleration.

However, magnetic amplifiers have certain disadvantages that have restricted their use. They are, first of all, much slower acting than vacuum tubes and are limited in frequency although (Chapter 5) special ferrites will function satisfactorily up to 10 mc. But, these would not be directly applicable for control in industry where 60 cycles is normally used.

In this case, the initial cost of magnetic amplifiers and their bulk would not be competitive with electron-tube equipment. Many devices do utilize magnetic amplifiers in their control functions, but the eventual use of magnetic amplifiers will not be so much in single, isolated units as it will be in coordinated complex control systems. Therefore we will discuss one such system which can carry out a great many control functions. We have already considered (Chapter 5) flip-flops built from ferromagnetic devices and derived from magnetic amplifiers, as well as ferroresonant devices. However, these were high-speed units, with ferrite cores, using 1-mc carrier currents, and not the 60-cycle low-frequency magnetic amplifiers we are presently discussing. Using the latter, we can build what are known as logic circuits, which we shall discuss next as an introduction to their use in an integrated control system.

Logic

Although there are many ways of controlling motors with analog type devices (Chapter 7), the majority of machinery controls are digital in nature. Think of the literally millions of motors

controlled by simple on–off switches, which are the simplest digital device.

Most large computers operate on a digital system. Even the most complex machinery controls can be reduced to a small group of simple digital operations. These operations have been labeled logic functions. The term logic as used here is a term borrowed from a special kind of algebra which is suited to handling digital data, namely Boolean algrebra, which calculates with the kind of information discussed briefly in Chapter 5.

Logic can be considered as a series of statements or conditions which are mutually exclusive or which are necessary to each other for fullfillment. Thus, if you want to drive a car, you must first
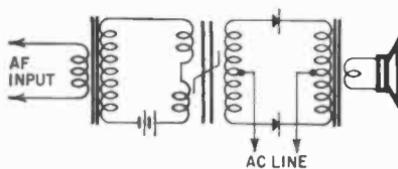
Fig. 807. *Magnetic amplifier has been used to amplify audio frequencies. Unless a supersonic ac source is used, the carrier is heard.*

know how *and* you must have the key to the car. If you want to buy a car, you must have either the cash *or* the equivalent credit. These are two of the basic logic functions, and we call them AND and OR gates. When a negative condition is required from either one, we get the NOT AND and the NOR gates. The third important function to logic is the MEMORY. With the MEMORY,
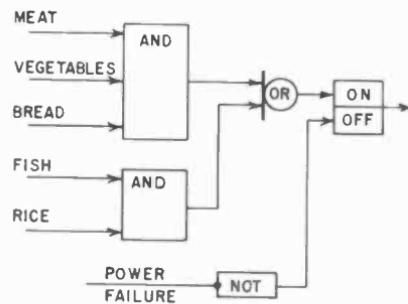
Fig. 808. *The basic idea of logic operation is illustrated here.*

AND, OR and NOT gates we can delineate any complex set of conditions about anything we wish, so long as the conditions are clear-cut. Ambiguous conditions would simply be unclassifiable in our logic machinery.

A simple example may help clarify this. In Fig. 808 the basic

conditions, meat, vegetables and bread or fish and rice, both would make a meal, provided there isn't a power failure. The AND functions combine the necessary ingredients, the OR function decides between the two, and the MEMORY remembers that either will be inedible without being cooked, so the NOT function prevents the output of a meal if a power failure prevents the cooking step.

Basic memory circuits are familiar. The flip-flop in its various forms is the best known. The Encyclopedia Britannica could be
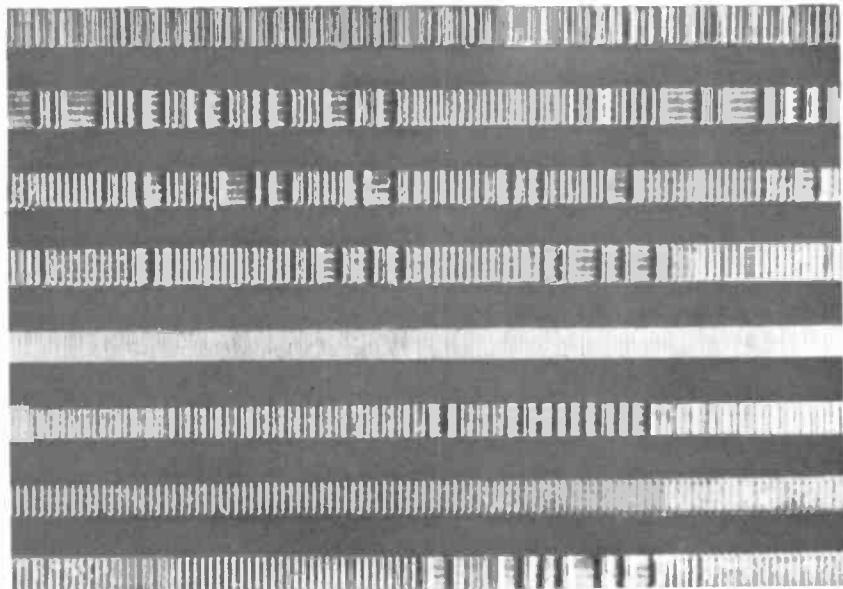
Fig. 809. *Information stored on magnetic tape can be made visible with fine iron powder.*

set down in the form of properly coded flip-flops, which could then be read by noting the state of each flip-flop. However, even in the encyclopedia not all the information can possibly be used to advantage at one time in one place; thus, only a small portion of the memory need be accessible at any one instant. This allows memory functions to be sequentially stored, so long as it is possible to find any part needed, when it is needed. Magnetic tape and punched paper tape can therefore be used far more economically than flip-flops for memories. Fig. 809 shows a section of magnetic tape in which a number of tracks with stored information in binary form has been made visible with the aid of a fine iron powder.

Radically new circuits are not required for AND and OR gates. Fig. 810 shows some of the gates used for these functions, with the functions alongside them. The same kind of functions can be carried out by transistor circuits as shown in Fig. 811. Logic circuits can also be of the magnetic-amplifier type such as those developed by Ramey and manufactured by Westinghouse. In the form of a coordinated, complex control system it can be used to control any
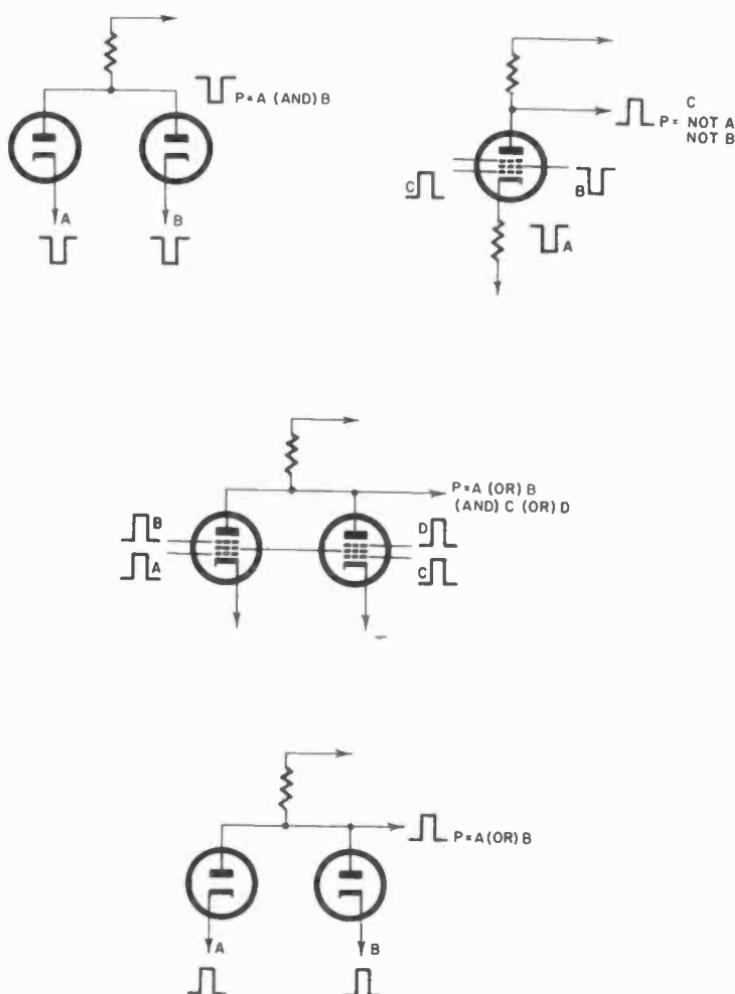

Fig. 810. *Gates for* and *and* or *functions can be made with either diodes or multi-grid tubes.*

number of large machine operations or can even be built into a computer for certain applications. We shall discuss this system, marketed under the name CYPAK, as an example of a complex
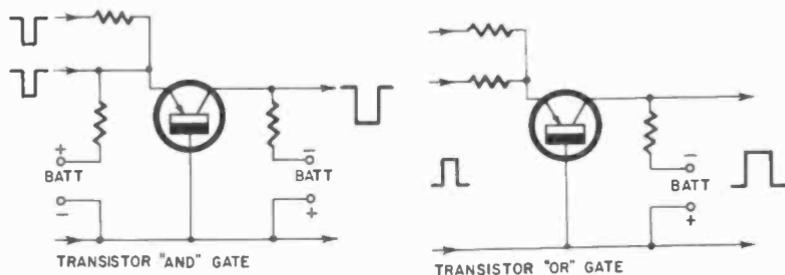
Fig. 811. *Transistors are preferred for most computer applications. Their use reduces the need for cooling equipment as well as making a more compact device.*

coordinated machine control system although there are, of course, other ways and systems of doing the same job.

Obviously, an industrial control system using magnetic amplifier principles, with the ruggedness, reliability and durability associated with this type of design, will have decided advantages.

A typical B-H magnetization curve has already been shown for high-quality core material used in magnetic amplifiers (Fig. 803). The Ramey units use a high-quality core material named Hipernik, which has an even steeper magnetization curve. This means that the material is rapidly saturated—so rapidly that, in the unit in Fig. 812, an applied ac of the proper value will make this unit self-saturating in much less than half a cycle of 60-cycle ac. When such a core is saturated, there is no reason for it to lose its magnetism, unless there is a decrease or reversal of current. If
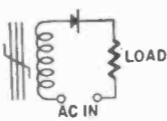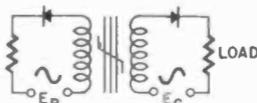

Fig. 812 (left). *Hypernik core with winding, rectifier and applied ac can be self-saturating.*

Fig. 813 (right). *Adding a second or reset winding was done by Ramey.*

we were to break the current at the high point of the ac cycle, the core would remain saturated for some time. If a second coil is now wound on the same core (Fig. 813) and an ac voltage is applied to it 180° out-of-phase with the first one, the core never gets a chance to saturate, and no current will flow in the load. Fig. 814-a is the

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normal output of one winding; at (b) a direct current has been applied to the other winding, which Ramey called the "reset" winding, and no output is available. The core may vary in its magnetism, but it will never reverse, and hence never produce an output in the load.

If we have only a small current in the reset winding, we would have the case of Fig. 814-c. The core does reverse magnetism for
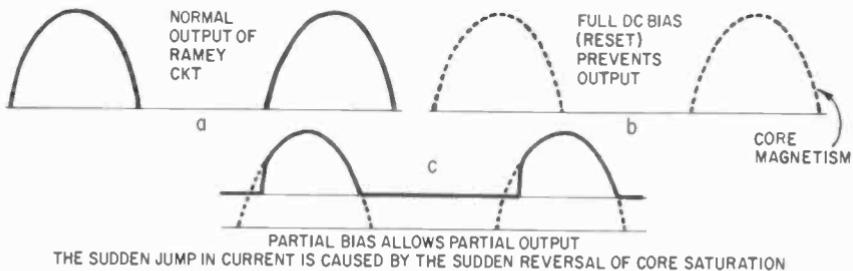

NORMAL
OUTPUT OF
RAMEY
CKT

FULL DC BIAS
(RESET)
PREVENTS
OUTPUT

a

b

CORE
MAGNETISM

c

PARTIAL BIAS ALLOWS PARTIAL OUTPUT
THE SUDDEN JUMP IN CURRENT IS CAUSED BY THE SUDDEN REVERSAL OF CORE SATURATION

Fig. 814. *Output currents from Ramey unit with dc reset.*

part of the cycle, and some output is transmitted to the load, depending on how much dc passes through the reset winding. If we magnetize the core with a half-cycle of ac in the reset winding, it would, for one cycle, be the same as if we had dc in it. The core would have no reason to lose its magnetism and consequently most of the load or "gating" cycle would be taken up with reversing the core magnetism, with the result that there would again be no output. This is the basis of the Ramey switching unit. There is a half-cycle delay: — if the reset is prevented, there will be a response from the gate a half-cycle later.
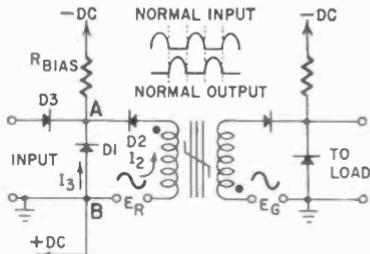
Fig. 815. *Ramey unit with dc bias, windings and waveforms indicated.*

−DC   NORMAL INPUT   −DC

R_{BIAS}

NORMAL OUTPUT

D3   A

INPUT   DI   D2 I_2

I_3 B E_R E_G

TO
LOAD

+DC

To match this unit to other similar units several conditions must be met. First, the reset winding must have a low impedance in order to assure positive reset. But to avoid loading the previous stage, a high impedance input is necessary. Therefore, the unit is equipped with rectifiers and a dc bias source (Fig. 815). The bias

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current in the reset winding flows continuously, and, of course, to balance conditions in the gating winding, a bias is also required in this circuit (see Fig. 816). When an input signal is applied, the bias current in D1 is, in effect, cancelled and reset can not take place. Consequently, the unit will produce an output on the next half-cycle of the gate.
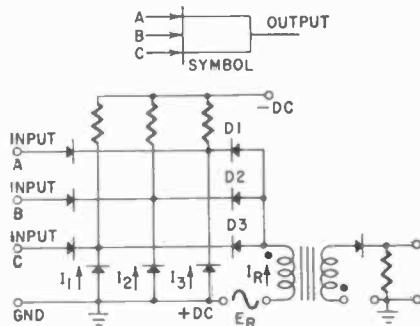

Fig. 816. *Basic Ramey* and *circuit and symbol. Relay equivalent shows all inputs must be present for output.*

This is the basic Ramey switching unit. From this, various other logic units can be built by adding input circuits, etc., to obtain the desired function. Thus, in Fig. 816 we have added in effect, three diodes. Of course, each one must be blocked by an input signal or the reset current will flow. Thus the unit becomes an AND unit, and all three inputs must be present to obtain an output. A similar circuit can be designed with a different number of inputs, so long as each bias path is blocked.
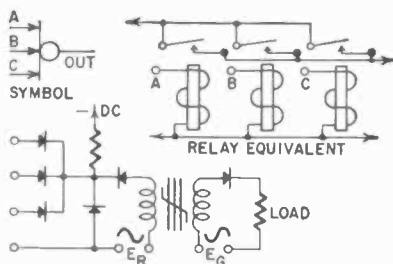

Fig. 817. *Basic Ramey or circuit with the relay equivalent and symbol.*

If input rectifiers are added, but only one bias rectifier (Fig. 817), any one of these inputs could block the bias rectifier current, and give us an OR unit. Again, the number of inputs is variable — there could be two, three (as shown) or more.

It is easier to make a unit that always gives an output except when a signal is present. All that has to be done is let the input

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signal be the reset current. The NOT unit in Fig. 818 is quite simple.

From two NOT and two OR units we can build a basic memory or storage unit. (Figs. 819 and 820). If NOT unit 1 produces a
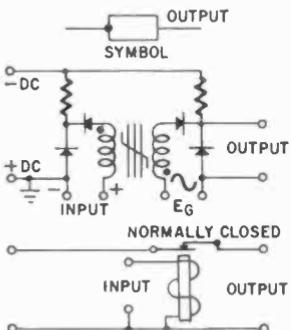

Fig. 818. *Ramey not circuit with symbol and relay equivalent. As in the relay circuit, if an input is present, there is no output.*

signal and this signal is fed back to NOT unit 2, through OR circuit 2, NOT unit 2 will not produce an output in the next half-cycle. Each half-cycle NOT 1 will provide the reset for NOT 2 in this way.

An input at 1 will reset NOT 1 through OR 1. The reset of NOT 2 is then blocked a half-cycle later. Thus NOT 2 will start
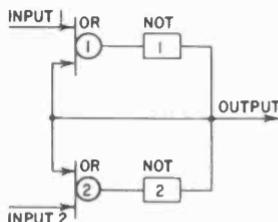
Fig. 819. *The principle of the memory unit.*

producing an output, which is then able to reset NOT 1's core, resulting in a changed stable state. A signal at input 2 can reverse the setup. This, then, forms a memory unit and, since nothing will happen to this setting unless there is an input signal, this kind of memory can be read repeatedly without losing its data. Fig. 820 shows the complete circuit. Only when power is lost will the stored data also be lost. However, there are units now which recover in the proper setting when the power comes on again.

Time delays are important ingredients of controls. With the Ramey circuits, we can also introduce a time delay as shown in Fig. 821 where C1, C2, R1, R2, R3, R4 and D1 and D2 have

been added to a memory unit. The time constant of C1 is small compared to C2. As we supply an input signal (we assume that unit 1 is saturated and supplying an output), each half-cycle will build some charge in C1. How much of that charge is left on the
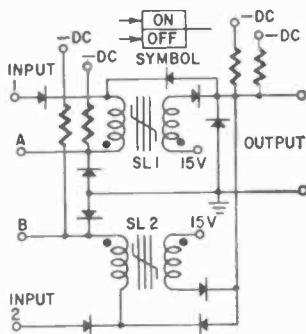
Fig. 820. *This* memory *is made with two combination* or *and* not *units. See text.*

next half-cycle depends partly on the setting of R2. The input to unit 1 (at A) is clamped at a voltage level by R3, R4 and D2. Each increment of voltage charge on C1 will be too small to reset the unit but, because of D1, these increments will add up in C2 until enough voltage has been built up to provide the reset current.
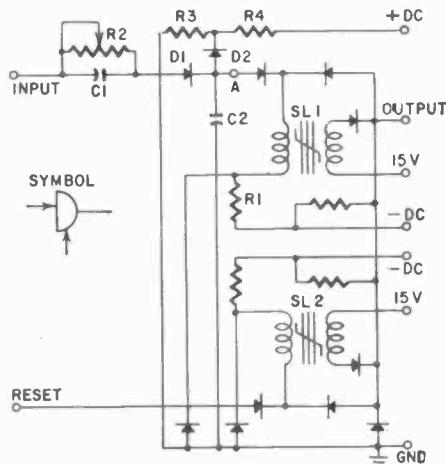
Fig. 821.*Time-delay circuit made from Ramey units. Varying C2 and R2 will change timing.*

As long as the input continues, without this clamping action C2 would continue to charge and would require a higher voltage capacitor. Also, it is possible to discharge C2 faster if the voltage on it is lower. Functionally, the clamp D2, R3 and R4 would not be

absolutely necessary. Discharge of C2 takes place when a signal is applied to the "reset" unit, and clamped at zero by D3 (otherwise it would go negative from the reset input). If a simultaneous
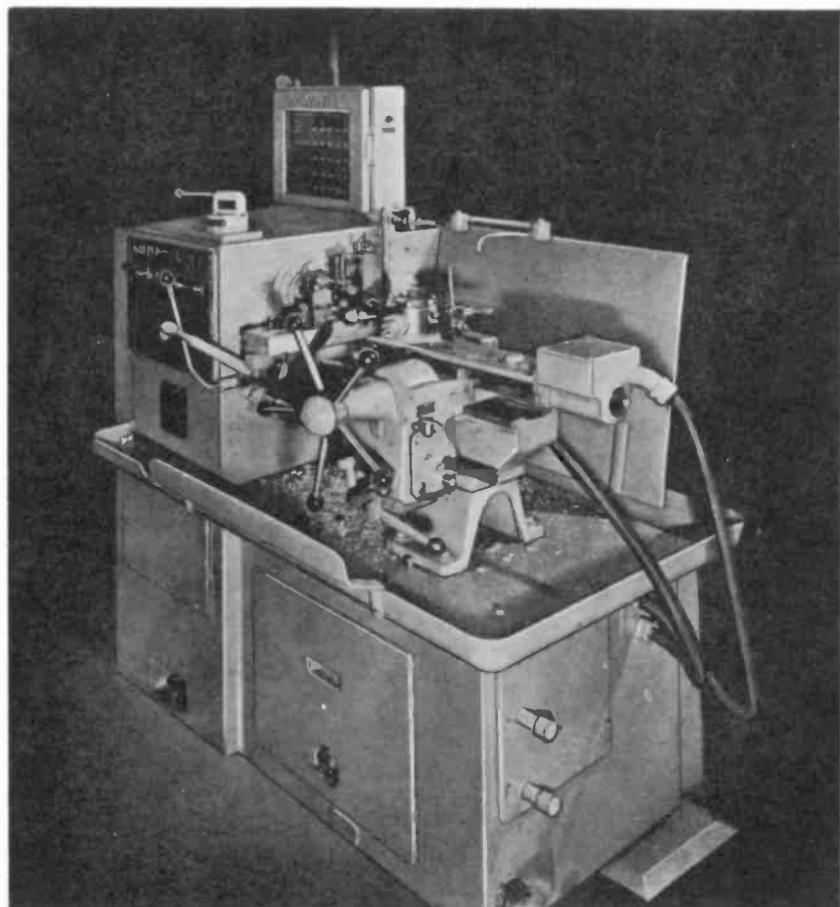

Fig. 822. *This turret lathe has sequential operation control with a* Cypak *system.*

input is supplied at both terminals, then the time delay will be generated as soon as the reset input is blocked. Thus, since the circuit is initially in its "reset" state and producing no output, the output will commence as soon as C2 is charged – in other words,

after the delay set by R2 — and it will stop only when a reset input is again applied.

It is easy to see how the operation of these memory units could be set with a group of toggle switches which would provide a definite sequence of operation, which, in turn, provides a sequence and nothing can be done until the previous cycles have been com-
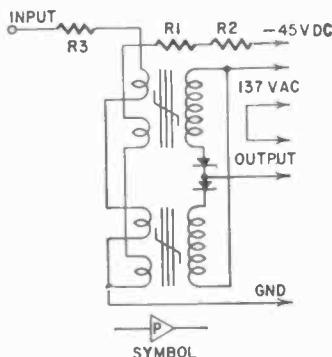

Fig. 823. *Basic magnetic output amplifier circuit for Cypak system has extra windings to allow the two inputs to be circuited in series while the outputs are paralleled.*

pleted. This is, of course, nothing new in industrial controls, but usually this sort of thing has been handled with relays which are subject to wear, mechanically, and to contact failure, etc. With the nonmoving CYPAK or similar units, the system is dependable as long as there is power to operate. (Relays would also fail with power failure, of course.)

Switching is also faster; few relays will perform a switching operation with the speed of a half-cycle. Also, apart from the dc bias supplies, the system operates on 60-cycle ac.

A typical control system using these CYPAK's is shown in Fig. 822. This setup controls the sequential operation of a turret lathe.
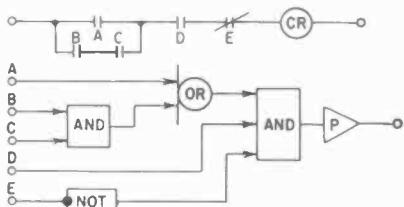

Fig. 824. *Cypak control diagram and the relay equivalent. Do not confuse the contacts with the electronic schematic symbol for capacitors.*

The basic Ramey unit can also be used as a preamplifier. If a preamplifier with more than one input is required, a two-input preamplifier is available which is very much like an AND circuit. Several Ramey units may also be combined and used as output power amplifiers to operate relays.

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Fig. 823 shows the basic amplifier. It consists of two one-input "AND" circuits with their outputs combined (the quotation marks are prompted by the fact that one input would not really make it an AND circuit – it merely looks like one). This amplifier produces a full-wave output, rather than the characteristic half-wave output, thus doubling the *average* power from the unit. Specially designed units are used for greater outputs, up to 300 voltamperes. These are double-type magnetic amplifiers, and not strictly the Ramey units we had been discussing.

Circuits

Let us see how these logic units can be used in circuits to replace relays or, to be more accurate, to replace relay *functions* with static switching functions.

Fig. 824, a partial schematic of a relay, is a typical configuration and might appear in almost any control diagram. Just below it is
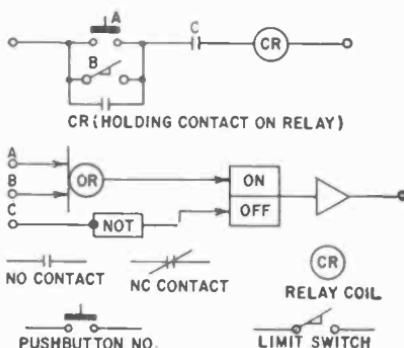

Fig. 825. *The holding or latching circuitry of a Cypak motor control and its relay equivalent. Schematic symbols are identified.*

the CYPAK equivalent. In Fig. 824 we see that coil CR will be energized when A, B and C are closed, when D is closed and when E is not opened. In CYPAK terms, this adds up to having a signal at either A or B and C, and also at E, but a signal from D must be present, regardless of whether the A signal or the B–C combination is available.

Fig. 825 includes starter button A, limit switch B and holding contact OR on coil CR. Thus if A or B is closed, and C is closed, CR can be energized. In terms of the CYPAK circuit, when a signal is present at A or B and there is a signal at C (producing NO output), coil CR will be energized so long as the memory is not reset. As soon as a signal is not received at C, the NOT circuit resets the memory. In other words, the coil will be de-energized, unless simultaneously a signal from A or B is received.

More complex, the circuit of Fig. 827 is a partial diagram of a hoist control. This portion deals with the hoist motion of the control.

First let us consider the meanings of the figures in the diagram. For convenience, the symbols are repeated in the chart of Fig. 826, together with the output and action of the circuits. Note that all logic elements are numbered. The number identifies the location of the unit, and the service technician would have to refer to a wiring diagram to locate the unit. This is not shown here. Letters (in Fig. 826) indicate the module function; A, AND; N, NOT; PA, preamplifier; T, input transformer; E, OR; TD, time delay; and AA, additional input AND.
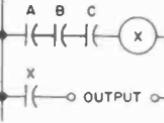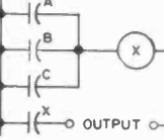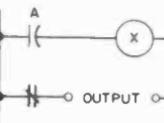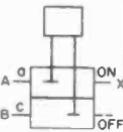
Note, for example, that module 11 (for typical module, see Fig. 828) contains both a pre-amplifier and an OR element, designated 11PA and 11E, respectively. Memory circuits are separately numbered but, since they are made up from other logic elements, these are identified. Memory M1 is actually composed of NOT 7N and NOT 8N. Power amplifiers are separately numbered, suffixed with the letter P. Potentiometers are separately numbered, suffixed "pot". The terminal numbers are those of the modules. These modules all fit into a prewired bus and can be inserted sev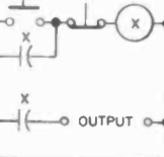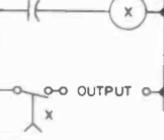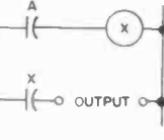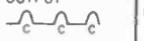eral ways, which is the reason for all the terminal numbers. In the catalog sheets describing the modules, the terminal designations are indicated. In our diagrams they were not shown. The power supply terminals, which automatically make the right connections when the unit is plugged into the bus, are not numbered.

In Fig. 827 we are concerned with the up motion of the hoist. The unit marked UP is the contactor which finally energizes the hoist motor. LS are limit switches, limiting the travel of the hook. We cannot readily translate this diagram into a relay diagram because it *is* a partial diagram — we have no way of determining where the various signals come from. Thus we could show a time-delay relay in place of 4TD and a contact, which would represent the signal on line 13, but we would not know which relay this contact belongs to. In any case, in servicing a CYPAK system, complete service and troubleshooting instructions will usually be available, and it will be found that most CYPAK troubleshooting is very simple.

Servicing a CYPAK system

The reliability of CYPAK and similar systems is so high that a failure is a rare event. But several things should be remembered

BASIC LOGIC ELEMENTS

ELEMENT	SYMBOL	RELAY EQUIVALENT	WAVEFORMS	OPERATION
AND			ALL INPUTS PRESENT OUTPUT ONE OR MORE OUTPUT	REQUIRES ALL INPUTS TO BE PRESENT DURING "a" PHASE IN ORDER FOR "c" PHASE OUTPUT TO APPEAR. GIVES 1/2 CYCLE DELAY
OR			ACCEPTS ALL POSITIVE SIGNALS UNDER 30 VOLTS PEAK. DOES NOT ALTER OR SHIFT INPUT WAVEFORM.	PRESENCE OF ANY ONE INPUT YIELDS AN OUTPUT IMMEDIATLY. NO TIME DELAY.
NOT	 FORMERLY 		INPUT PRESENT OUTPUT INPUT ABSENT OUTPUT	PRESENCE OF "a" SIGNAL PREVENTS OUTPUT ON "c" PHASE. ABSENCE OF "a" SIGNAL CAUSES "c" SIGNAL TO APPEAR. GIVES 1/2 CYCLE DELAY.
RETENTIVE MEMORY CONFIGU- RATION		LATCHED IN RELAY 	INPUT OUTPUT (ON) INPUT OUTPUT (OFF)	OUTPUT ASSUMES THE PHASE OF THE LAST INPUT SIGNAL THAT APPEARED. ONE CYCLE DELAY COMPOSED OF TWO NOT ELEMENTS AND ONE RETENTIVE MEM- ORY ELEMENT. RETAINS EXISTING STATE THROUGH A POWER FAILURE.
OFF RETURN MEMORY			INPUT OUTPUT (ON) INPUT OUTPUT (OFF)	OUTPUT ASSUMES THE PHASE OF THE LAST INPUT SIGNAL THAT APPEARED. ONE CYCLE DELAY COMPOSED OF TWO NOT ELEMENTS. EXTERNAL CIRCUITRY ARRANGED SO THAT UNIT SWITCHES OFF(c) ON POWER FAILURE.
TIME DELAY			a OR c INPUT OUTPUT VOLTS D.C. TIME	USED IN CONJUNCTION WITH MEMORY TO PRO- VIDE DELAYED SWITCH- ING. SWITCHING OF MEMORY OCCURS AT SOME PRE-SET TIME AFTER INPUT APPEARS ON TIME DELAY ELEMENT. NOT PHASE SENSITIVE.
PRE-AMP LIFIER (HALF WAVE CON- FIGURATION)			INPUT OUTPUT	AMPLIFIES LOGIC SIGNALS TO A LEVEL WHEREBY THEY MAY ENERGIZE SMALL RELAY, 6 VOLT PILOT LAMP, OR POWER AMPLIFIER.
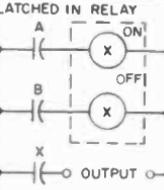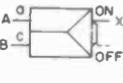
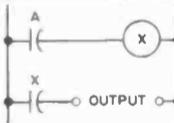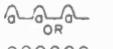| ELEMENT	SYMBOL	RELAY EQUIVALENT	WAVEFORMS	OPERATION
PRE-AMP LIFIER (FULL WAVE CON-FIGURATION)			INPUT / OUTPUT	SAME AS THE HALF WAVE CONFIGURATION EXCEPT OUTPUT IS 12 VDC AND PROVIDES 4 TIMES AS MUCH POWER. USED WITH AMPLIFIERS AND RELAYS
ADDITIONAL AND		NONE	INPUT / OUTPUT NOT USED. THE OUTPUT SIGNAL IS MEASURED FROM THE MAIN AND UNIT TO WHICH THIS ELEMENT IS CONNECTED.	PROVIDES ADDITIONAL INPUTS TO AND ELEMENTS.
INPUT TRANS-FORMER UNIT	FORMERLY	NONE	INPUT 120V. 60CY / OUTPUT ABOUT 12V FULL WAVE	PROVIDES VOLTAGE TRANSITION FROM 120 VAC, WHICH IS RELIABLE VOLTAGE FOR PILOT DEVICES, TO LOW VOLTAGE CYPAK LEVEL
POWER AMPLIFIER		NONE	INPUT / OR / OUTPUT 120V. 60CY	AMPLIFIES LOW ENERGY CYPAK SIGNALS SO THAT THEY CAN ENERGIZE A LARGE LOAD SUCH AS A MOTOR STARTER.

Fig. 826. *Basic logic elements are shown related to their symbol, relay equivalent and normal waveforms. Brief description of operation is included.*

when servicing. For example, the output signal does not appear at the same time as the input, but one half-cycle later. Phase of the output and input is therefore of importance, and all the units in the chart of symbols have been marked with the conventional phase designations, (a) and (c). To reverse the phase of any one unit it is necessary only to reverse its position on the bus.

A phasing detector, (a phase-sensitive voltmeter) or a unit made up from two preamplifiers and an OR unit and two indicator lamps will also serve the purpose (Fig. 828). The green lamp will glow if the (c) phase output is measured, the red lamp for the (a) phase, and both if the signal is full-wave, as it would be from a power amplifier, for example. An oscilloscope with the sync circuit connected to the same power-line phase as the units will also detect phase. Normal peak value of a CYPAK output signal is about 21 volts. This registers on the dc meter as 6 volts. For full-

wave signals you would read a higher voltage, of course, but not on a dc meter.

As in any troubleshooting, the first things to check are the availability of power and the operation of the power supply. Half-wave dc voltages of —23 volts should be available on the buses, and —45 for power amplifiers. The next step is to check the end item,
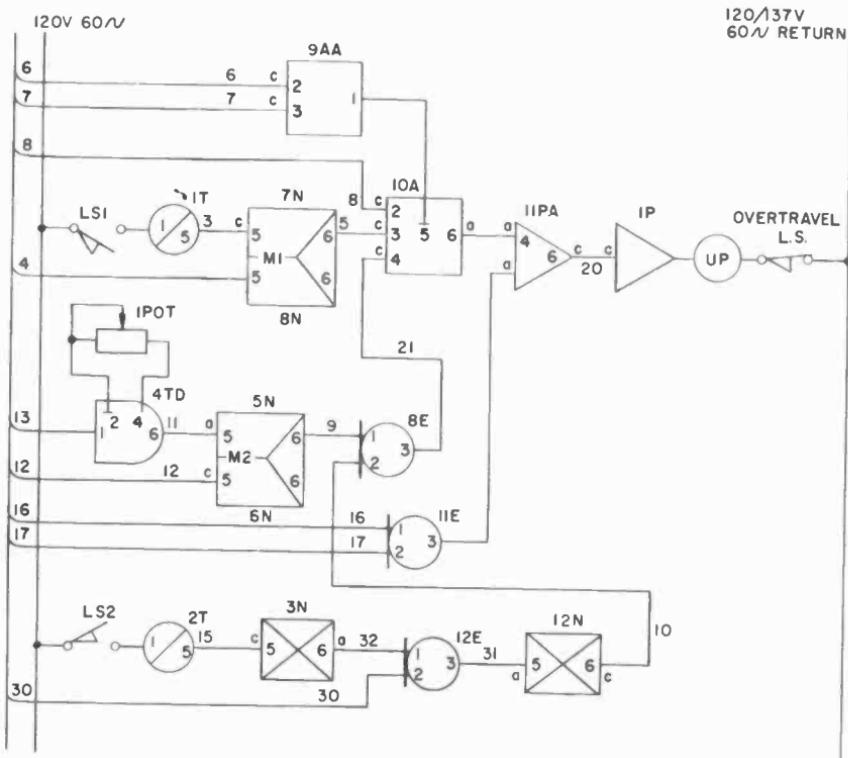
Fig. 827. *Portion of a typical* Cypak *control diagram dealing with the* up *motion of a hoist.*

which may be a contactor or a relay. Note that in our sample diagrams there was more than one way to energize such a circuit.

While working on a system, to insure that the machine will not accidently start, disconnect some lead, or fuse either to the machine proper or to the final output items of the control system. From our discussion of logic units and the chart (Fig. 826) you know what voltages must be present to make them operative, and the troubleshooting procedure then becomes one of finding the appropriate voltages or the absence of them, step by step, so that

the faulty unit can be located and replaced. Nothing could be simpler after that—simply obtain a replacement and plug it in.

To service such a system effectively in a minimum of time, it is advisable to study any and all manuals which come with systems under your care until you are familiar with their operational sequences. They should be completely understood from a logical build-up of the units we have shown, and, if special units are used in the system, the manuals will explain their operation in detail.
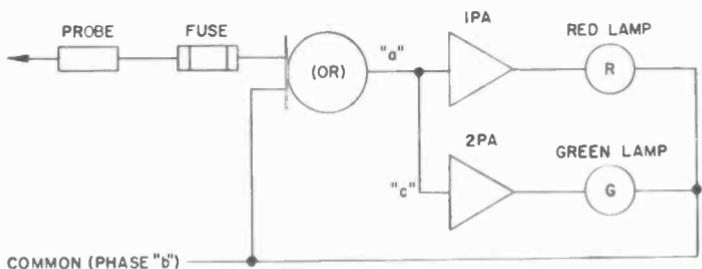

Fig. 828. *Phase detector made from or unit and two preamplifiers.*

Other magnetic control systems

So far the discussion has been limited to the Westinghouse CYPAK system which is based on Ramey units, and which is presently being used to control many kinds of large industrial processes. But conventional magnetic amplifiers can do the same control job if we build logic units from them. To do this we must take advantage of the switching characteristics which all of them will exhibit with the application of proper signal, bias, feedback and power voltages. We can then switch these units between two states of saturation, as we choose, or between a state of saturation and non-saturation, again depending on the applied voltages.

General Electric builds two kinds of control systems, one based on conventional and the other on pulsed magnetic amplifiers. We will briefly discuss both systems.

Static system from conventional magnetic amplifiers

Fig. 829 is the schematic diagram of a conventional magnetic amplifier arranged for logic service. Here we have two cores, each with load windings, and a set of bias and combined feedback and signal windings common to both cores. Note that a center tap is required on the supply, which then gives us full-wave output.

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The on and off windings have obvious purposes. Note that the bias winding is also center-tapped so that we can apply zero, one unit or two units of bias as we need or choose. The bias opposes the effects of the signal windings. The feedback in the winding will tend to aid the on winding.

It is fairly obvious how logic units can be built from these amplifiers. If we have two units of bias and require an on signal at terminals 1 and 2, we have a two-input AND unit. If we tie the two input terminals together and supply only one unit of bias, we simply have a switching unit. If we set the bias at one unit and supply separate signals for either 1 or 2, each of which is sufficient to turn on the unit, we have an OR unit. With zero bias, the feedback winding keeps the unit saturated even when the
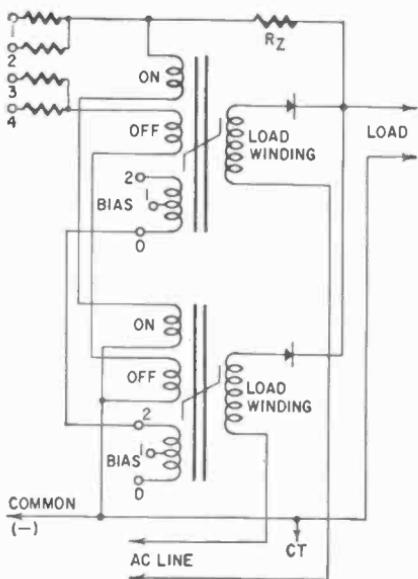
Fig. 829. *Switching unit made from conventional magnetic amplifier can be used for* logic functions.

input signal is removed, and we can call this a memory unit which will remain "on" or "off" according to the last pulse signal. Similarly, we can manipulate the bias and the "off" windings to produce a NOT and an OR–NOT circuit, which is a unit turned off by either of two NOT pulses, one at 3 or one at 4. The OR–NOT unit, commonly designated as the NOR unit, may be used as the basic element of an entire control system. We have discussed to some extent how these logic units can be used to form a control system. With this type of conventional magnetic amplifier unit, a relay or contactor may be used as the final element, if the sys-

tem must function as a binary device. However, a magnetic amplifier can be designed that does not require a relay or a contactor and may be used for certain control functions directly.

Static control system using pulsed magnetic amplifiers

The other General Electric system uses magnetic amplifiers in a somewhat different way. (Fig. 830). This basic unit has three windings: a gate winding, which we have been calling the load winding; a bias winding and a signal winding. Note that, in the

Fig. 830. *Basic circuit of pulsed magnetic switch with waveform.*
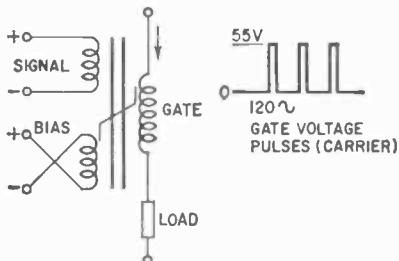
diagram, the bias winding is shown in reverse, indicating that it opposes the action of the signal winding. If we apply a pulse to the gate winding, with the core unsaturated, a constant voltage on the bias winding and no signal applied, this pulse will start to drive the core in to positive saturation, but it will not succeed very well, and the effect at the output will be negligible, due to the bias. However, with signal applied, the pulse will now go toward
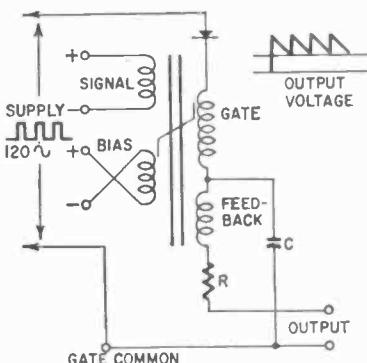
Fig. 831. *Adding feedback makes the pulsed magnetic amplifier suitable for logic functions.*

positive saturation, and load current will flow. The signal has, in effect, nullified the bias current. Remember that we are again dealing with a rectangular magnetization curve, which indicates

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that after a certain level of current is reached, the core will magnetize very rapidly.

If we add a feedback winding (Fig. 831), a rectifier and a capacitor, we have a true *switching* unit. As the pulses arrive, the capacitor will charge. When no pulses are present (*between* pulses), the rectifier will prevent the discharge of the capacitor in anything but the feedback winding, which keeps the core saturated between pulses. We can make the feedback strong enough (or the bias weak
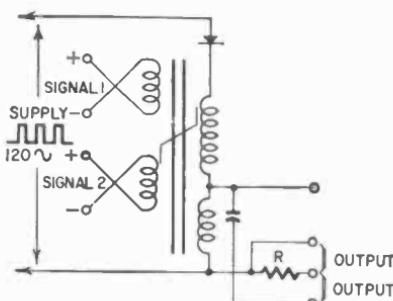
Fig. 832. *Pulsed* not *circuit.*

enough) to keep the core magnetized with no signal at the input. To turn the unit off we will need a strong negative signal. This we can supply by reversing the connections of the off winding.

Essentially, this is all there is to simple logic units. For example, the NOT unit of Fig. 832 looks very much like the basic switching
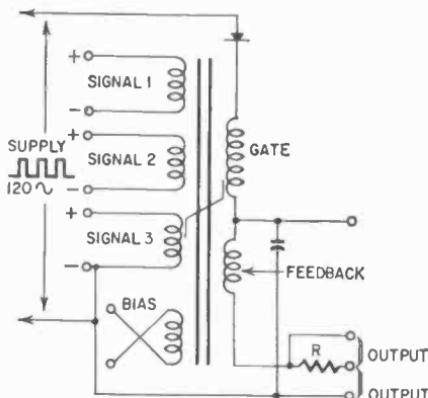
Fig. 833. *Pulsed* or *circuit.*

unit, except that the bias winding has been replaced with the NOT signal winding, and notice that it is also "reversed." Instead of the constant bias which opposes saturation, we now apply a NOT signal to prevent it.

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If we have several windings, each of which is sufficient to turn the unit on, we have an OR unit (Fig. 833). The core is not saturated until as lease one input is present, and then the bias effect is cancelled and an output is produced.
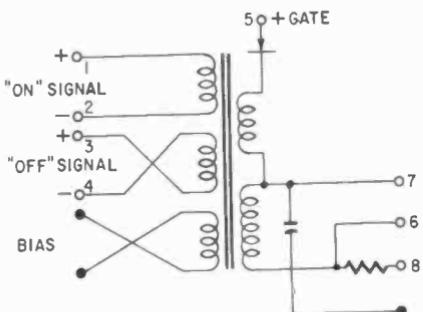
Fig. 834. *Pulsed* memory *circuit*.

The memory must include a bias winding, an *overgrown* feedback winding and an *on* and an *off* winding. Used as a switch, such a memory unit is not changed by being *read*. It simply *conducts* or does *not conduct* the signal from input to output (Fig. 834). When provided with enough feedback (or little enough bias) to
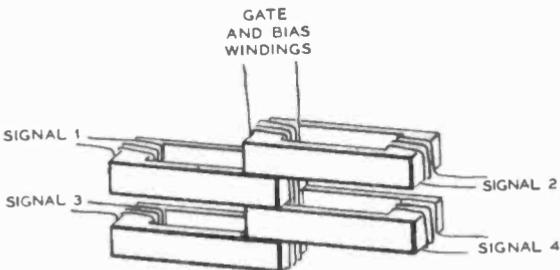

Fig. 835. *Stacked cores for* and *unit have common gate and bias winding but separate signal windings.*

keep the unit saturated, a signal, once applied, leaves a condition that does not change even when the signal is removed, giving us a *memory* for the system.

The construction of AND units is a little more ingenious. Several cores must be stacked and given a common gate and bias winding but separate signal windings (Figs. 835 and 836). Any one of the cores is capable of blocking the gating current, and an input to all of the core signal windings is required to effect an output.

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In a control setup, all the bias windings (those in a section of very large systems) are connected in series to provide a fail-safe system. Otherwise, failure of a bias would turn a unit *on*, and units operating out of sequence could have disastrous results. It is better to have the entire system shut down rather than take a chance on losing bias only. In series with each chain of bias windings, there is a relay coil to shut off all the power.
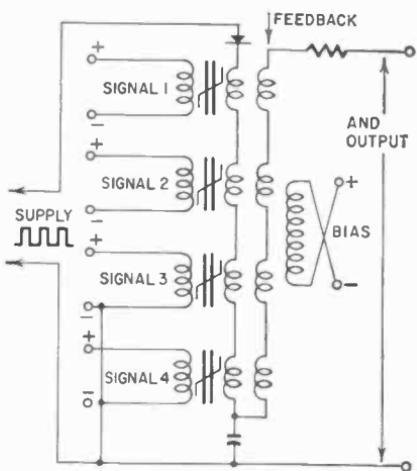
Fig. 836. *Schematic of four input and units.*

Power for the system is obtained from a supply using saturable reactors and rectifiers to form the pulses, which come out at the rate of 120 per second. The method will be shown in several steps. Fig. 837 illustrates the first step. If we put a reactor in series with impedance Z, and this reactor saturates near the peak of the sine wave, the resultant voltage across A–B is as shown because the voltage drops sharply to zero when the core saturates.

If we put a second reactor which saturates even more easily in series with the first one, the voltage across it will rise with a very steep wavefront. (It has the same waveform as across Z in Fig. 837-a.) But since it also saturated, the decay will be sudden as before, and the result will be pulses with both a short rise time and a short decay time; in other words, sharp rectangular pulses. Replacing the second reactor with a transformer and the Z with a bridge rectifier, we have the complete power supply as shown in Fig. 837-c, which also shows the bias windings in series. For the signals, we must include yet another dc supply, but this has no unusual features.

Finally we come to an important control element, the delay unit (Fig. 838). Here we have two cores each with a link winding and a load winding. Gate pulses which drive the cores will alternate. When a pulse drives core 1 toward saturation, the link winding
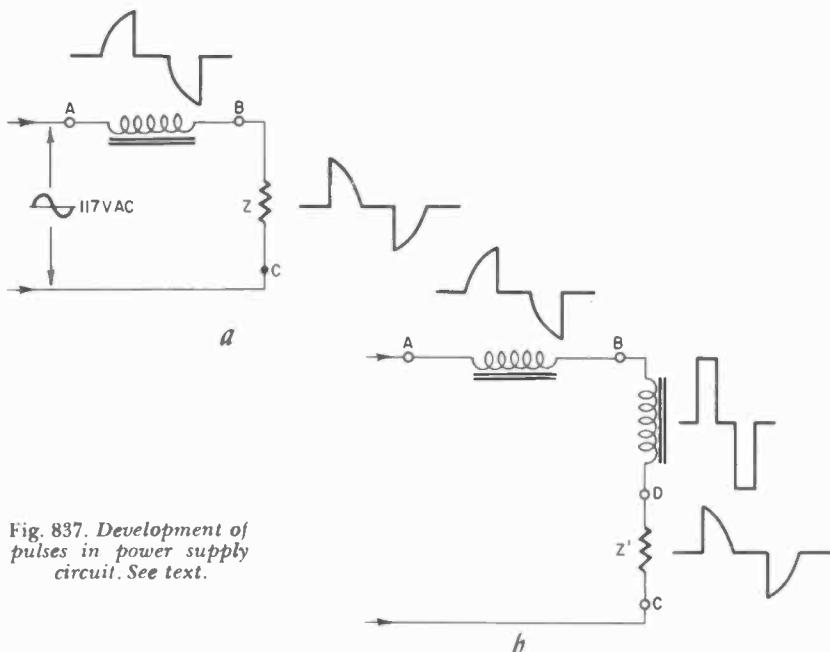
Fig. 837. *Development of pulses in power supply circuit. See text.*
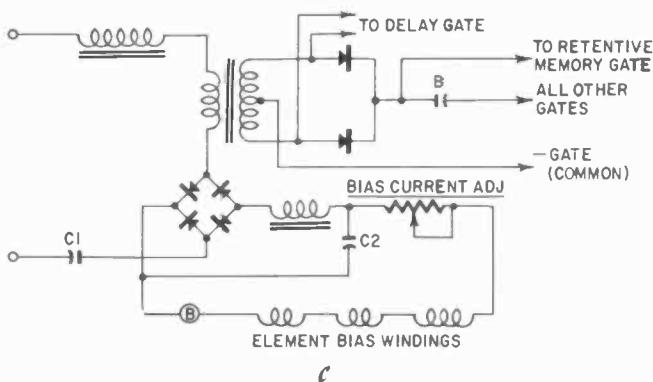
causes a small negative saturation to be induced in core 2. When the gating pulse of core 2 arrives, it will negate this by driving the core a bit positive and, incidentally, will reduce the positive satura-

tion of core 1 through the link winding and so on. The amount of each step will be determined by the setting of the potentiometer. Eventually, a bit at a time, the cores will saturate and allow the load current to pass.
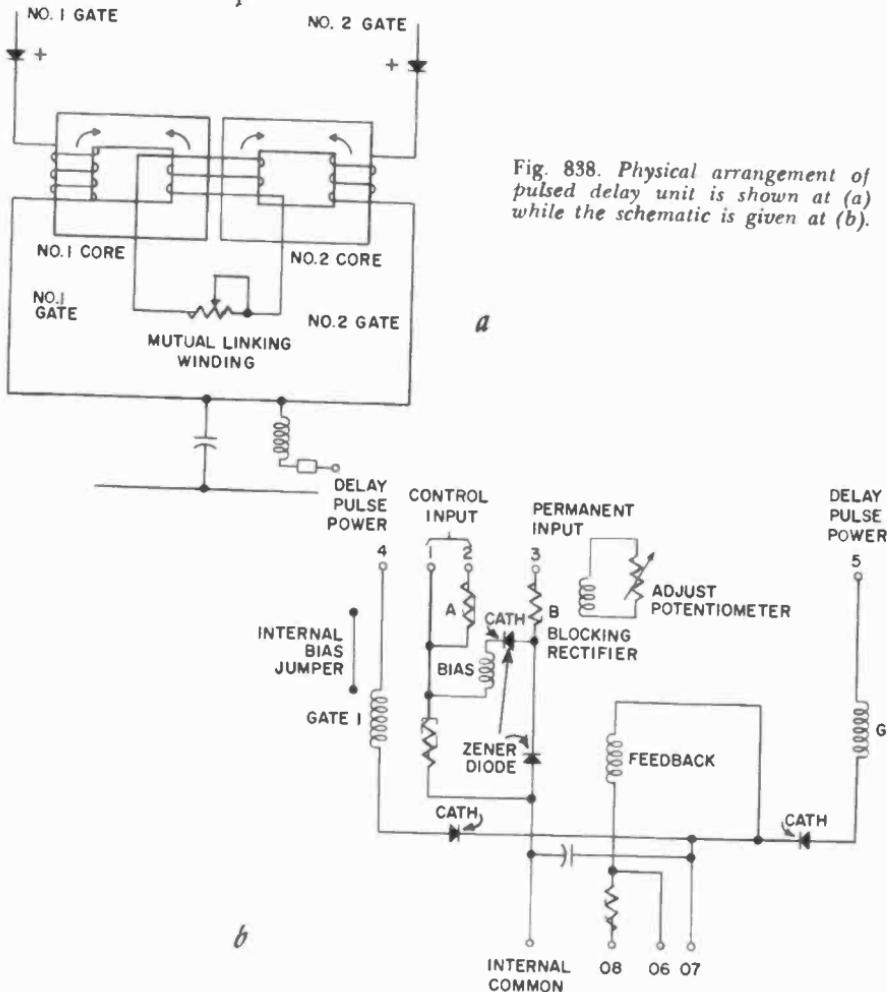
Fig. 838. *Physical arrangement of pulsed delay unit is shown at (a) while the schematic is given at (b).*

Actually, we must have some way of making the cores pass the load current *suddenly* after the time delay, and not by bits and pieces at a time. How this is done is shown in Fig. 828-b. Bias, permanently applied, is opposed by the control input. As the cores approach saturation, the control current increases, increasing the drop across resistor C. When this drop reaches the breakdown value of the zener diode, the bias current suddenly flows to common, and the sudden removal of the bias gives the cores their

final "kick" toward saturation, thereby permitting the load current to pass through.

The G-E systems are packaged in encapsulated units, that plug in, so that their servicing and troubleshooting problems are similar economically to those of the CYPAK, though technically different. No phase differences need be reckoned with.

Although static control systems function differently, and their logic units are made up in different ways, have different input and output signals and different ways of connecting together etc., the principles of building systems from logic units do not change, since these are a matter of system concepts only which we shall discuss later.

Other types of magnetic-amplifier switching units

Knowing the switching characteristics of magnetic amplifiers, we might ask if they could not also be used to build what is famil-
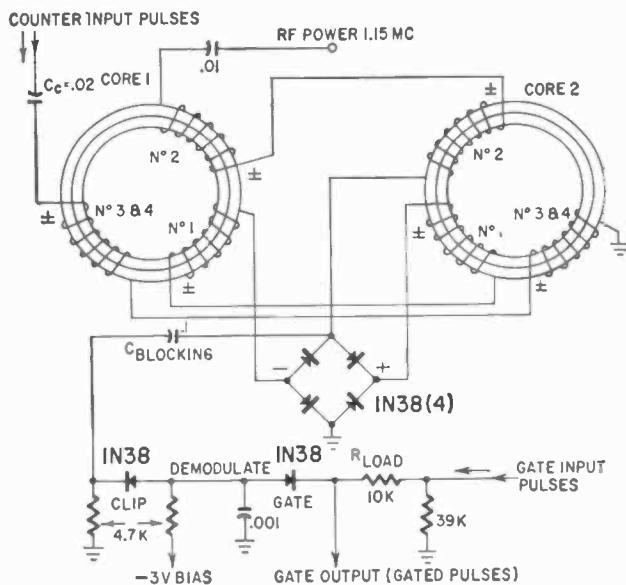
Fig. 839. *Magnetic-amplifier flip-flop demodulator circuit is used to obtain square output pulses at the counting rate.*

iarly termed a flip-flop, one of the more common types of switching circuits. They can. Fig. 839, a magnetic amplifier flip-flop, shows two cores with appropriate gate (or load), signal and feedback windings. The latter also serve as bias windings as will be shown. The rectifiers provide the dc voltages used to saturate the cores. The power winding also generates some dc voltage in the rectifiers.

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With conventional flip-flops, we are accustomed to thinking in terms of *conducting* and *cutoff* states of the tubes. Keep in mind that, in magnetic amplifiers, the saturated state corresponds with the conducting and the nonsaturated with the cutoff state. In the saturated state, however, the magnetic amplifier (unlike the cath-
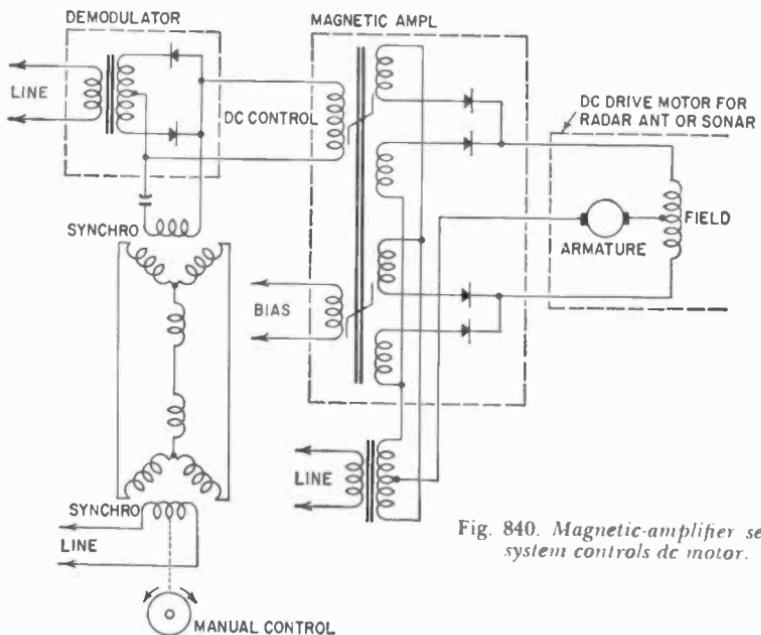
Fig. 840. *Magnetic-amplifier servo system controls dc motor.*

ode circuit in a tube flip-flop) will not generate a bias, since no voltage is induced on the winding, while in the cutoff state a very large voltage is induced on the bias winding.

Looking at Fig. 839, we see that the bias windings are in series with each other. Assume then, that core 1 is saturated, and this circuit conducting. Since no voltage is generated in bias winding 1, but a large voltage is in the bias winding on core 2, which *aids* the voltage generated by the power winding, core 1 will have a relatively large dc in its bias (feedback) winding, keeping the core saturated. If we apply a signal to the signal winding, this core will momentarily desaturate a bit. This causes a voltage to be induced in the bias winding on 1, which will, after rectification, produce a dc in the bias winding on core 2, giving this core a bit of magnetization toward saturation. This in turn reduces the dc feedback fed to the bias winding on core 1, and so on, and we have the typical "runaway" or regeneration process as we know it from

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other kinds of flip-flops. Thus, with a strong enough signal in the signal winding, the units will change state. Inversely, the next pulse will give core 1 a bit of magnetization, reducing the dc bias it is now feeding the bias winding of core 2, and reducing the current keeping core 2 saturated. The units will again change state, a typical flip-flop action.

In this kind of a flip-flop, we will not usually employ the core material used in magnetic amplifiers generally. To be of real value, the flip-flop must be much faster than we can make it with ordinary core steel, or even with the special high-permeability steels used
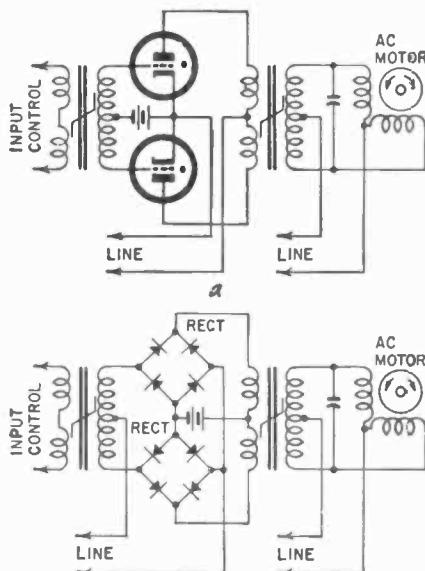
Fig. 841. *Thyratron and magnetic-amplifier circuitry to control a split-phase motor are quite similar.*

in magnetic amplifiers. Instead, we use a ferrite, something which looks like the material in the loopstick, but has radical magnetic characteristics which yield even more sharply defined square-waves in the magnetization curve. Thus ferrites also have two states, saturated (in either direction) and unsaturated.

For the flip-flop shown in Fig. 837, we need not concern ourselves with the negatively-saturated state, since we use only positive-going pulses for the power supply and there is no way negative saturation can be achieved.

Other magnetic amplifier applications

Although we have been discussing mostly digital control systems and have consequently stressed the switching characteristics

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of the magnetic amplifier and its various derivatives, there is also hardly any limit to the analog applications of magnetic amplifiers. Some of these were indicated in the beginning of the chapter— the magnetic audio amplifier, as an example. Fig. 840 is a more realistic industrial application, and one which represents a whole class of applications, the control of motors by magnetic amplifiers. The function of this equipment is apparent from the diagram. There are a host of such applications in industry, all more or less related to this kind of a control job. Fig. 841, for example, compares a control using thyratrons and one using magnetic amplifiers for the same job. Here the polarity of the input signal in the saturable input reactor determines which half of the amplifier will allow its thyratron to function first, or its magnetic amplifier half to saturate first, and thus determines the phase relation of the two windings in the split-phase motor. This, in turn, determines the direction of rotation of the motor. In both cases there is no speed control, merely directional control.

Summary

Development of magnetic amplifiers has not stood still. One type has recently been invented which can show a variable g_m just as does the variable-mu vacuum tube. But this is so new that industrial applications are still, at best, theoretical.

Magnetic amplifiers are by no means the only static type of control. Industry uses many types of control processes, and the way these processes progress in time has a great deal to do with the types of components used in them. Thus, the binary devices we have been discussing, magnetic amplifiers, are primarily used in repetitive processes, although they really have no inherent limitations that prevent their use in programmed systems. However, such systems rarely have need of logic elements, and the magnetic amplifiers in this case are amplifying and switching devices.

the nor system static switches and program control

9 *

Transistors can be used for logic gates, but they are more likely to be found in a complete coordinated system, such as the NOR system marketed by Westinghouse, so called because it is based on the NOR circuit, a simple logic circuit with but few components.

To build logic functions we must have some kind of switch with two stable states, conducting and nonconducting. The transistor can be used in this way. The developers of the NOR system chose the grounded-emitter as the best circuit configuration for its reliability, economy and the possible variation of transistor characteristics.

Fig. 901 shows the basic common-emitter switch circuit. The base is provided with reverse biasing to get complete cutoff, within limits of the transistor quality. The switch of Fig. 901 is the basis for the logic circuit of Fig. 902. This circuit will have an output as long as the transistor is biased to its nonconducting state. In other words, as long as we have an input on neither 1 *NOR* 2. This is how the circuit derives its name.

The circuit is shown with two inputs, and, for convenience in making connections, with two outputs. Actually, as many as 10 can be included. When, rarely, more than 10 are needed, we must

include some means of isolating the various inputs and outputs more efficiently than through the resistor. We can, of course, use only a single input, and then we have what we label a NOT unit, since the unit will provide no output, due to the shorting effect of the transistor.

From this basic NOR we can build all the units (Fig. 903) needed for the logic functions of a control system. In fact, they can even be made into a computer—Westinghouse has built one called the NORDIC.

Fig. 903-a shows the NOT circuit symbol and Fig. 903-b the NOR circuit with two inputs. An OR unit (Fig. 903-c) can be made from a two-input NOR followed by a single-input NOT. Its
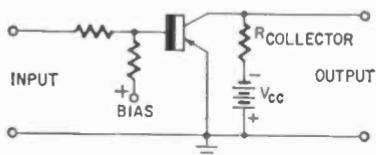
Fig. 901. *Basic common-emitter transistor switch circuit.*

action is simple to understand. So long as we have no output from the NOR, with a signal input on either A or B, we will not have a signal at the NOT, and consequently an output from it.

Fig. 903-d shows an AND circuit built from two NOT's and a NOR. Either NOT circuit will prevent an output from the NOR,

Fig. 902. *Basic* nor *logic circuit with two inputs and three outputs.*
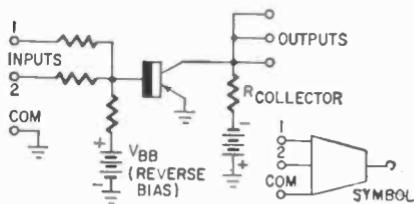
so long as we have one NOT without a signal. It takes a signal on both NOT's to get one from the NOR. Thus we get the AND function. We can add as many inputs to the NOR as we wish and, by adding more NOT's, we can make an AND circuit for more than two items.

Fig. 903-e is another kind of circuit, an inhibiting gate, made from a NOT and a NOR circuit. It looks like half an AND. So long as we have a signal on the input but nothing on "control," we will have an output from the NOR. But as soon as we put a signal on the control, the NOR will saturate, and we get no signal.

Remove the control, and we have an output again. This gate circuit is a very useful one for isolating, connecting, disconnecting and control, used in conjunction with other NOR units.

Fig. 903-f shows a NOR circuit flip-flop, which can function as the memory unit. The operation of the flip-flop can be easily understood if we start with the power off and both transistors
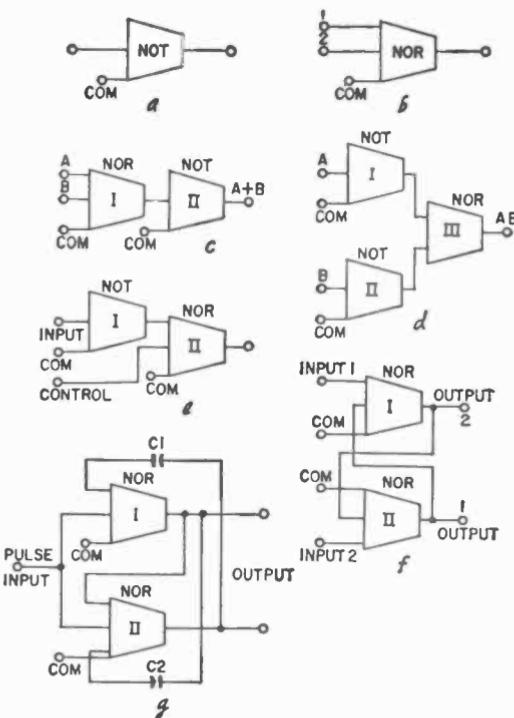
Fig. 903. *Block diagrams shows how basic* not *unit (a) with a second input becomes a* nor *unit (b). An* or *unit (c) is made from one of each. An* and *unit is at (d),* inhibit *gate at (e),* memory *flip-flop at (f) and* time-delay *unit at (g).*

nonconducting. When we turn on the power, both transistors will give an output. One will be very slightly faster and will saturate cutting off the output from the other one. Suppose I is cut off and II is now conducting. The output from II keeps I cut off until we apply a signal at 2 to make II nonconducting. This immediately stops the output from II, and I becomes saturated.

The flip-flop has changed state. A signal at 1 will again reverse the condition, and so on; each pulse, provided it arrives alternately on 1 and 2, will change the state of the memory unit.

Time delay, an important function in control systems using logic, is also used in the NOR system (Fig. 903-g). Here it consists of a two-input NOR, a three-input NOR and two capacitors. Normally, unit I is cut off, producing an output, which keeps II saturated with no output. If we apply a short pulse to the common input, both transistors will momentarily be in the conducting state. With the pulse removed, II tends to become "open," but capacitor C2 will have a charge stored on it, which will keep II
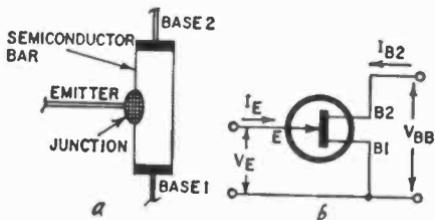
Fig. 904. *The symbol for the Unijunction transistor and its internal construction.*

saturated. The charge on C1 will do the same for I, until this charge has leaked off. During this time there will be no output. But as soon as C1 is discharged, I again becomes nonconducting, and the output reappears. The time constant is determined by the size of C1 and the circuit resistances. But C2 will have to be at least as large, since it must keep II saturated until I is again in the nonconducting state, producing an output and holding II conducting with it.

The NOR is an economical system. It uses only one kind of circuit configuration in the unit, one simple building block, the ideal situation for mass production.

Other static switches

Besides the NOR system, there are many static kinds of switches which could at some time be developed into industrial control systems. For some, the basic logic units have been designed as well as many other circuit configurations. Many kinds are already used in computers for military uses. There are some potentially useful industrial circuits among them. Other devices are so new and some so expensive to manufacture that they have not yet been applied to industrial electronics.

One of these promising devices is the Unijunction transistor (Fig. 904). A silicon bar is mounted on a ceramic wafer with

two gold "base" contacts. This gives the transistor two bases. An emitter junction is applied to the bar, usually closer to one base than the other. With no emitter voltage applied, the silicon bar will act as a resistor. But the field inside the bar will create an emitter-junction voltage which, in effect, reverse-biases the emitter.
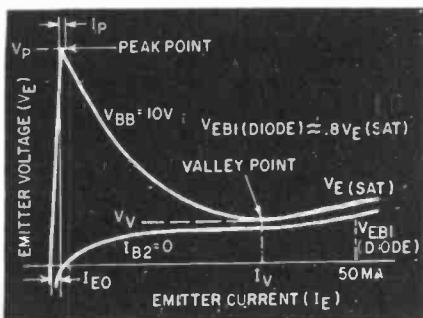
Fig. 905. *Unijunction transistor characteristic curve with valley point indicated. Curve reversal makes it usable as a switch.*

If we apply a voltage smaller than this emitter-junction voltage from an external supply, the junction will remain reverse-biased. But if we apply a larger voltage, holes will be injected into the
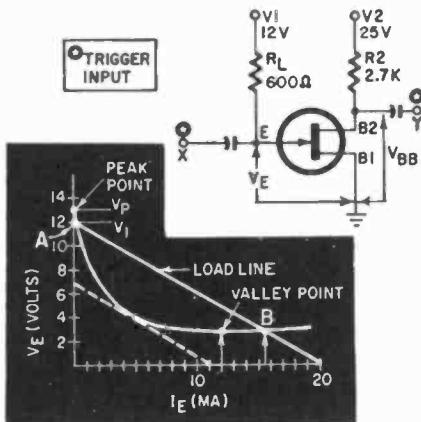
Fig. 906. *Basic Unijunction transistor circuit is bistable. Emitter characteristic curve is typical.*

bar, and these will drift to base 1. They will increase the conductivity of the bar between the emitter and base 1. This will increase the emitter-to-base-1 current but, at the same time, because of the increased conductivity, will decrease the emitter-junction voltage—in other words, a negative resistance effect. We can make use of this characteristic (Fig. 905), since it allows us to exploit the "switching" nature of the device.

The simple flip-flop of Fig. 906 needs a positive trigger at X to change state, or a negative trigger at Y. A negative trigger at X will again make the circuit change state.

Obviously, the Unijunction transistor will make an excellent switch for logic design, but as yet it is more expensive than the transistor now used for the purpose.

A static switch which started out to be something else is the
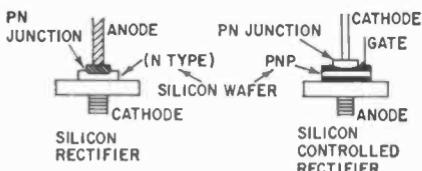
Fig. 907. *Silicon controlled rectifier construction is shown and compared to the silicon rectifier.*

silicon-controlled rectifier (Fig. 907). It is analogous, in a way, to the thyratron in that we can trigger it with a signal, but we must lower the supply or bypass the rectifier to shut it down. Different from the thyratron, we need a *current* rather than a voltage signal. Note in the drawing that the standard silicon rectifier has a single n-type wafer to form the junction, while the controlled rectifier has an n-type layer with two p-layers diffused onto it.

The principle of operation can perhaps best be understood by

Fig. 908. *The transistor-diode circuit is used as an analogy to the silicon controlled rectifier.*

the analogy to a diode and transistor. (Fig. 908). Here the transistor is in the nonconducting state, and a signal to the base will make it conduct. Then the current through it will develop sufficient voltage at the diode to break down the diode, and at the same time generate sufficient voltage to keep the transistor conducting. The only way to stop the current is to reduce the supply, so that once again the diode will be reverse-biased. Note that the breakdown comes as the result of the signal applied to the base, which reduces the "resistance" presented by the transistor, allowing the full supply voltage on the diode. The signal itself was too feeble to initiate the breakdown directly. Consequently, the signal would also be insufficient to turn it off.

Many circuits, besides straight rectifying circuits, have been designed based on the controlled rectifier. Even flip-flops can be

made. But in general, the controlled rectifier will find its place in industry primarily as a substitute for the thyratron, and as a final element in control systems, possibly replacing relays and contactors in the last step of other control systems.

Another p-n-p-n device is the trigistor. Although it uses the same sequence of semiconductor layers, it differs from the controlled rectifier in that it can be turned on and off by the trigger signal, thus making it an ideal switch for bi-stable circuits.

In Fig. 909, a p-n-p and an n-p-n transistor are so connected that each collector drives the base of the other. The gain of this circuit is the product of the gains of the two transistors. So long as these are both less than one, the unit is quiescent. But if we apply a trigger to the base of the one transistor, this transistor will conduct, increasing its gain and firing the other one, also increasing its gain. Then the two are conducting and have reached
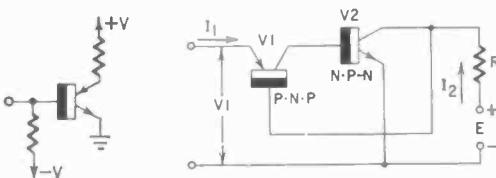
Fig. 909. *Basic trigistor circuit replaces two transistors in flip-flop circuit.*

the other stable state, conducting. A signal to the base will again reduce the gain of the one transistor, and degeneration takes place, turning the trigistor off. Obviously a very simple bi-stable device, the trigistor has been designed into counter and logic circuits, primarily for computer applications.

A static switch which is of interest, although also a long way from being applied in industry, is the cryostat. A tantalum wire, when super-cooled (4.2° K), will change its conductivity from virtually zero to a few milliohms per inch, when we apply a small change of magnetic field. A few milliohms seems like very little to build logic circuits with, but consider this in the light of *relative* resistance change, which becomes quite a lot when we consider that the zero is just about that. Cryostats consist of 1 inch of tantalum wire, 9 mils in diameter, with about 250 turns of Niobium wire around it (Fig. 910-a). Niobium has a different point at which it changes from superconductive to a resistive state, and

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thus is not affected by the temperature at this point. The cryostat is operated in a bath of liquid helium, which reaches its boiling point at room temperature.

Logic units have been built with cryostats, and experimental
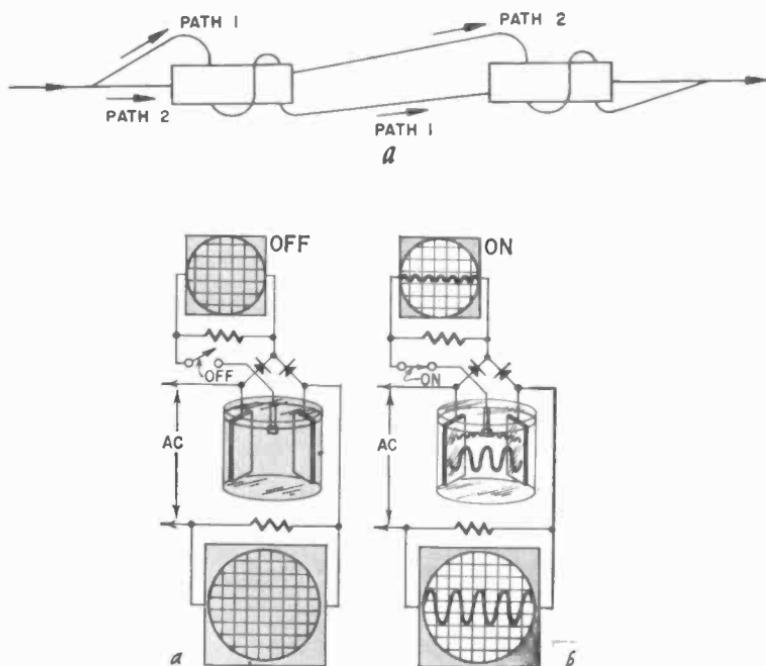
Fig. 910. *Both the cryostat (a) and the electrochemical switch (b) must be housed in special containers.*

computer circuits designed, but most of these are at present in a laboratory stage.

Electrochemical switch

More likely to appear on the industrial scene is the electrochemical switch invented by Ovitron (Fig. 910-b). Electrodes in a bath of electrolyte have relatively low conductivity until a d-c signal is applied to the "polarizing" electrode. Then the load ac passes as through a conductor. Ovitron engineers anticipate building logic units and all kinds of control circuits with the electrochemical switch. Perhaps the fact that there is no satisfactory theoretical explanation for the phenomenon as yet will hold back development somewhat.

Program control

Logic units used in computers are concerned with what we can term "decisions," as in the logic example we gave in Chapter 8.
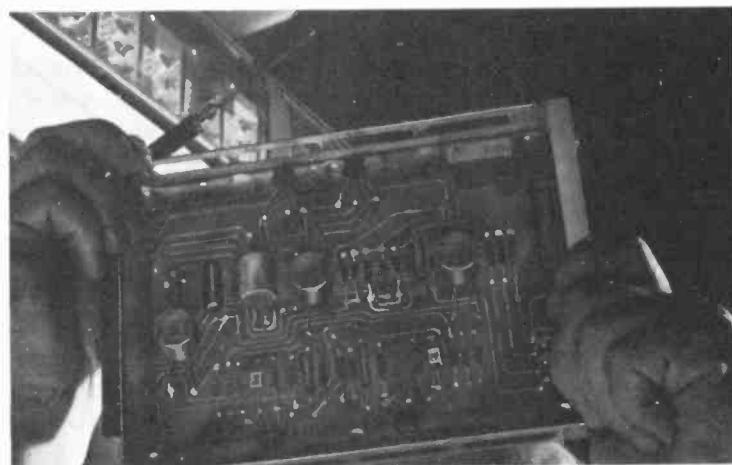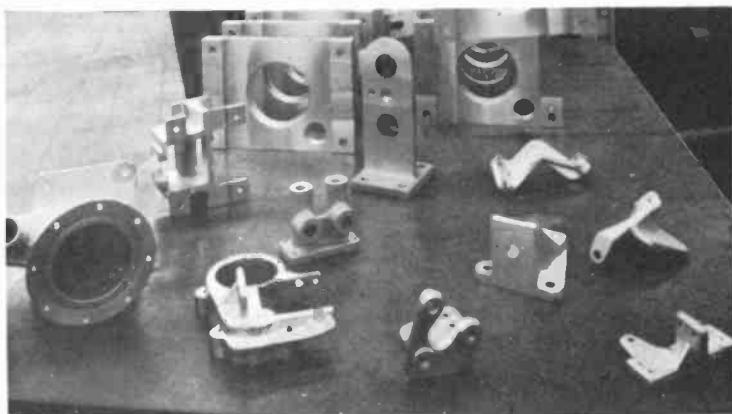
Fig. 911. *Machine tools can make many precision parts auto-matically after the material has been set into the machine.*

This kind of decision must often be made in industry on the production line, but human operators make such decisions habitually and so often, that they hardly regard them as decisions any

more. For example, an inspector will examine each product as it comes off an assembly line, and reject or accept it. If we set up the criteria for such acceptance and rejection carefully enough, there is no reason why a machine could not do the same thing, even to deciding whether the unit is worth repairing or must be rejected permanently. And indeed such automatic testing equipment is made, particularly for electronic equipment, which will check out a piece of electronic gear in all its circuits, and will reject it if specified criteria are not met. It will also indicate why the unit was rejected, record the number of the unit, the point at which it was rejected, etc. In such a testing machine, relatively few decisions are made.

But in a complicated process involving many ingredients whose application is interdependent, decisions must be made continually and rapidly. If we imagine, for example, that a cake factory would automatically weigh the materials for a batch of cakes, and would find a certain condition in the flour, which would require a bit of extra salt in the mixture, the instruments would have to make the decision to add the salt, and implement it. This kind of decision can be made with the proper logic units. Going on with the cake factory, the ingredients for a cake must not only be exact, they must be mixed in the proper order and for a specified length of time. Then they must be baked at an exact temperature for an exact length of time, provided the mixture reacts as it should. There is another decision perhaps, to decide whether the cake is of good quality.

The entire procedure of baking can be described in terms of sequences, one thing to be done after another. This is a program. In industrial controls—control engineering—we deal with numerous programs. Some are repetitive, relatively short programs for a sequence of operations on one kind of product. Others involve a series of different products, one after another. Automatic machine tools can make a whole series of different products to precise tolerances and perform all the necessary operations—drilling, turning, milling, broaching, grinding, polishing and, what is even more important, inspecting dimensionally the final products. A self-checking machine as it were.

One reason for such automated programming is that many machining operations take a lot of time to complete but require initially only one setup. The skilled operator, who set up the work, will then stand by "in case" something goes wrong with the machine or the tool bit or the product. In a machine shop where

large pieces are being bored or milled, the operator sometimes stands around watching for days and days. This is unproductive time, and, if we can make the machine do the "watching" and report any failures or troubles, we can free the skilled man for other work. Figure 911 shows some of the products which such automatic machines make from programmed instructions. All of these pieces were made by the same group of machines, one after
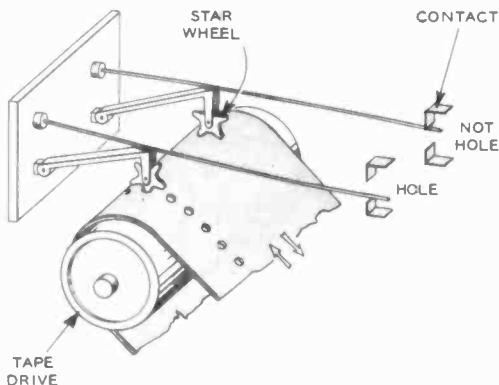
Fig. 912. *One kind of punched-tape reader. Only two of the many fingers are shown.*

another, without human intervention. To do such a complicated job these machines must receive instructions and must compare the instructions with the stage of progress.

Instructions are provided to the machine by one of several methods (this applies to *processes* as well as automatic machine
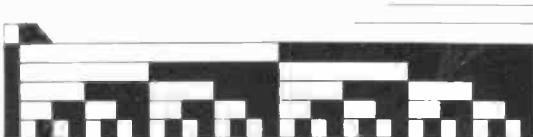
Fig. 913. *Digital (binary) scale used in linear positioning.*

tool products). Generally, a punched card or punched tape or magnetic tape is used. Sometimes a combination of two or more of these methods is used in various stages of a process. Punched cards have the advantage that they can be processed, punched and checked by business machines which a company is likely to have on hand for other purposes. Punched tape is somewhat faster than punched cards, and is more easily stored. And magnetic tape can be used over and over again for different programs.

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Most often the information is applied in binary form, since this is the way in which it can be used immediately by the logic units which process the information. Paper tape and punched
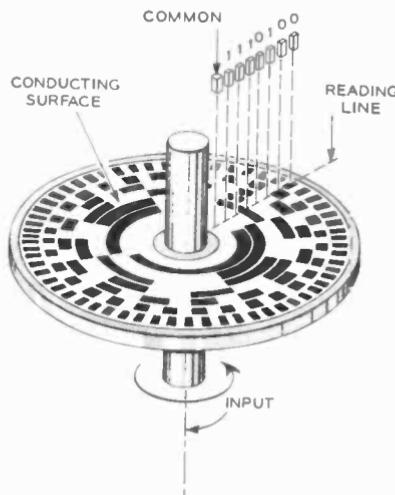
Fig. 914. *Shaft-position trans-ducer is used to convert rotation into binary-digital form.*

cards are "read" usually by mechanical means, such as the "feelers" illustrated in Fig. 912. Other kinds of readers make direct contact through the holes. Photoelectric readers have a small photocell for each possible hole position.

Often such instructions will be a direct means of translating analog type of information into digital form. For example, if
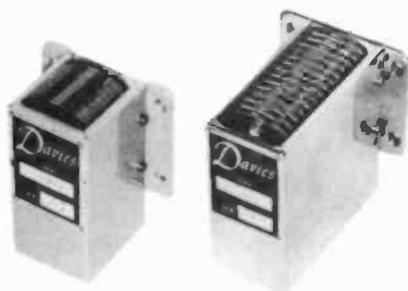
Fig. 915. *Multichannel magnetic tape heads use tape inches wide.*

a cutting head on a machine must describe a certain curving motion, the information is translated into digital form, giving

the position for the head from moment to moment. This permits its use in the "computing" elements. If the steps are small enough, the machine head will, for all practical purposes, execute the curve accurately, and mechanical friction and tolerances make it difficult to discern any discontinuity in the product. But *theoretically* the head may have moved in step-wise fashion unless, of
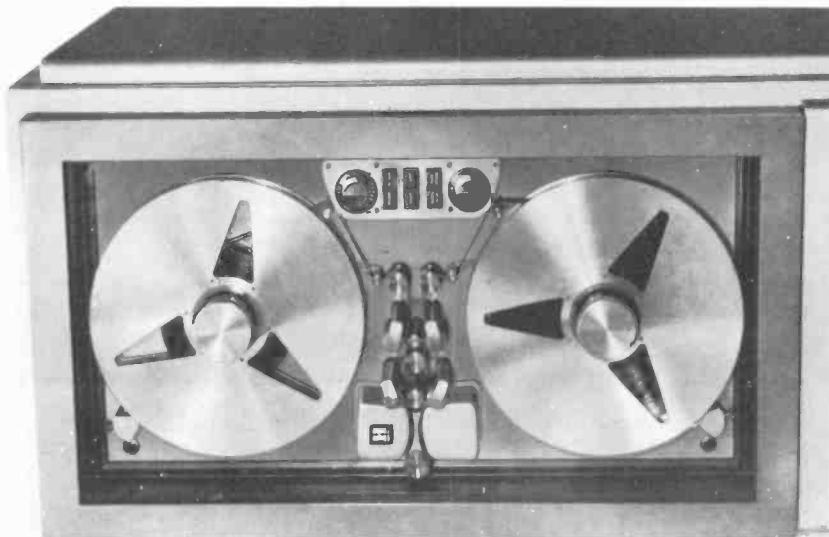
Fig. 916. *Tape drive mechanisms used for control may not use the same speeds as the recording equipment.*

course, the control system includes an "averaging" circuit as, for example, the filter in a power supply, which "averages" the pulsating dc from the rectifier, thereby acting as a digital-to-analog converter of a sort.

By using scales with alternate black and white squares, and reading the positions of such squares with photocells, we can provide the machine with a mechanism which accurately reports directly in digital form, although this could be considered analog information. Again we have "chopped up" or "sampled" the analog information to provide us with digital codes which can easily be handled by the logic units, which must make the decision as to whether or not the machine is in proper position in accordance with instructions. Discrepancies can either be corrected or reported as a malfunction to a supervising operator. Fig. 913 shows such a scale which can provide digital (binary) information with
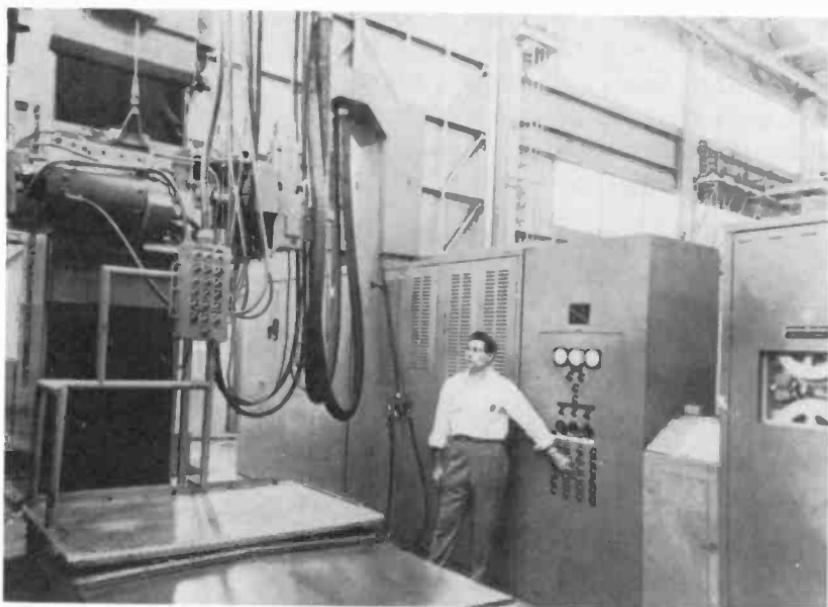
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photocell readers, and Fig. 914 shows a similar device for reading shaft position. There are at least 30 different systems for positioning and reading digital data from shafts, etc.

The machines which impress information on magnetic tape are basically the same as a home tape recorder but much more versatile. Many of them use wide tape, up to 2 inches in width, and record many channels simultaneously through multiple heads (Fig. 915). Fig. 916 is a typical industrial type data-recorder mechanism. These mechanisms are built with a great deal more precision than the home recorders. Fig. 917 shows a machine controlled by a tape-recorder installation.

Their principles of recording are similar for home and industry with one exception — with the pulses of digital data it is often unnecessary to use bias for recording, although bias for erasing may be included.

The machines which punch out tape instructions are similar to those which punch cards, and often a card-punch machine can be adapted to tape punching. Manual key punchers and computer-controlled automatic punchers are also used.

The instructions for a particular operation are carefully worked

out though they need not be extremely complicated. For example, they can be arranged in sets of three digital sequences. one for each of three coordinates, giving the readings from three base lines in some meaningful dimension for the machine which is to use them—cutter speed, cutting depth, etc. In the case of processes, the instructions would cover say, the range and rate of change of heating, the rate of mixing chemicals, as well as the total amount
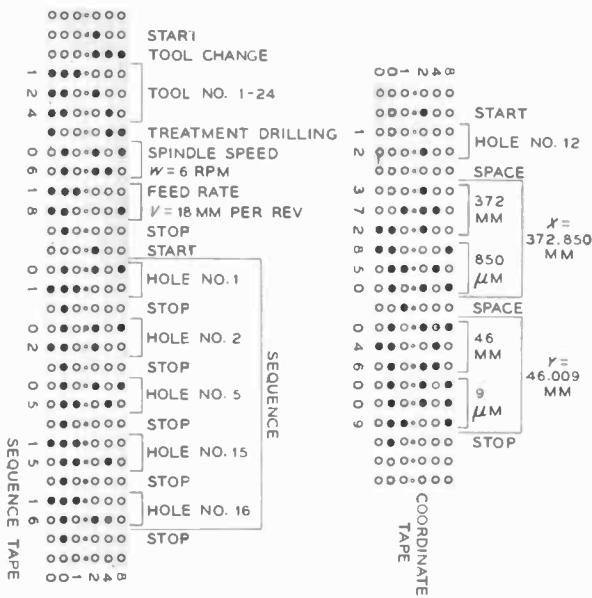
Fig. 918. *Typical instructions for machine tools as punched into tape. Some installations may have several drive mechanisms for tape.*

of chemicals mixed, the fraction of vacuum to be pumped over a period of time, etc.

Fig. 918 shows typical numerical positioning data on tape, and Fig. 919 on cards, providing all the information needed to locate a machine cutting head exactly. The tape or card signal can be fed directly to some logic circuits, such as OR, NOT, NOR, AND and MEMORY, to determine whether the control system should take action to reposition the head or, in the case of cards. to give the signal for the next punched card to be dropped for reading.

If the information is in analog form, such as a particular voltage variation or current signal, we can read them with discriminator or bridge type circuits. Discriminators can be voltage, frequency

or phase types, and all of them are familiar from communications practices: phase and frequency discriminators are used in FM communications, and voltage discriminators can look exactly like the well known vtvm circuits with the reference turned up to read other than 0. Coincidence gates (Chapter 5) also can read positioning data, where the signal depends on the simultaneous activa-
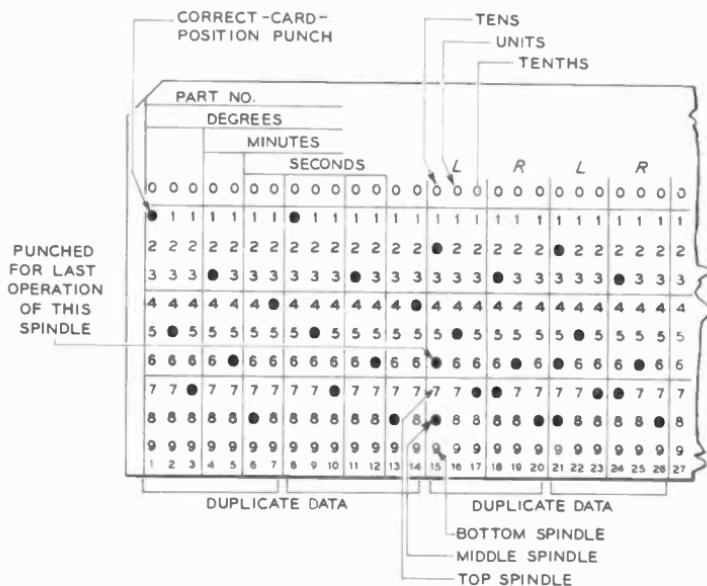
Fig. 919. *Machine-tool program instructions may be punched into cards. Both cards and tape may be used in one system.*

tion of a number of gates. The presence or absence of a signal on the scales, tapes, cards or punched paper tapes can constitute one of the code "bits" needed for the circuits to judge action to be taken or not taken.

Fig. 920 shows a system used by the Pratt & Whitney Co. to position their jig borers, and Fig. 921 a numerical positioning system of Kearfott's. Notice that the former uses punched tape, and the latter punched cards for data input. A number of other systems use stepping switches, their rotary equivalents, or relays to process the information.

The planning chart (Fig. 920) goes with every system. On it the punch operator can find the proper punch code for any particular feature of the blueprint, for several coordinates.

Cost of the systems marketed for control machine tools varies
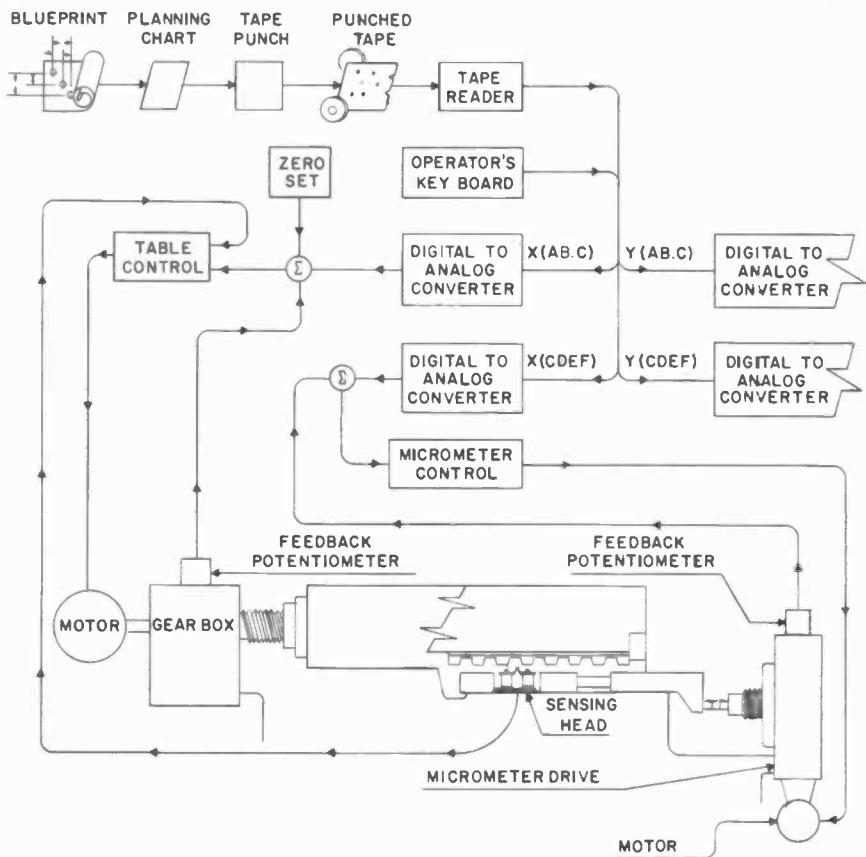
Fig. 920. *Block diagram shows all steps from blueprint to jig boring used in numerical positioning of tool bit.*

with the number of operations and measurements expected, and ranges from $2,000 to $30,000.

Control systems may use computers. Suppose, for example, that we would want to know the weight of a gas in a large container. This could be determined by weighing the container with and without gas. But suppose the weight of the gas is a very small fraction of the weight of the container, then it would be extremely difficult to measure the small changes of the weight. But the weight of the gas is proportional to three factors: temperature, volume and pressure. Volume is a constant, in a container, but pressure and temperature can vary. Thus by accurately measuring the temper-
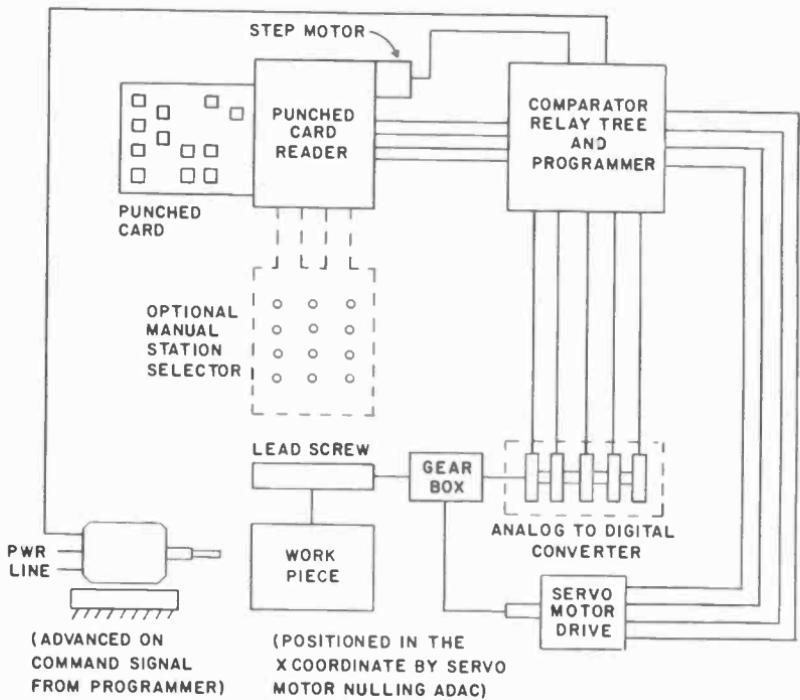
Fig. 921. *This block diagram has a punched-card reader to program numerical positioning system. Only lead screw-drive portion of system is shown.*

ature and pressure, we can, with simple arithmetical procedures, compute the weight. But suppose we try the same trick with a mixture of gases. Then we would, to obtain the weight, also have to determine the amount of each gas present, and include that information in the computation. Considering only this example as representative of control-system problems, you can see that it may very well be necessary to include one or more computers to provide "feedback" signals about the process, or a computer which can handle several operations simultaneously or in rapid sequence. Either digital or analog computers can be used.

The basic digital computer generally contains input, output, arithmetic, storage and control sections (Fig. 922). The lines in the diagram show the possible flow of information between sections. Input could be from magnetic or punched tape or card readers, or direct input from process or positioning circuits. Output can be some form of readout, as in electronic counters, although here we use the term in a broader sense. Instead of think-

ing just of lights and figures and letters formed by lights, we must also include punched cards, and tape, and magnetic tape, as well as direct printed write-out by electric typewriters, operating like the teletype printers of communications, and printed tape, with binary codes. Direct control of processes or machine part positions may also be considered as readouts.

The arithmetic section usually consists primarily of serial adders specially designed to fit into computer operation. But the arithmetical sections also may include logic. For example, the instructions may read like this: "If A is larger than B, add C but,

"WORD" CHANNEL
— — — — CONTROL CHANNEL
—·— ·— ACTION REPORTS
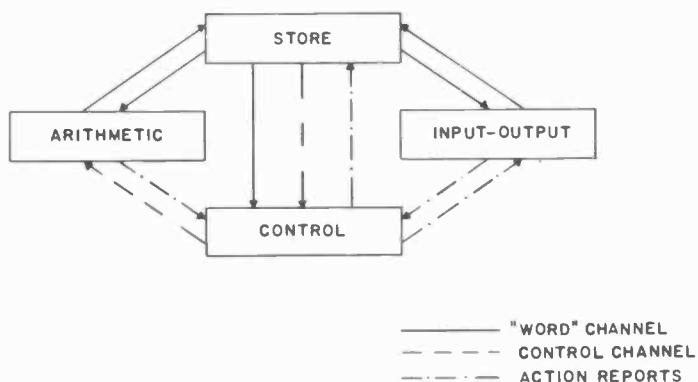
Fig. 922. *Block diagram of basic digital computer.*

if A is smaller than B, multiply by 2." In other words, to make a decision, the computer must compare the result of the product A with the product B and take action accordingly. Such a decision can be handled by a NOR circuit, for example, or a NOT gate.

The storage section will include the memory, and again there are many forms of computer memory. Besides magnetic tape, punched tape and cards, there are many other possible memories, such as the ferrite-core memory (Fig. 923), and storage tubes, which are special cathode-ray tubes with long-persistence mosaic screens; magnetic drums, and even relays.

The control section determines what all the other units will do. It includes the circuits which translate the instructions for the various units, such as the arithmetical and storage units. It will also contain the circuits used to "read" and "set" memory units, erase them when necessary and select the proper memory unit. The control section will report the result of the operation to read-

out. The control section must, of course, receive instructions itself for these various functions, and these are also included in the instructions to the computer. Or there may be a fixed, cycled program within the computer so that, whenever a batch of data is
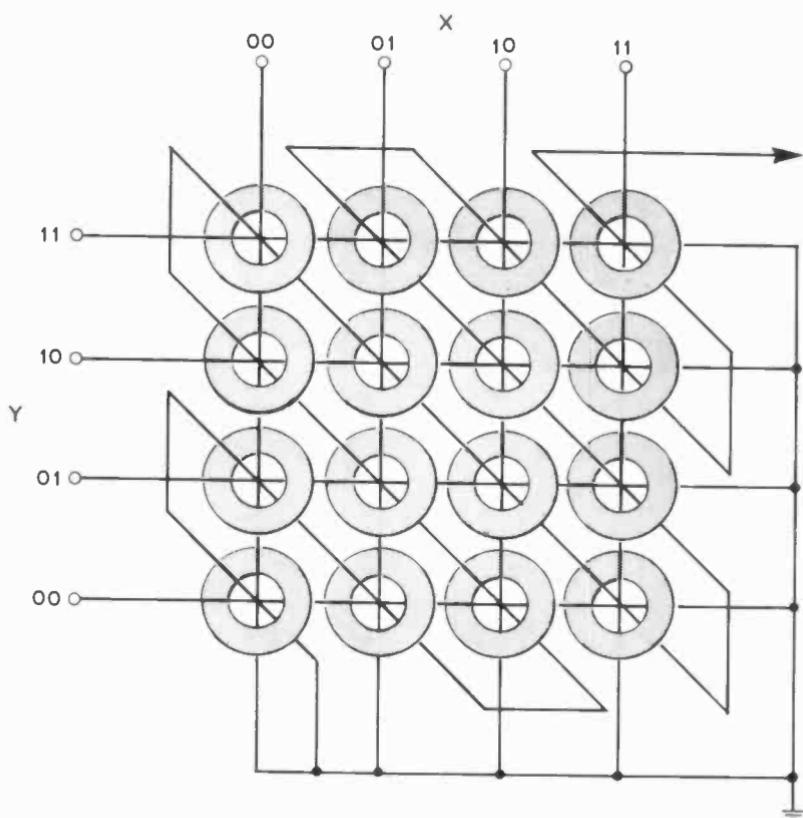
Fig. 923. *A two-dimensional array of magnetic cores will store many "bits" of information.*

received, the computer will treat the entire batch accordingly each time. This is characteristic of business machines, which are set up for one particular treatment of a set of cards, whether it be selection of certain groups, a single card, addition of data to the cards in accordance with another set of cards, etc.

Digital computers can become very large (Fig. 924). The largest computers are generally employed in military, scientific or business work; industry uses the more-moderate-sized ones. Unless a factory is automated completely and all control is centralized in

a computer, it seldom is economical to use a large computer. Specialized small computers capable of more limited operations will generally be sufficient, particularly when included in the control for one particular process or operation.

Analog computers, as their name indicates, operate on analog

Fig. 924. *Computers can cover many square feet of floor space.*

or continuously variable information. Analog means a simile, a model, so in many industries analog computers are used to determine the results or reactions of certain processes or designs while they are still in a planning stage.

Analog computers operate by setting up a model in mathematical terms, and running through the process or design configurations to determine the results. For example, if we charge a capacitor through a certain resistor, from a specified voltage source capable of delivering a minimum current, the curve according to which this capacitor will charge is well known. But suppose it were not. Then an analog computer could tell us, by drawing a curve on a recorder in its output, what the charge on the capacitor would be after a selected time interval.

Or suppose we heat liquid in a vessel, at the same time increasing the pressure on the liquid gradually. A certain amount of heat leaks off from the top of the vessel, and a very small amount of the liquid penetrates the walls of the vessel. What would be the condition of stress in a particular curved section of the vessel

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after 3 seconds of the specified treatment? Such a problem could get very, very complicated. If we tried to work it out mathematic-
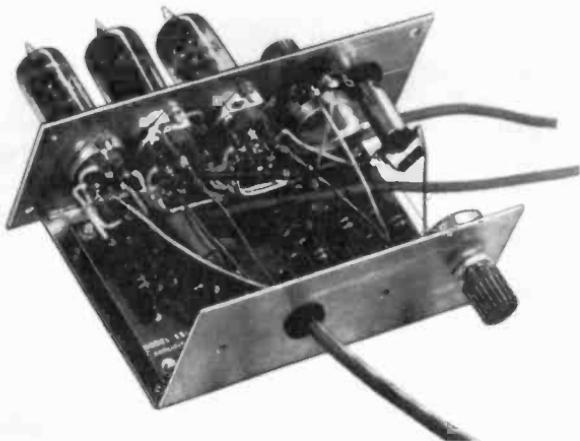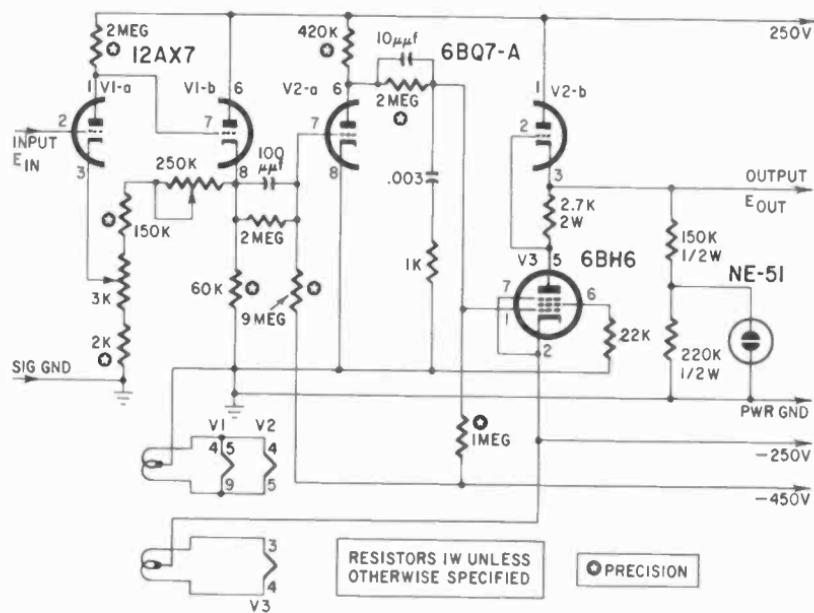
Fig. 925. *Simple dc amplifier is applied in many ways in industry where extremely low frequencies are used. Analog computers often have decade outputs from which gains of 1, 10, or 100 may be selected.*

ally, even with a calculator, it would take considerable time for each set of conditions. An analog computer can do this kind of

a job without too much strain, if the problem is properly programmed.

The increase in temperature will gradually change the pressure exerted by the liquid, and we can represent this as a rising voltage. The increased temperature applied also can be represented as a rising voltage: the leakage as a slowly dropping voltage, as well as the heat escape from the top. The stress in the section that interests us will progress according to a formula we can work out first, and then we can combine in some way all these variables and come out with a variable voltage which represents the strain in the metal as we apply pressure and heat.

Fig. 926. *Even computers are available in unassembled kits.* (Heath Co.)

We cannot simply add the voltages in a direct manner, since they all represent different quantities and must be reduced to some common units, some common denominator. This may involve proportionally increasing some or decreasing others, adding a constant value to a third set of variables, or maybe subtracting a

constant. All these jobs are the province of the workhorse of the analog computer, the operational amplifier.

Operational amplifier

The operational amplifier most often is a dc amplifier (some analog computers work entirely on ac) which is very stable and has a gain which can be adjusted or varied, according to a specified course of events, with external feedback loops. Fig. 925 is a schematic diagram of a relatively simple dc amplifier, with a cathode follower output votltage-regulated for stability. Not shown is the feedback loop, which is external to the amplifier. The gain of this amplifier, it can be used to control the gain, and thus the pro Since feedback in a negative sense can reduce the gain of an amplifier variable over a certain period of time and, with the portion of input and output voltages. If the feedback loop includes a capacitor, which gradually charges, we can make the gain of the amplifier, without feedback or "open-loop" gain, is about 50,000. methods discussed earlier in this book, we can make the charging progress linear and the gain variable in a linear sense.

And so, with the operational amplifier, we can change voltages according to the expected progress of some quantity in a process, we can make an *analogue* of the process variable.

Accessories

With the operational amplifiers we need a number of accessories. Usually the analog computer contains a large number of operational amplifiers. Fig. 926 shows the Heath analog computer; on top are the amplifiers. The computer also contains power supplies and a number of relays, which are used to delay the operation until all the variables have been set up, so that all factors in the process can start changing simultaneously. Potentiometers help provide the proper input voltages to the amplifiers. Into the jacks, each identified with the circuit to which it belongs, we can plug resistors, capacitors and other components, such as inductors, and perhaps diodes, etc., to make the feedback loop we need to build our analogues. The computer also contains a direct readout, the meter shown on the panel. A recorder can be added to provide a drawn curve readout.

Function generator

Another important accessory is the function generator shown in Fig. 927. It contains a number of diodes and bias potentiometers, with which we can set any bias we want for the diodes. For example, if we need an *input* voltage to the operational am-

plifiers which varies according to a certain specified curve or formula, we use the function generator to create the curve by "limiting" the voltage as it increases. Visualize a rising voltage on a diode plate. At a certain point this diode will conduct, and maintain this voltage at that point. This point can be preset by arranging for a particular bias on the diode. If after that voltage has been reached, we supply more than is leaking off through the diode, the voltage will still climb. Then if we add a second diode which conducts at a higher voltage, we again at that conduction point change the shape of the voltage rise, and so on. Actually what we have then is a generator which, by varying a voltage rise according to short straight-line sections, makes this voltage rise follow an approximation of any curve we need as input voltage
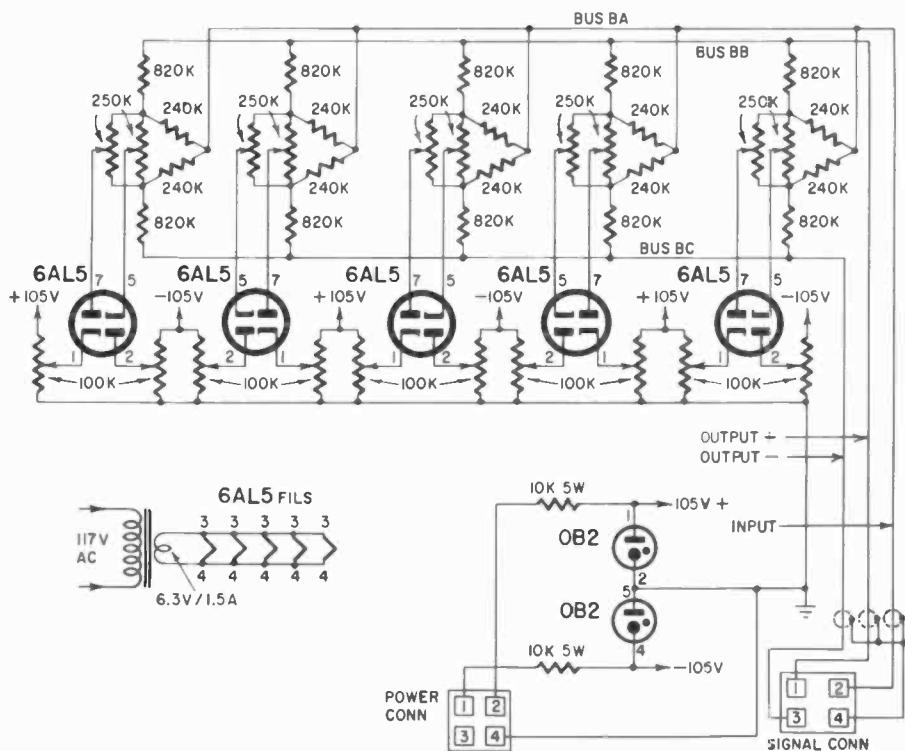
Fig. 927. Vacuum-tube diodes have economically sound characteristics for this function generator.

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for the amplifiers. Fig. 928 shows, for comparison, the curve of a sine wave, a sawtooth and one kind of curve we can generate with a function generator. We can make many different curves with the function generator, adding many diodes to make very complex curves.

These are some of the items which go to make up an analog
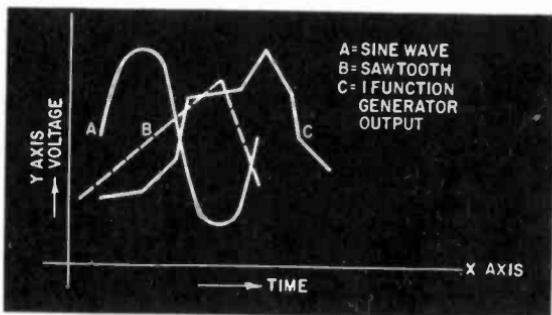
Fig. 928. *Function generator can create wave-forms for special conditions that cannot be satisfied with sawtooth and sine waves.*

computer; there are others, such as the potentiometers with which we can calibrate various readings on the meter, etc. Analog computers, besides being used in analyses, can be inserted directly in some process control systems where the computer, according to a preset "program," will modify the process to keep it within specified limits. It is often used in pilot plants of the petroleum and chemical industries to prevent "runaway" factors.

10 * industrial recorders

As it is important in a process or production line to keep count of raw materials or units produced in a certain amount of time (Chapters 5 and 6), so it is often also very important to keep an accurate and permanent record of various parameters of a process. We may for example want to know the amount of power consumed, the variation of temperature, the amount of current or voltage employed in a process, the continuous state of conductivity of a liquid or variations in its flow. There is almost no end to the factors we may want to keep a record of for various reasons; such as being able to trace back through a process if something has gone wrong with the product. Or we may be able, through an analysis of records, to establish ways of economizing in a process.

We may also be able to use the recorder for the actual control of the process, in which case the instrument not only adjusts for changes but also informs us when and how much adjustment was made. In the case of a boiler, for example, we may want to know what the schedule of demands has been so that we can rearrange various aspects of the consumption to flatten out the demand curve.

Recorders have been in use for a long time, and there is a great variety of them. Before the application of electronics, there were many recorders in use in industry based entirely on mechanical principles. Millions of them are still at work today.

Electrical means of recording began with the galvanometer,

POWER SUPPLY AND AMPLIFIER

RECORDING ELEMENT

PHOTO TUBE

RECORDER

120 V 60~

LIGHT-DIVIDING MIRROR

MIRROR ROTATED BY RECORDING ELEMENT

MIRROR ROTATED BY BASIC ELEMENT

SPHERICAL MIRROR

OPTICAL FOLLOW-UP SYSTEM

INPUT

BASIC ELEMENT

a

TO HTRS

6X5(2)   6V6   6SJ7

117 V AC

F

TO LIGHT SOURCE

PJ-23

TO RECORDING ELEMENTS
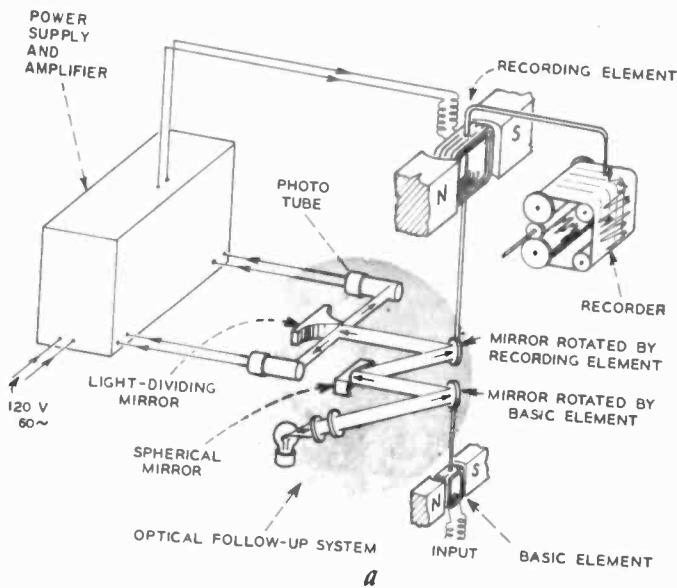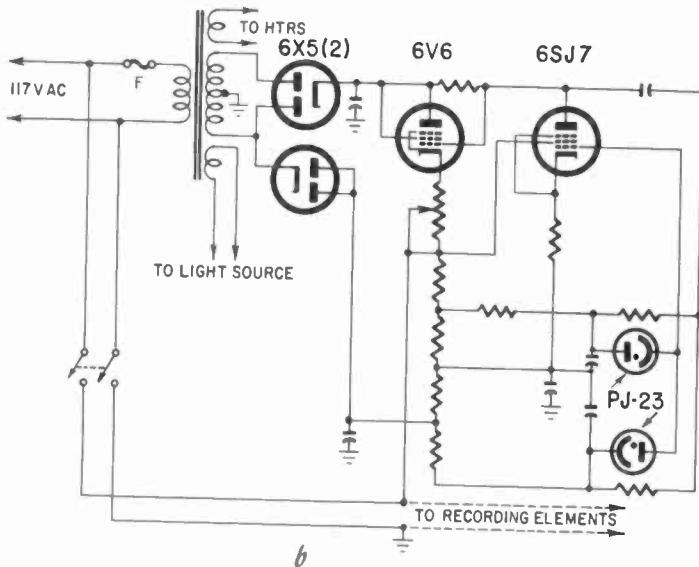
b

Fig. 1001. *The mechanics of the deflection type photoelectric recorder are diagrammed at (a) and the electronic portion is detailed in the schematic at (b).*

using a pen instead of the customary pointer. This is the basis of the direct-writing pen recorders, still used often in many places. The pen arm is driven by an oversized d'Arsonval movement, and

a chart is moved electrically or by a clockwork past the pen, leaving a permanent record of the pen position, and thus of whatever value the movement was responding to.

For such a recorder the signal must be electrical. Thus whatever
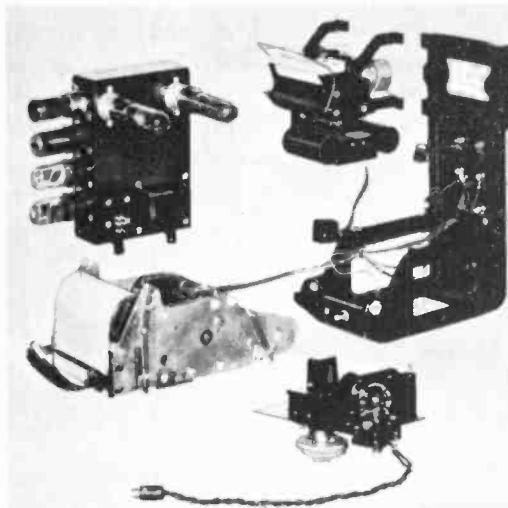
Fig. 1002. *This disassembled photoelectric recorder shows the many subassemblies that go into the complete unit.*

is measured, if it is not an electrical signal, must be converted into an electrical signal by a transducer. Transducers are used to measure pressure, temperature, vacuum, flow, mechanical position, level, oxygen or carbon monoxide content, moisture content, viscosity, density, weight, specific gravity, and all kinds of other physical and chemical factors which are significant in industrial processes. The electronic industry itself has many such applications of transducers and recorders, particularly in the manufacture of vacuum tubes. In Chapter 11 we will show some of the transducers used. Here we will assume that we receive an electrical signal of some kind for recording purposes.

From the simple pen-movement-and-paper-strip recorder, many other types have evolved with different methods of deflection, of making the trace and of recording. All these changes will not be reflected in a single recorder. Some modern recorders still use a version of the d'Arsonval movement with pen and ink, but have complex amplifiers ahead of the movement or photoelectric followups. Others use the same old drive, but special electrical or chemical paper and so on.

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Industrial recorders can be classed as either the potentiometer or the direct-recording type. But there is only a thin line between them, and a few units fall outside or overlap both classifications.

One disadvantage of the direct-writing recorder is that the pen movement must be relatively powerful to drive the heavy pen, which limits its sensitivity. The required weight of the parts also reduces the frequency response. To increase sensitivity, we can use a sensitive mirror galvanometer for the measuring movement, amplify the motion and apply the result to a heavy pen motor, which does the actual recording.

Such a system is used in the G-E Type CE Recorder (Figs. 1001-a and -b). As shown, the input element carries a small mirror. The
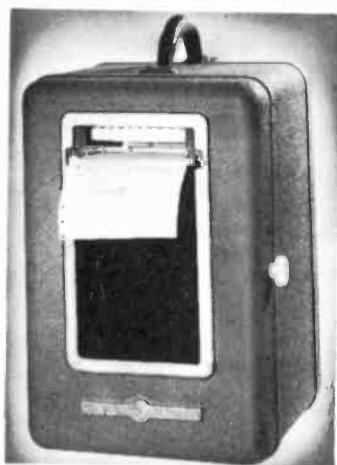
Fig. 1003. *General Electric type CE recorder.*

light reflected from this mirror is divided between two photocells. By moving the beam back and forth, greater distance and effective "pointer" length—and therefore sensitivity—are obtained. The phototubes are connected in a differential amplifier. The difference signal from the phototubes, which results when the galvanometer mirror turns and throws more light on one tube than the other, is amplified by the 6SJ7 and fed to the 6V6 power tube which operates the pen motor. Fig. 1001 shows the components in the instrument. The followup amplifier and power supply are shown at the top left in Fig. 1002, the recording motor and optical assembly at top right. Fig. 1003 shows the external appearance. Fig. 1004 shows the paper drive mechanism. Note the numbers of gears to allow a change of chart speed by shifting from one set to another.

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The chart is driven by sprockets which fit into holes in the chart edge, maintaining precise timing.

Fig. 1005 shows the galvanometer and lamp housing. This setup
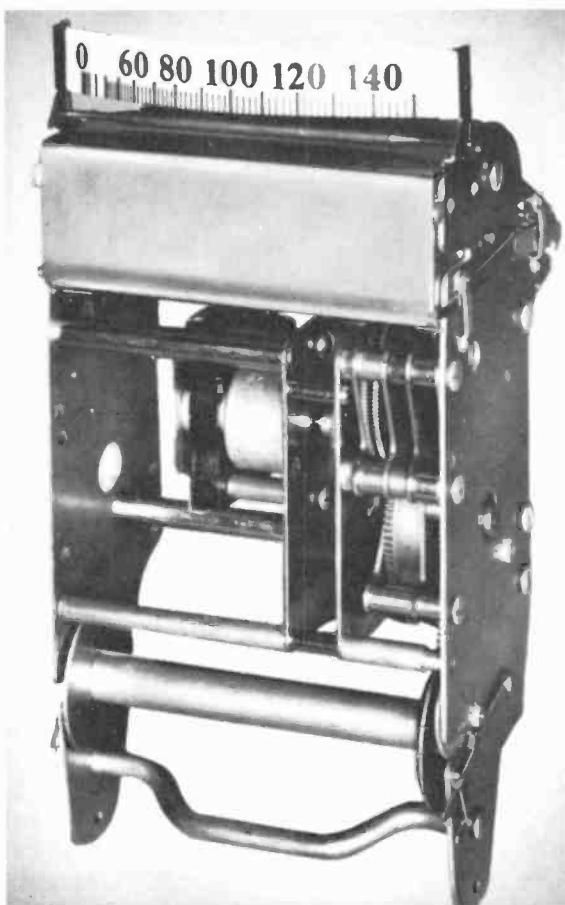
Fig. 1004. *Paper drive mechanism of General Electric type CE recorder.*

can be made very sensitive and, due to the now much greater driving power, also can respond to higher frequencies, depending on galvanometer response and other factors. This type of "amplified" recorder, uses a light beam for part of the amplification, since the long arm of the light beam quickly changes the light on the cells with a minute movement of the galvanometer mirror.

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A similar instrument of the potentiometer type is shown in principle in Fig. 1006. Here the small voltage that moves the galvanometer results in a current in the pen motor which is then proportional to the applied signal. This current causes a drop in resistor R, which, at one of its taps, is equal to the input voltage.
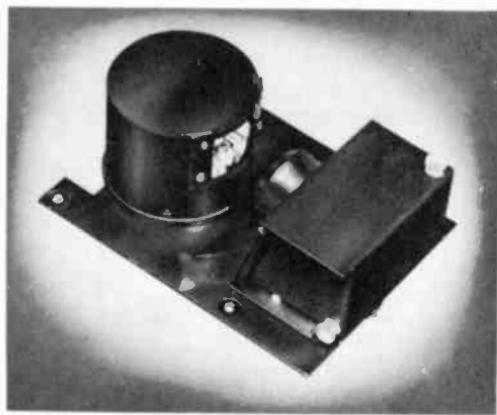
Fig. 1005. *Basic instrument assembly used in photoelectric recorder with protective cover and light source.* (General Electric Co.)

As the voltage is received from the amplifier to drive the pen motor, this portion across R is applied to the input to compensate for the signal and thus adjust the galvanometer back to zero. Note that this system requires a spring return on the pen motor in order to maintain a balanced condition between input signal and pen-motor position.

Chart speeds of the recorders shown vary from $\frac{1}{2}$ inch an hour to 30 inches a minute, depending on the gears used. Sensitivity can vary greatly depending on the basic units used. Frequency response usually varies from $\frac{1}{2}$ second ($\frac{1}{2}$ cps response) for full deflection to 100 cps for the highest frequency range available. In terms of what you are used to in communications, this is a low frequency range, but other recorders will permit much higher frequency response as you will see. The recorders under discussion are primarily useful where the change they are recording is relatively slow.

There are many variations of these instruments including the inkless GE Type CF Recorder. The type CF uses a "tapping" system: the hinged motor pen is tapped on the paper by a small solenoid, once every 2 seconds, and *types* the record with a carbon

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ribbon on the chart. This makes the recorded line a series of points spaced so closely together they look like a line.

Where several records must be kept simultaneously, we can
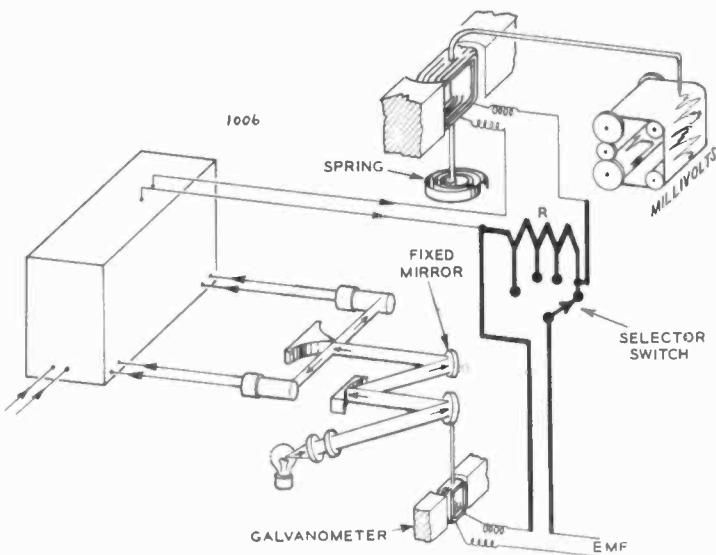
Fig. 1006. *Mechanics of the potentiometer type photo-electric recorder are similar to the deflection type. Added circuitry is shown in heavy lines.*

either install several mechanisms to write on one chart, several recorders separately or several recorders in one case. The latter
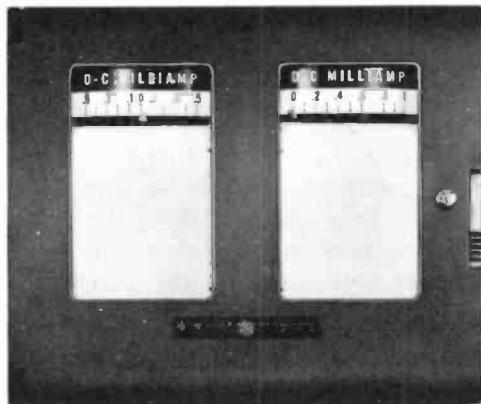
Fig. 1007. *For some work, two record-ers are mounted in one case for convenience.*

is illustrated in Figs. 1007 and 1008, which show the CH-39 recorder as it appears externally and with the door open.

An entirely different approach to the problem has been taken in the Mark II twin recorder shown in Fig. 1009.

The Mark II consists primarily of a well-balanced dc amplifier, utilizing a well-regulated power supply, driving the pen motors.
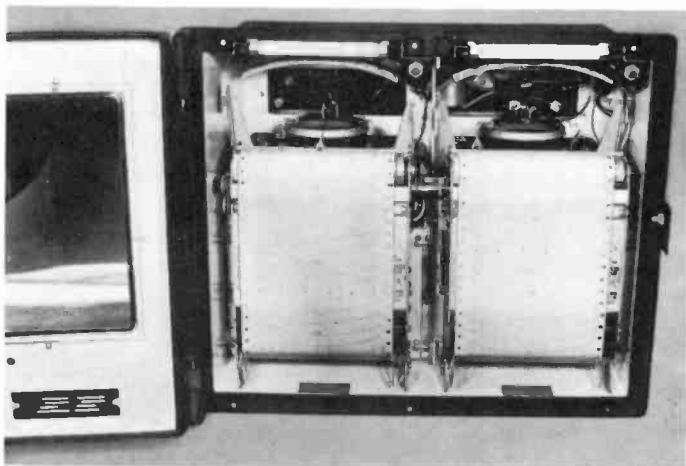
Fig. 1008. *Front door opens for routine maintenance and roll-chart replacement.*

Because the amplifier is balanced all the way through from input to output, drift, so characteristic of dc amplifiers is avoided, since it is most likely equal in both halves and thus cancelled.

Sensitivity of this kind of recorder is limited only by how much amplification we manage to apply. Frequency response is still limited, since we are again dependent on a pen motor as a final recording means. Not only the inertia of the motor parts is responsible for the limitation in frequency, but we must also consider the writing speed. If we move the pen too fast across the paper, no trace will result. Move a pen fast enough across a sheet of paper, and only a scratch will result!

Various methods have been worked out to overcome this. One of them is to use special electrically-conductive paper which has a platen behind it. When the "pen" arm, here carrying a stylus, is supplied with dc, a chemical change takes place in the paper due

to the current conducted through the paper, and leaves a permanent trace. A similar approach is to provide the stylus with a small heating element and to use a paper which is sensitive to temperature. Where the hot stylus touches the paper it leaves a chemically-changed surface which is clearly distinguishable.

These special recording means have permitted writing speeds up

Fig. 1009. *Dual electronic recorder has both traces on one tape for easy comparison.*

to the equivalent of 2,000 cycles on a chart width of about 2 inches, which is quite high. Pen motors can be driven this fast if they are given enough power, but this is not a universal method. For higher frequencies we almost always use oscillographs.

The "potentiometer" recorder previously shown is not typical. Most potentiometer recorders operate according to the principle illustrated in Fig. 1010. The incoming signal can be considered as a leg in a bridge circuit. One other leg of the bridge is a variable voltage. The "galvanometer" of the bridge is a null detector, and this can be anything from a meter movement (as we have seen) to an amplifier—pen-motor system operated by ac. The null detector perceives the unbalance in the bridge and adjusts the voltage accordingly, meanwhile also moving the pen. As the voltage applied to the input terminals varies, the pen follows it and leaves a permanent record on the chart. It would be easy enough to add another potentiometer to the mechanism, also moving with the pen, to control some other devices. This is the very simple principle of the control recorders commonly used in industry.

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Fig. 1011 shows the input system, with chopper circuit, and ac-operated output of a typical industrial recorder. The instrument is shown in Fig. 1012. It uses a wide chart. With a potentiometer system we can move the pen over a much larger distance than with just a d'Arsonval pen motor. Notice also that the lines
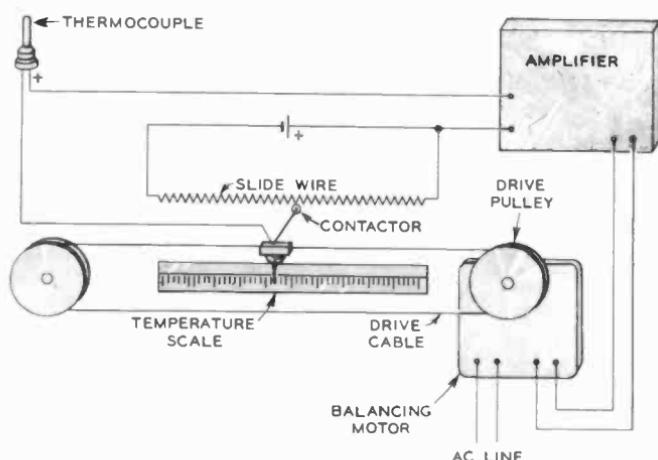
Fig. 1010. *The principle of most potentiometer type instruments is as shown here. An additional slide wire can be added for control circuitry.*

on the d'Arsonval type are curvilinear, because the pen executes a circular motion. For the potentiometer instrument just discussed this is not necessary, since the pen rides on a rail or rack and thus moves in a straight line.

Having such a wide chart, we can use the recorder for multiple records. Suppose we do not need a continuous graph, but only a graph of approximate change, with a recorded point, say, every few seconds. Then we could just as well use the "typing" approach and type a dot when we wish to record.

If we give the instruments several inputs (as many as 12) and make the "pen" a little printing wheel (Fig. 1013) with 12 distinct symbols or numbers on it, we print these each in turn as we turn the switch through all the inputs and turn the wheel with it synchronously. Thus if channel 1 is on the input, the wheel will present symbol 1 to the chart, the potentiometer will move the printing wheel to the proper position, and a solenoid will print the number. As we move the switch to position number 2, automatically the wheel presents symbol 2 and, after it is in a rest
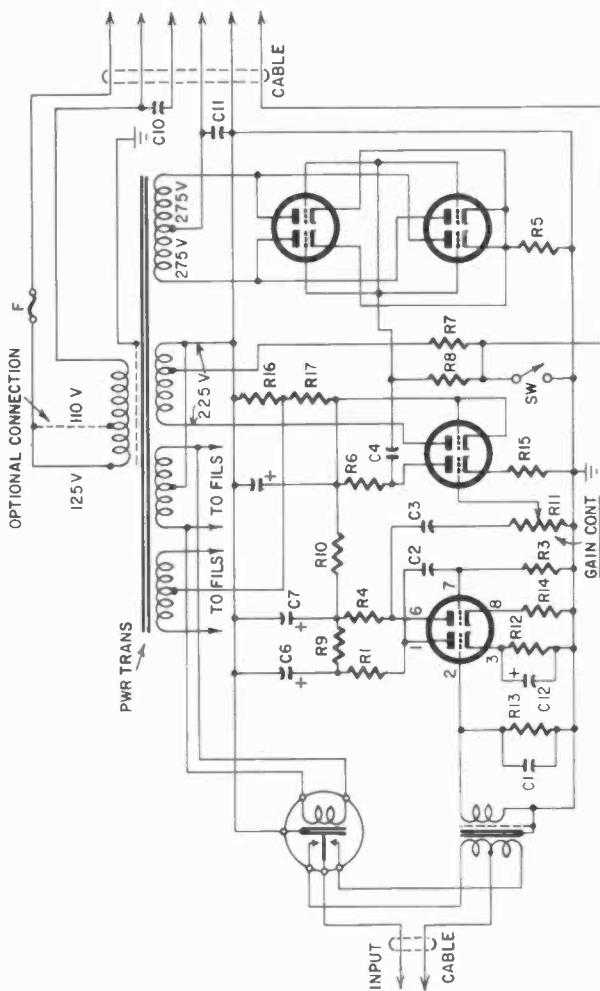
Fig. 1011. Schematic diagram of Brown Electronik recorder has some unfamiliar circuitry.
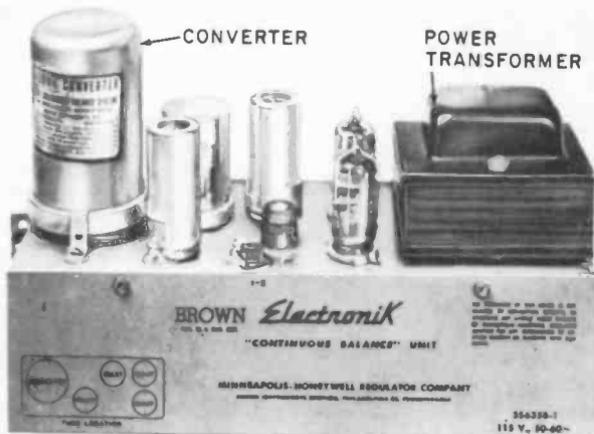
position, prints the number 2 symbol, and so on. If we make the switch an automatically stepping type, which also steps the wheels with it, then we will keep a continuous spot check on 12 channels
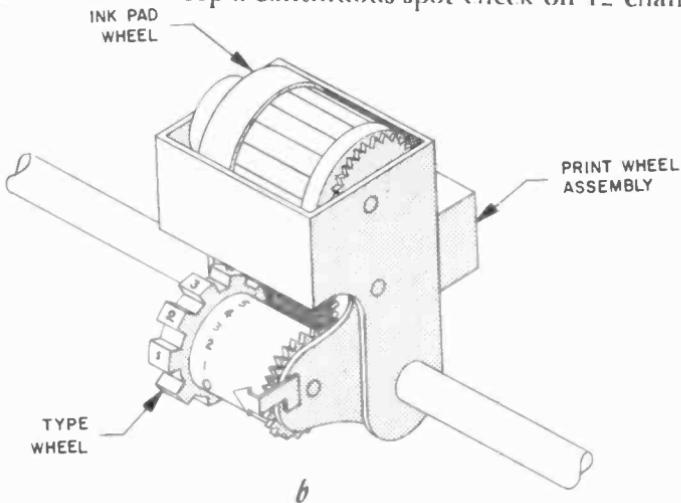
Fig. 1013. Print-wheel recording mechanism allows many channels to be "read". Only samples are recorded. Most transients go unindicated.

on one chart. This is the system used in the Minneapolis-Honeywell Brown multichannel recorder. Notice in Fig. 1013 that the pointer has a number near it, and that right next to this number you can see the printing wheel.

Most industrial recorders now being purchased and installed are of the potentiometer type, although there are numerous variations in the method of moving the pen, in the balancing system, in the paper and the recording means, in the amplifiers, etc.

One which is particularly different is the Microsen recorder-controller. Fig. 1014 shows the instrument, and Fig. 1015 illus-
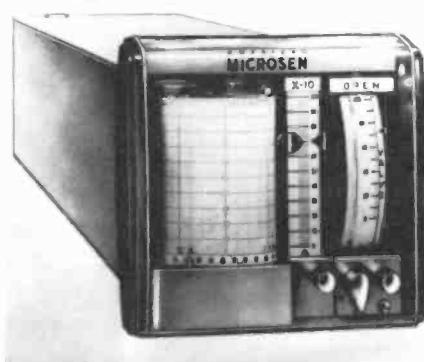
Fig. 1014. *This recorder–controller uses the principle diagrammed in Fig. 1015.*

trates the basic principle. An electromechanical sensing element consisting of a coil suspended on a rotating beam is placed in the field of a permanent magnet. Current from the transducer passes through the coil, and tends to change its relative position with respect to an oscillator coil. The movement of the vane increases or reduces the oscillator current. This varies the current delivered by the oscillator to a rotary solenoid type motor. The solenoid motor increases the tension on a spring, which counteracts the effect of the current in the sensor coil (which would otherwise keep on traveling). The position of the lever which applies the tension to the spring is then proportional to the input current in the coil, and the end of this lever carries the recording pen, which here executes a vertical motion.

In Fig. 1015, the "amplifier" section contains both the oscillator and an amplifier, and more besides. The Microsen, in so far as we have discussed it, has exerted what is known as a *proportional action* only, and the output signal, and hence the pen position,

is a proportion or multiple of the input signal, depending on the sensitivity used. The instrument has a repeatability accuracy of 0.1%.

The pen has indicated only how much adjustment has resulted
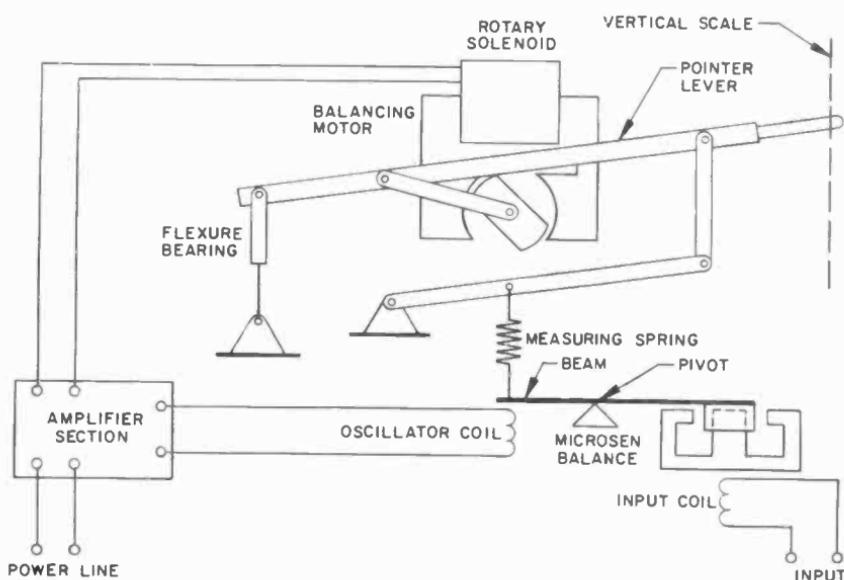
Fig. 1015. *Principle of operation of the Microsen recorder is simplified in this diagram.*

from the input signal; in other words, we have a record of the control action taken by the instrument.

But the Microsen can do a great deal more. It can also take action in relation to the *rate* of change of the input signal, and this is important in dealing with a "runaway" process. If the process tends to deviate *more* rapidly, we can set the Microsen so that a greater signal is received from the output, thus allowing, for example, a rapid shutting of valves when this is most needed. Fig. 1016 shows the controller unit of the Microsen.

Still another form of recorder is shown in Fig. 1017. Here the input signal is applied to the control windings of two saturable reactors in a bridge circuit, and the bias of the two reactors is so arranged that the signal will aid the bias in one and oppose it in the other, causing unbalance. Amplified, the resultant signal is then applied to an ac amplifier which controls the balancing motor by means of saturable reactors.

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Many other systems use their own special methods for one function or another. The Leeds & Northrup recorders use a gravity kind of balancing system for the followup of a galvanometer pointer. Others have photoelectric followup systems with pen carriages (rather than a rotating pen motor) or use a small change in capacitance in the input measuring element, and so on.
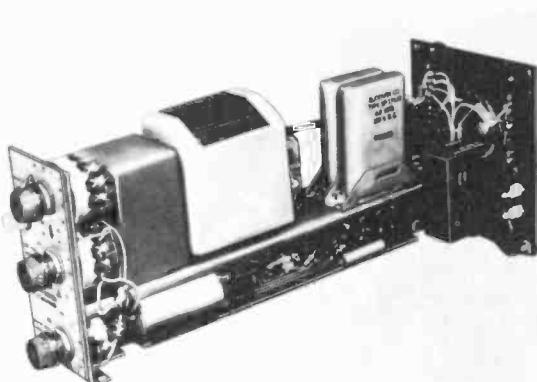
Fig. 1016. *The electronic circuits of the Microsen recorder are quite compact.*

One unusual group is the X–Y recorders, found mostly as the output of analog computers, but which *could* become very useful in checking out complex control-system functions. These recorders, as their name implies, are capable of recording in two axes, X and Y, and can draw graphs involving any variation of two independent or dependent inputs, or one (X) can be used as a time base. Originally slow, some X–Y recorders can now plot a curve in a fraction of a second with great accuracy. However, these are not primarily *industrial* recorders, and we will not discuss them further except to say that their moving systems are akin to the potentiometer type controllers and recorders.

So far we have shown means of making multiple recordings which consisted basically of using several instruments on the one hand, or time-dividing the recording between a number of signals. There are still other ways of doing this. Particularly (but not exclusively) in rotary chart recorders, as many as six overlapping pens make simultaneous recordings. A typical single-pen recorder

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made by Foxboro is shown in Fig. 1018. The instrument has a camlike device. This is used to obtain an output signal which has some of the "rate" characteristic — the greater the deviation from a set point, the greater the output signal, due to the spiral shape of the cam. This recorder is then also a controller.
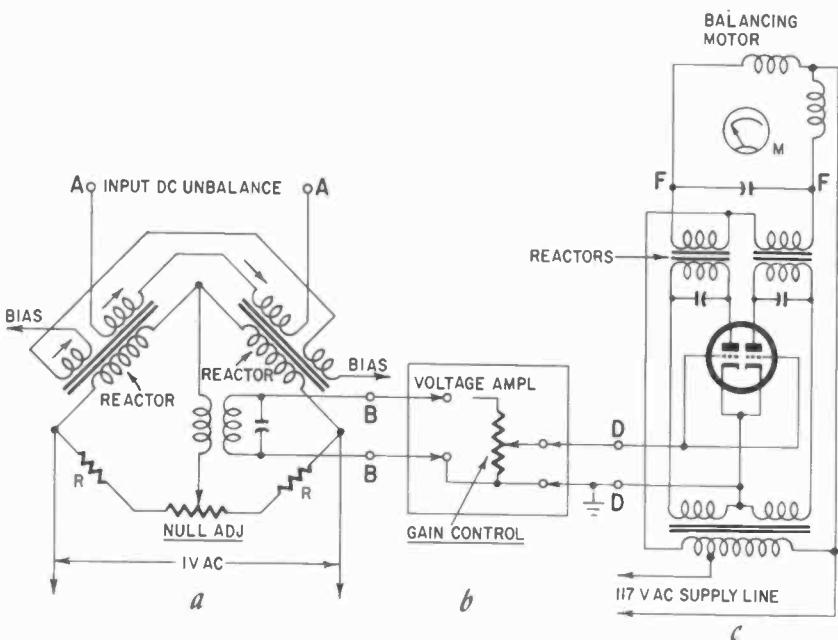
Fig. 1017. *Another recorder circuit makes use of saturable reactors as input and control elements.*

Another method used to make multiple recordings consists of four separate pen motors each operating its own pen arm. The arms are all *pivoted at the same point* and operated by linkages. This allows us to make the arms slightly longer progressively, yet make a common reference line for the pens which takes the form of a mathematically simple curve.

Circular chart recorders are usually slow and most likely used where a continuous process is watched, such as the steam pressure in a boiler, etc., which is continuously attended by engineers. The record shows when the heavy loads are applied, so that the engineers may schedule loads to even up the demand.

In a large operation requiring more records than can be satisfactorily handled by a multiple recorder, recorders in banks are

installed, such as the group of Foxboro units shown in Fig. 1019. These are designed as draw-out units, so that their internal structure is easily accessible for service and maintenance.

Service work on a recorder depends a great deal on the unit you are dealing with. In many cases the ink supply of recorders must be periodically renewed, but the so-called inkless recorders may need a new carbon ribbon instead. On the other hand, the styli of recorders using some chemical or electrical recording medium need no attention to speak of.

Recorders in industry are practically always designed to fit into

Fig. 1018. *Circular chart recorder may cover an hour, day or week, depending on details required for process.*

the environment, and delicate internal components are adequately protected. Where this is not the case, a recorder may need periodic cleaning. This can best be done with a set of cleaning brushes and a *low-pressure* air supply. (Any strong air blast will easily damage delicate parts.) The air used must be dry and free of oil and particles. It is always better, if possible, to remove a recorder to a clean workbench, where maintenance can be done without danger of physical damage to the recorder, than to service it in place, unless it was specially designed for this type of maintenance. Be sure to follow the manufacturer's recommendations on recorder maintenance.

One chore is chart replacement. This again varies a great deal with the recorder used. The circular-chart recorders are the simplest. The chart is held on the spindle with a special nut or clip, and all that need be done is to remove the old chart, slip the

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new one in, and fasten the nut or clip again. All recorders have some means of removing the pen from the chart for this process. In many cases this is a simple hinge arrangement in the pen arm, while in others the entire pen-arm mechanism swings out of the way. A typical chart-removal procedure is shown in the series of
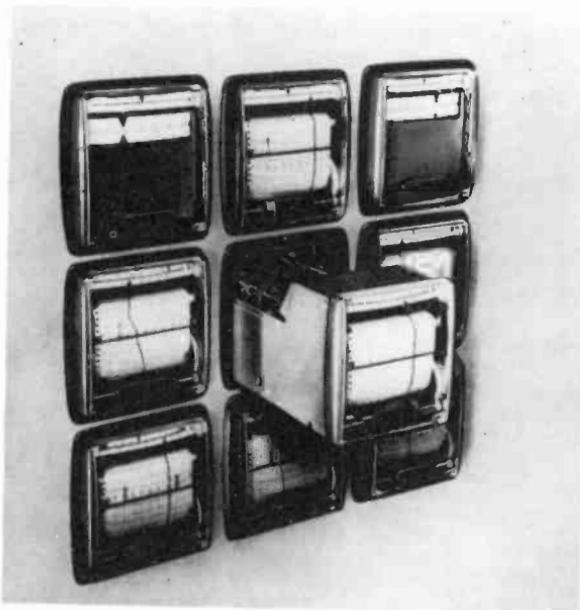
Fig. 1019. *This bank of recorders is installed on slides easily accessible for maintenance.*

pictures of Fig. 1020. In any case, the manufacturer's manual will give detailed chart-changing procedures.

Actual repair to the amplifiers or the mechanism of a recorder must be done in 90% of the cases with the recorder removed from its case and normal location. Treat the recorder electronic gear like any other delicate instrument. Be especially careful to do no violence to any of the mechanical parts of the recorder—it is a safe bet that they are much harder to replace than the electronic components!

Oscillographs

Oscillographs are in a class by themselves and will not normally be encountered in the industrial plant, but rather in the plant
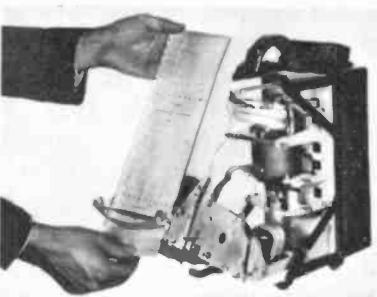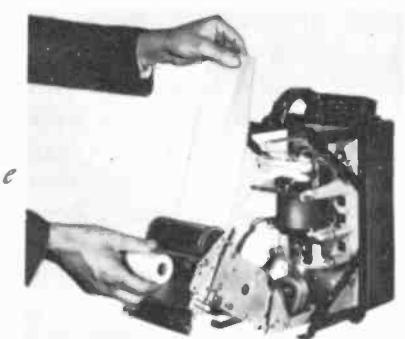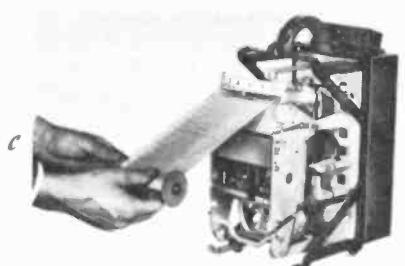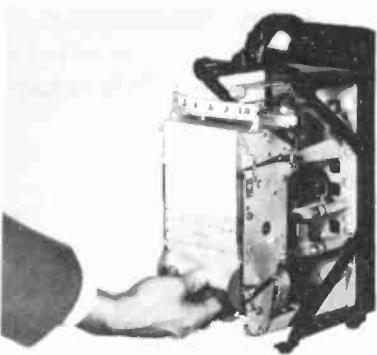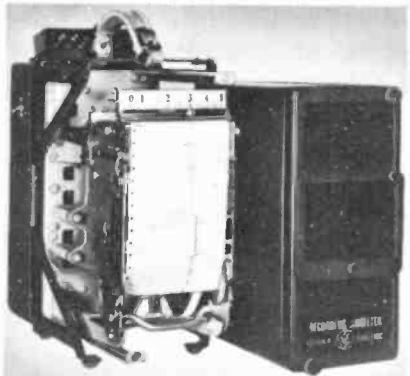
Fig. 1020. *The chart-removal sequence: remove case (a), pull out takeup spool (b), remove unused chart paper (c), remove empty spool (d), start new roll (e), thread new paper through guides (f). Procedure is similar for most recorders and is detailed in their individual maintenance manuals.* (General Electric Co.)

laboratories, where they may see some rather heavy use. They are expensive instruments, and anyone not contemplating frequent

In any case, the elements are made so small — they are scarcely thicker than a pencil, not counting the magnet — that many of them will fit into one instrument. Often one magnet serves for a number of galvanometer coils. The optical system of such an oscillograph is arranged to produce very thin collimated beams of light, which can be reprojected from the galvanometer mirrors and maintain their thin beam character, to produce clean traces.
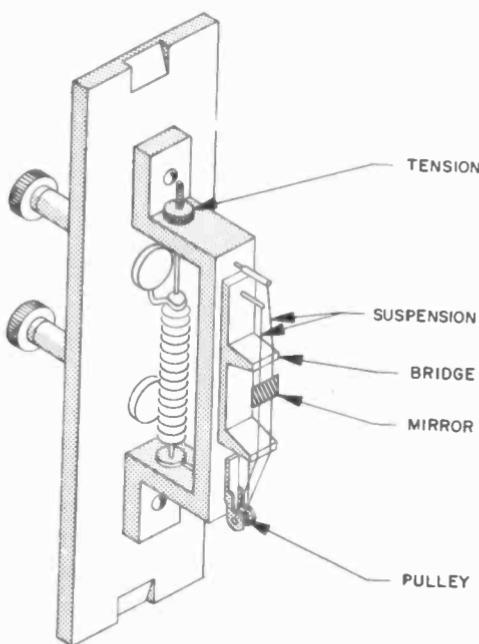
Fig. 1023. *String galvanometer assembly depends on the magnetic field around the wires to twist the mirror when in place in their normal permanent magnetic field.*

One modern oscillograph is so versatile and easy to use it could be regarded as an industrial recorder rather than a laboratory instrument, although it has the sensitivity and frequency response of the typical laboratory instrument. This is the Visicorder, made by the Heiland Div. of Minneapolis Honeywell. The thin galvanometers used in the instrument are especially compact. A section of the galvanometer, a small elongated coil which rotates on suspension wires, is shown in Fig. 1024. With such a small coil there is no question of inserting a core inside the coil as in the normal

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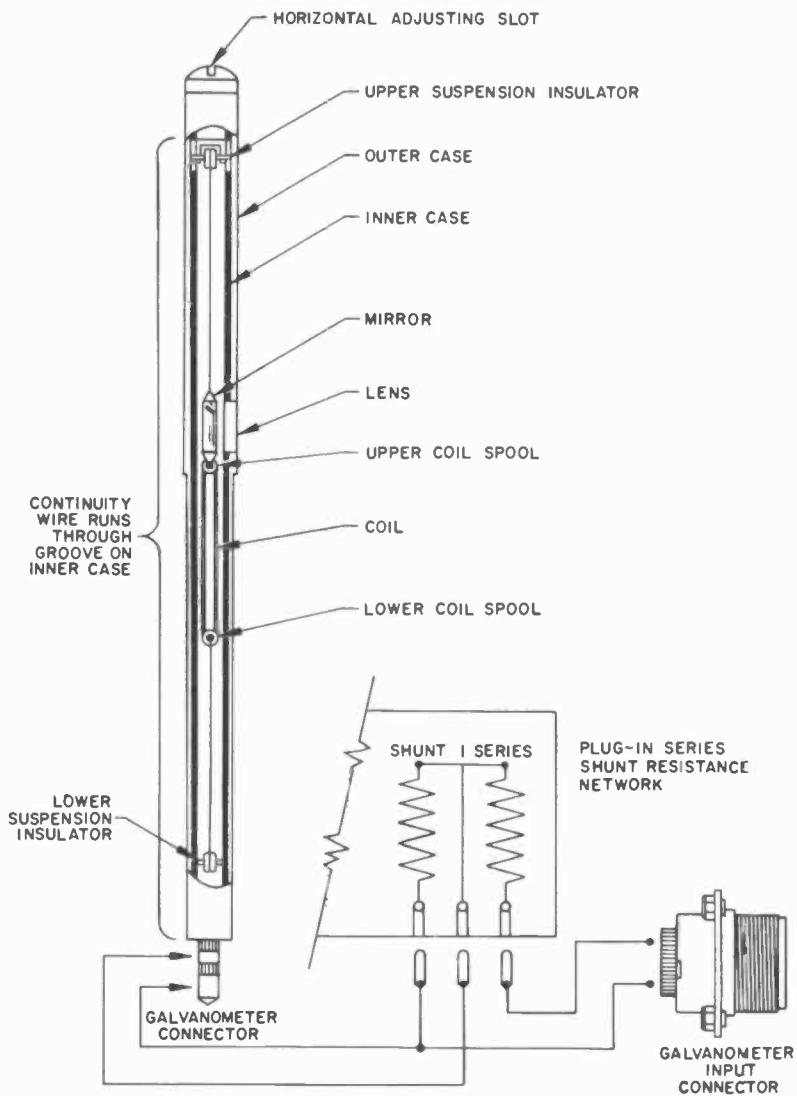
Fig. 1024. *This subminiature galvanometer movement is shown nearly twice its normal size. Some models will indicate at 5,000 cycles.*

d'Arsonval movement but, since the coil is so small, we approach a perfectly homogeneous field closely enough without it.

These galvanometers for the Visicorder can be obtained in a great variety of sensitivities and frequency response. Elements vary from a frequency response of 0–24 cycles, flat within $\pm5\%$

and a sensitivity of 6.7 microamps per inch to 240 cycles and 77 µa per inch, for the electromagnetically damped type, and from 0–600 cycles and 2.63 µa per inch to 0–4800 at 37 µa. Note that as the frequency response increases, the current per inch of deflection goes up. To obtain greater frequency response, the suspension must be tighter, and thus requires more torque and greater current to turn the coil.

It must be pointed out that the figures given above are meaningless unless we know we are speaking about a specific galvanometer system, as we are here. If we say the deflection is so much per inch, it gives no performance data unless we specify the length of arm at which we measure the deflection. Deflection is the result of the rotation of the current-driven coil, at a certain distance. The greater the distance, the greater the deflection with the same rotation. In the Visicorder we have an arm of 11.8 inches. This is not an industry standard; each manufacturer builds into his instrument as much arm as the physical size and the optical system will allow, which gives him the most advantageous deflection per unit current figure.

The Visicorder is different in another important aspect from most oscillographs in that it uses a system of direct writing in an optical sense. The optics for the galvanometers are designed so that the instrument can use a high-pressure mercury-vapor light source, which is rich in ultraviolet. The paper used is related to blue-printing paper, which is also affected by such light. In this case, however, no developing solution is needed; the process is immediate and dry. Ultraviolet leaves a clearly discernible trace on the chart.

Since normal glass does not transmit a sizable portion of the ultraviolet spectrum, the Visicorder has optics made from a special material. For a time base, the Visicorder contains a built-in flash lamp, so that no galvanometer need be used for a timing record. The timing lamp also can produce fine grid lines on the chart if need be, so that immediate reference lines for reading the record are available, which are spaced at the timing-flash points. This again is a very unusual feature for oscillographs.

Up to 24 galvanometers can be accommodated in the instrument. With this kind of sensitivity and frequency response, no amplification is used. With direct-recording and amplifier industrial recorders, we generally have an input impedance which varies from 2,000 ohms to several megohms. Although the lower

end of this scale can seriously load a source being recorded, the high end certainly does not. However, with galvanometers we are not this fortunate. Galvanometer resistance for the Visicorder, for example, varies from the 21 ohms of the very sensitive galvanometer to a maximum of about 112 ohms for the least sensitive unit with the high-frequency response. This means that, unless we have a low-impedance source, the galvanometer will most certainly load the source. This can be avoided by using a matching transformer or a cathode follower with the oscillograph. The cathode follower is preferred because it can also respond to dc, and can be made virtually linear over the range of the galvanometer. The transformer is easier to use but is likely to introduce some nonlinearity in the response, particularly at the low frequencies. If extreme accuracy is needed over the entire range, use a cathode follower and compensate for zero-set.

Recording oscillographs are used in many places besides the industrial laboratory. They keep written records in such applications as missile performance and nuclear reactor control as well as the readout of computers. In industry, they have been particularly useful for checking circuit-breaker and thyratron performance and similar applications where they are the most convenient means of showing the interrupting speed of the devices tested.

Where frequencies greater than 5,000 cycles per second must be recorded, we have to resort to the inertialess cathode ray tube (CRT) or the oscilloscope. This is primarily designed for *viewing*. However, with a properly designed camera attachment, we can turn the oscillo*scope* into a very efficient oscillo*graph*. This does not mean it is always best to use, as we shall see.

Oscilloscope photography

While an experimenter can often do a satisfactory job of photographing the traces on a cathode-ray tube (CRT) screen by setting a camera in front of the scope and making the room dark to minimize reflections, such a method would be clumsy in a laboratory or industrial setting. Many special cameras have been developed for industrial use to provide a series of oscillographs with very high frequency response and sensitivity. They have enough disadvantages, however, that recording oscillographs are not in immediate danger of being replaced with oscilloscopes and cameras. It is difficult, for example, to do a good job of getting more than 20 traces on an oscilloscope screen, and for high-speed response it might be very difficult to get more than two. In fact

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for transients it is impossible to get more than one, per each CRT gun, if the transient must be observed in its entire length. Then all methods of "switching" and "chopping" sweep interfere with the proper presentation. With a good oscillograph, 20 transients could be observed simultaneously!

Several systems can be used, and cameras have been developed for all of them. There are two Dumont cameras, one of which is shown in Fig. 1025. These differ in that one uses the Polaroid-Land system, making direct prints in less than a minute (but of course it must be idle during the development) while the second uses a rapid-sequence camera which takes many sequential shots on standard 35-mm film. Note that these camera mounts have been so designed that the user can get full binocular vision of the screen while taking the pictures, so that necessary adjustments can be made without removing the camera.

Another system of CRT photography is used when a continuous record of considerable length is desired. In that case the sweep circuits of the oscilloscope are not used, and the spot is deflected only in the vertical axis, while a film travels by the screen rapidly in a horizontal direction. Cameras are made which can utilize several hundred feet of 35-mm film this way, giving a continuous record which can last minutes or even hours, depending on the film length and speed.

For high-speed photography, a CRT with a special phosphor, P11, is used. This blue-white phosphor is used because films are generally very sensitive to this color, permitting high "writing" speeds. The customary green phosphor is fine for observation, since the human eye is especially sensitive to green, but films are often not. Color shots of CRT traces are now possible in a reasonable exposure time with the new high-speed color films, and several manufacturers are now building cathode-ray tubes for special displays with a number of colors, somewhat on the principle of television color tubes. These are used where a number of traces must be clearly distinguishable from each other, and color film is needed or the distinction is lost.

CRT photography is not an everyday practice in industrial electronics servicing itself, but it can be a valuable tool when appropriate. For example, if equipment or a process needs adjustment and there is some reason why it should not be operated with this defect for any length of time, brief checks with an oscilloscope camera can be a valuable aid in adjusting. It can also provide a record of the kind of malfunction that takes place in the equip-

ment, so that it can be analysed without having to continuously operate equipment that may be seriously damaged.

Cathode-ray oscillographs which are designed with photography in mind, as most good-quality professional scopes are, will include circuitry to increase the intensity of the trace as needed. Their normal operating intensity for viewing is not as great and, if the tube were operated at the great intensity used for photography, the phosphor would soon deteriorate.
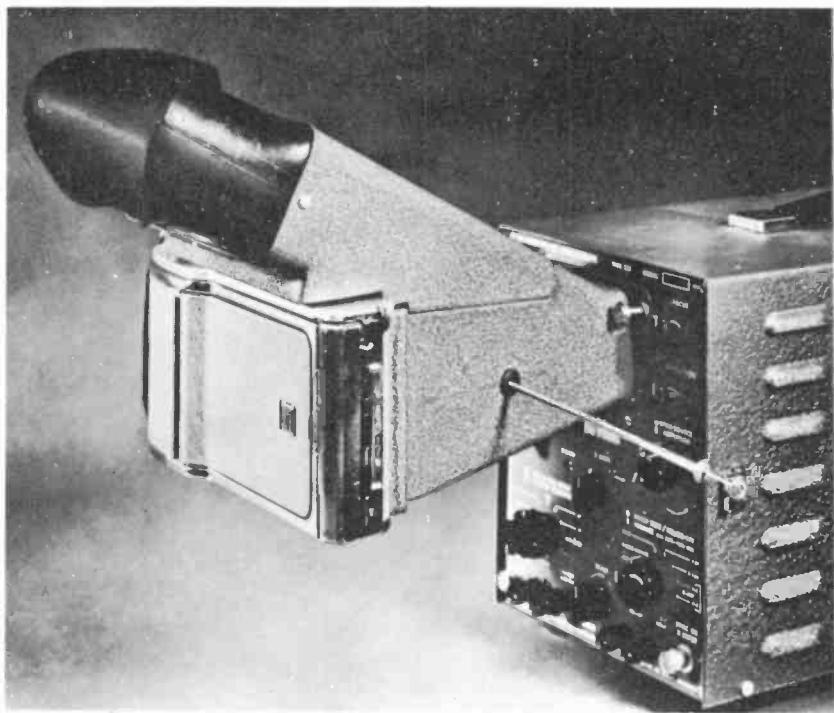
Fig. 1025. *Oscilloscope camera shown here uses Polaroid-Land film.*

Circuitry for intensification is simple. Sometimes it consists simply of boosting the accelerating voltage on the final anode, but most often it simply increases the positive voltage on the grid of the CRT. With such means and the new films and developers which allow film speeds up to 3,000 ASA, very high writing speeds can be obtained.

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Increased writing speed

To obtain even greater writing speed we can record with an electron beam directly on a sensitive photographic emulsion. To do this, the photographic plate is inserted into special tubes which have a removable front. This means that we must have a door which can hold a good vacuum, for each time we change film we must evacuate the tube with a set of high-vacuum pumps. Such oscillographs are in use only in laboratories which specialize in testing such things as impulse generators in which an artificial lightning flash is created which lasts only a fraction of a microsecond.

11 *

transducers and industrial electronics applications

I N this volume so far you have met a number of transducers. In Chapter 3 we considered some ultrasonic transducers. In Chapter 6 you learned about methods in counting, using transducers such as the magnetic flow meter which operated a counter. Even the cells or phototubes of Chapter 7 can be considered transducers In fact, even a simple switch is one so long as it is used to convert some mechanical motion into an electrical signal for control or recording purposes. (In other words, power switches would not be transducers.)

There are many thousands of special transducers suited to each particular control or recording job, all designed to convert some physical, chemical or thermal change into electrical signals. We have space only for a few, to give you the general idea of how some transducers operate, what they will probably look like on the outside and what can be done to keep them in condition, if anything.

Pressure transducers

Most industrial processes use pressure in some phase, whether this is liquid, gas, steam or simply air. Vacuums are simply negative pressures. We have been using mechanical means of measuring these quantities for many years, and the simple Bourdon tube

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(the spirally-wound tube which tries to unwind if we put gas under pressure inside) and aneroid barometers are familiar to most everyone. Fig. 1101 shows an aneroid chamber bellows, and
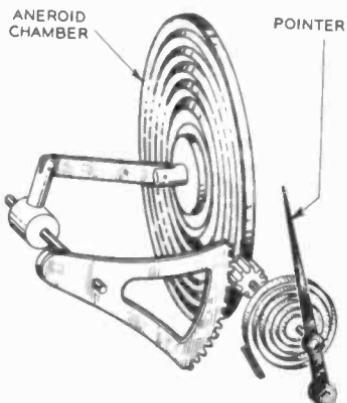
Fig. 1101. *Aneroid chamber responds to air pressure. A potentiometer in place of the pointer would make this a barometric transducer.*

you can see that if we replace the pointer with a potentiometer and apply a dc voltage to the ends, the wiper will give us a varying dc potential, proportional to the motions of the chamber. This,
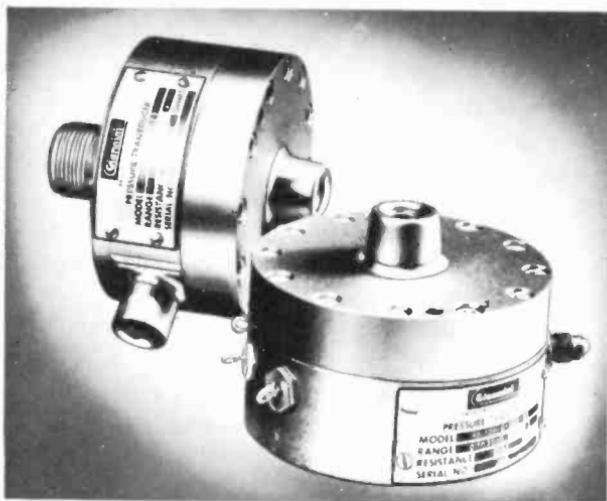
Fig. 1102. *These pressure transducers use Bourdon tubes to drive potentiometers.* (Gianinni Corp.)

in short, is the principle used in many pressure transducers; the pressure sensors shown in Fig. 1102 use a Bourdon tube with a potentiometer to do the same job.

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An active element often used for the strain gage transducer, is a length of extremely fine wire laid back and forth on a piece of paper, formed into a grid which is cemented to a paper. The paper
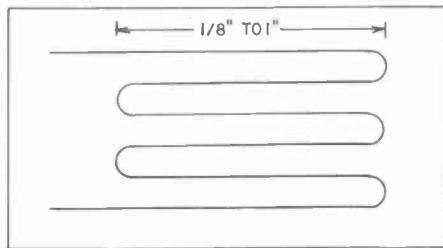
Fig. 1103. *Bonded strain gage is a very thin wire cemented to a thin piece of paper. The whole unit is then cemented to the material under test. Any stretch of the material also stretches the wire. The increase in resistance can be measured.*

can then be cemented to any structural member which tends to change shape under the forces applied to it. Fig. 1103 shows such a bonded strain gage. Fig. 1104 shows the fine wire wound onto insulating pins. This is called an unbonded strain gage.

When the member to which the gage is attached deforms ever
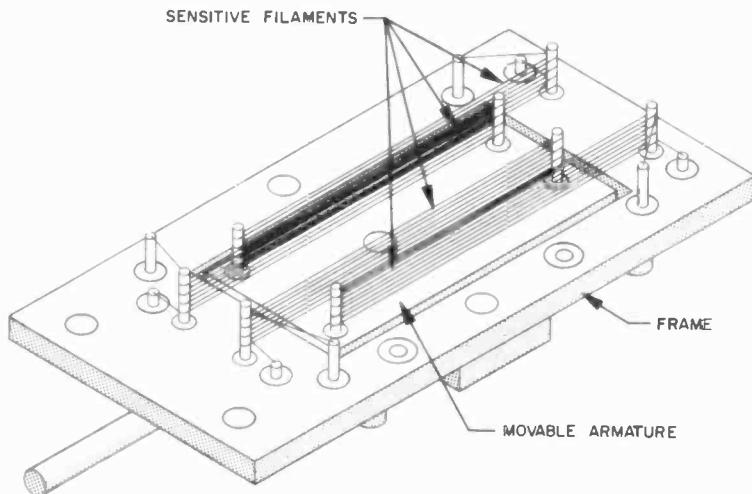
Fig. 1104. *Unbonded strain gage is made of wire wound on pegs. Resistance change is relative to the movement of the two plates. It can be attached to a diaphragm to measure pressure.*

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so slightly, the wire will be very slightly elongated also. If we add up all the bits of lengthening of all the turns, it amounts to quite a lot. In addition, lengthening the wire also reduces the cross-section of the wire somewhat. Since the resistance of the wire is proportional to its length and to its cross-section (and thus the square of the diameter), a slight elongation of the member can change the resistance of such a fine wire a measurable amount.
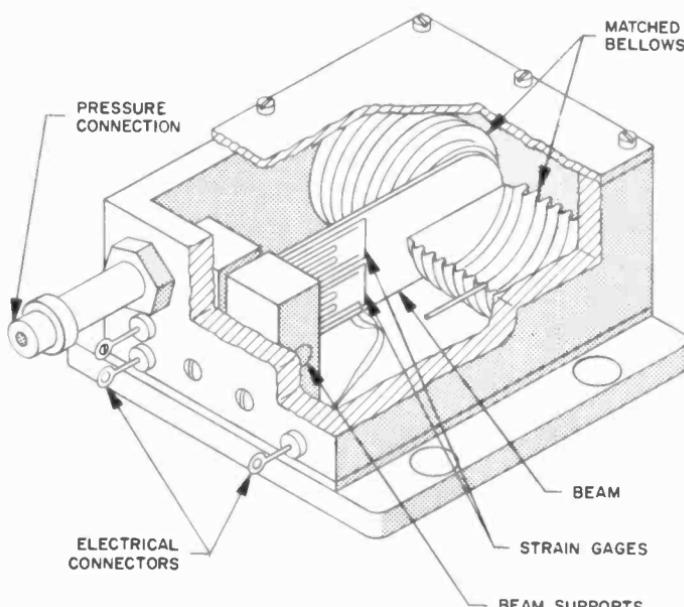
Fig. 1105. *This pressure transducer uses bonded strain gages attached to the beam, which is flexed by the bellows. Vacuum gages are also built using this principle.*

The strain gages can be set up to indicate thickening, bending or even twisting of a bar. In the pressure transducer of Fig. 1105 we use this principle by bending a small bar, with a strain gage attached, with a bellows, which we put under pressure. The resultant signal is applied to the input of a recorder.

Usually the strain gage will be one leg of bridge circuit. Most often the bridge is fed with an audio voltage, so that the signal is easy to separate from the noise and amplify in a tuned amplifier.

Another form of pressure transducer is the capacitive transducer (Fig. 1106). It is used with very high pressures such as those encountered when taking a pressure diagram of a Diesel engine cylinder and in similar applications. The capacitor is formed by the isolated electrode and the bottom "diaphragm," which is quite

thick. The capacitor is part of the tuned circuit of an oscillator, changing the oscillator frequency. Or we can use it as part of a discriminator circuit, so that the change in tuning changes the amplitude of the signal in the link coil.
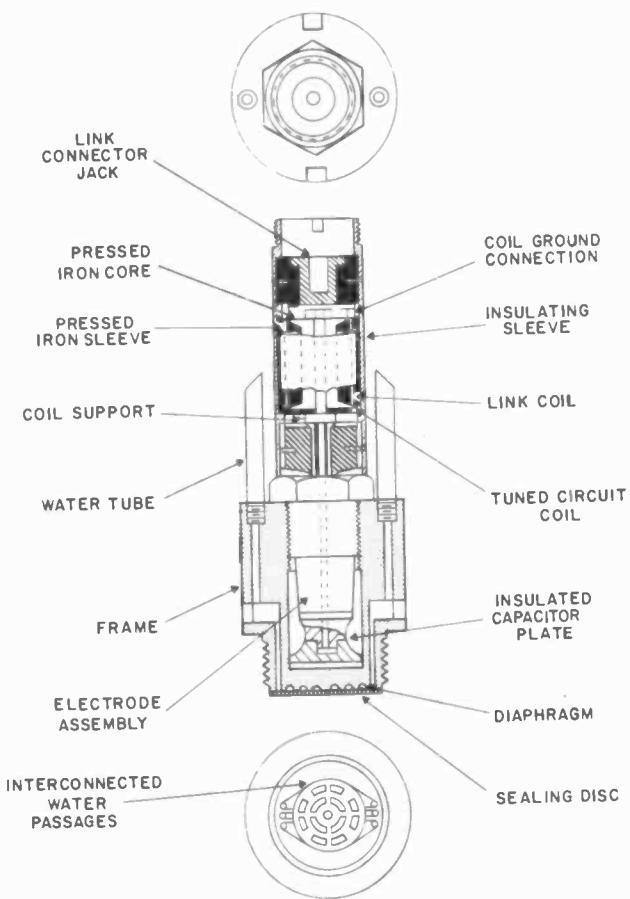
Fig. 1106. *The capacitive transducer has plates connected to some form of tuned circuit. High pressures produce minute capacitance changes. External circuitry for this transducer is more complicated than for the potentiometer type.*

The ordinary Rochelle salt crystal forms the active element of a pressure transducer in which the crystal is deformed by a diaphragm. There are also several kinds of inductive pressure transducers. In one the diaphragm, bellows or Bourdon tube moves a core, changing the air gap in an inductor, thus changing its im-

CONNECTION TO
UNKNOWN PRESSURE

READ
PRESSURE

TUNGSTEN SPIRAL
GRID +150 VOLTS
COLLECTS ELECTRONS

I_1

I_2

REGULATING
SUPPLY
(KEEPS I_1
CONSTANT)

RANGE

+150

−20

VACUUM
TUBE
VOLT-
METER

ION-COLLECTING
PLATE −20 VOLTS

TUNGSTEN
FILAMENT
EMITS
ELECTRONS

a

ELECTRONS
PERFORM MANY SPIRAL
OSCILLATIONS BEFORE
REACHING ANODE CYLINDER

CATHODE

READ PRESSURE
(MICROAMMETER)

2000
TO 4000
VOLTS

CONNECTION TO
UNKNOWN
PRESSURE

ANODE
CYLINDER

CATHODE

MAGNETIC FIELD
500 TO 1500 GAUSS

b

Fig. 1107. *Ionization gage (a) measures the number of ions, which indicates the gas molecule quantity left in the system. This gage can be used only with very high vacuums as the presence of oxygen would vaporize the filament. Note that the plate (collector) has a negative voltage to attract the negative ions. The cold-cathode ionization gage (b) depends on many collisions of electrons with gas molecules to form ions. This gage will not burn out in low vacuum.*

pedance quite drastically. Another type uses a ferrite core which moves in and out of a coil. The latter type uses radio frequencies for a carrier.

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Vacuum transducers

Many of the ideas of the pressure transducer can be applied to vacuum transducers. Very common in the electronics industry are the so-called vacuum ionization gages (Fig. 1107-a). The one shown appears to be just a triode. Actually, the tube is not normally evacuated, but is instead connected to a vacuum system to be measured. The cathode of the tube emits electrons, which are attracted to the positive grid. These electrons move with a considerable velocity and, if they encounter gas molecules, they

c
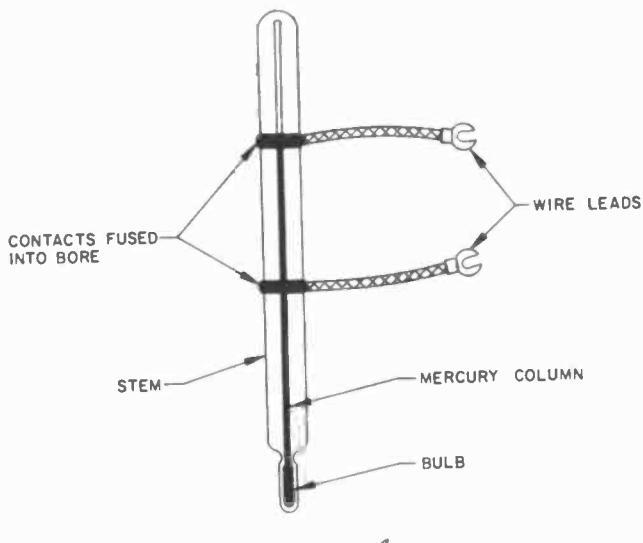
Fig. 1107-c. *Contacts inserted through the glass during the manufacture of this highly accurate thermostat complete the circuit through the mercury column.*

will ionize them; that is, stick to them and form positive ions. These ions are attracted to the negatively charged plate, and the current on this plate is thus a measure of the number of gas molecules encountered by the electrons—in other words, the amount of gas left in the bulb. The filament is not turned on until after a substantial vacuum has been obtained, or it would rapidly burn up.

Although there are several improved versions of the basic ionization gage, many of the simple primitive kind are still used. Fig. 1107-b shows a cold-cathode type.

Temperature measurement

Temperature is another quantity often measured in industry.

SEALED TERMINAL HOUSING CAP

THREADED CONDUIT FOR CONNECTOR

MOUNTING THREADS

STAINLESS STEEL STEM

CERAMIC BUSHING

WINDING TERMINAL STUDS

DOUBLE SPIRAL HELICAL COIL RESISTANCE WINDING

ALUMINUM WINDING SUPPORT

d
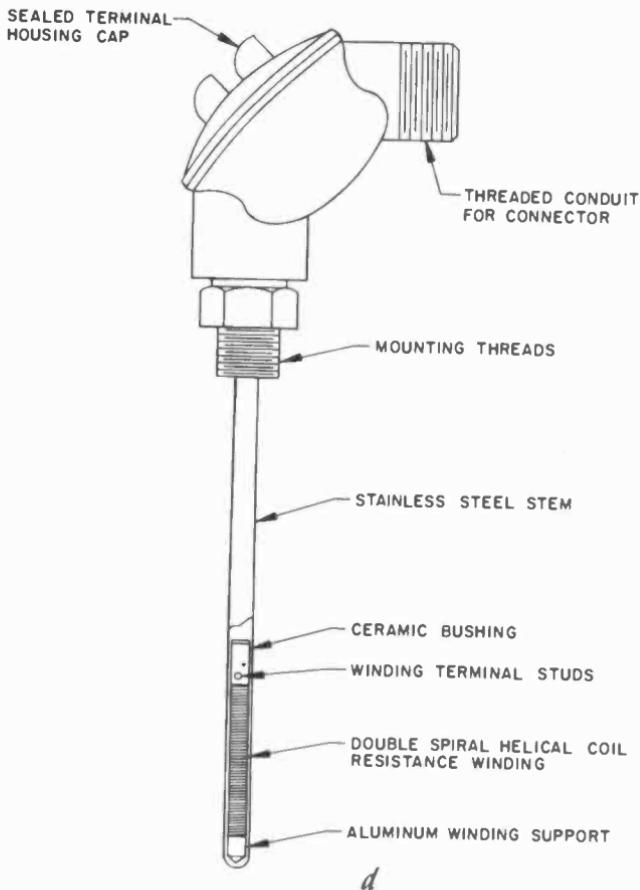
Fig. 1107-d. *Resistance-change readings indicate the temperature in this sensing element.*

There are many ways to transduce temperature into electrical signals, all of them relatively familiar. The simplest is the contact-making thermometer, which closes—or opens a contact, inserted into the mercury column, through the mercury at a preset temperature. (Fig. 1107-c). Thermometers have been made with as many as 10 contacts, but these are relatively rare.

There are thermocouples, junctions of dissimilar wires. Almost any two wires can serve, but certain combinations of metal wires offer advantages. Copper–constantan and platinum–copper are a couple of the popular thermocouple combinations. Then there are thermistors, small beads, discs, wafers or rods of semiconductor

material which change their resistance drastically with applied heat. Thermistors always have *lower* resistance when they get warmer.

Thermopiles are simply stacks of thermocouples connected in series, and thus give a much greater output. Also popular are resistance-temperature bulbs, which are wire coils installed in a protective case. Temperature is measured as a function of the increased resistance of the wire (Fig. 1107-d).

Bi-metallic elements have been used for temperature transducers. The deformation of the bi-metallic element is used to drive the shaft of a potentiometer. Similarly, Bourdon tubes partially
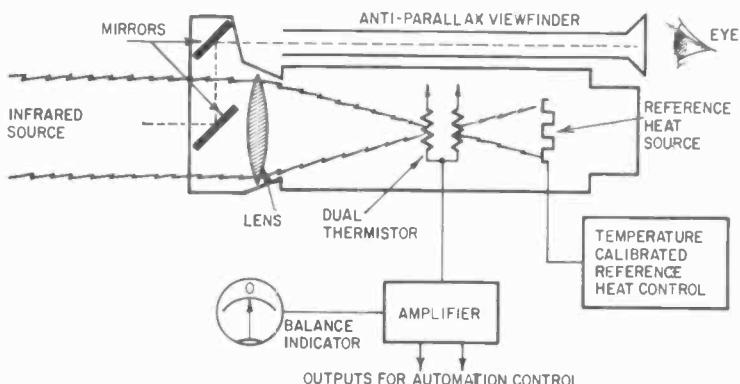
Fig. 1107-e. *Infrared radiation pyrometers are useful in determining surface temperatures without actual contact.*

filled with a volatile liquid will tend to expand and straighten out, and we can use this motion to drive a potentiometer.

When selecting a particular transducer, an important parameter to be considered is the time lag. Resistance bulbs and thermistors may be quite slow in response. Thermocouples, because they are very small, may respond much faster. To get really fast response, special thermocouples in vacuum bulbs must be used. These are then pointed at the area of which we wish to know the temperature, and the resultant voltage measured. This is what is called pyrometry; we look at the hot spot from some distance. Optical systems often are used to concentrate heat rays on the cell. Thermistors are also used in some pyrometers. These pyrometers generally are employed only when we deal with great heat, such as blast furnaces, steel converters and similar industrial hot spots.

Some pyrometers use a bolometer as an active element. When used with the proper lens system and *black-body* heat or cold

source reference (Fig. 1107-e) it is possible to measure temperatures quite close to ambient at a considerable distance. Adapted to astronomy it is possible to read the temperature on the surface of distant stars and planets of our solar system. The use of a reference temperature source makes it possible to measure heat or cold.

Level and position indicators

Levels of liquids or solids are a very important measurement in industry. The simplest liquid level transducer is a float which drives a potentiometer, either directly or through gears, belts and
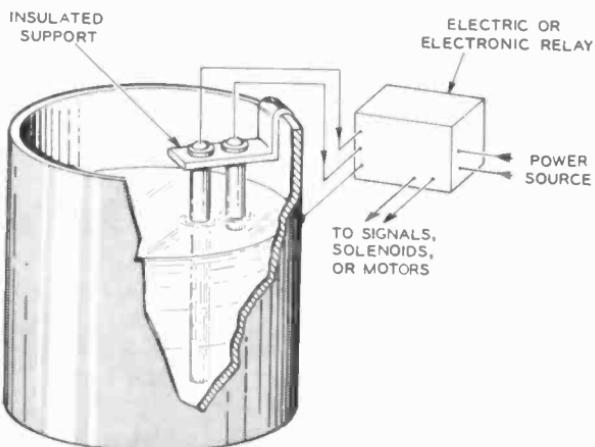
Fig. 1108. *Conductivity method of measuring level. Control can also be activated by using one rod for low level and one for high level as shown.*

pulleys or linkages. These can indicate a limited level change. Similarly limited are photoelectric devices which "read" level glasses. Ingenious designs have been used to extend the range of float-level indicators. The float may be guided through the entire tank-level change on a rod, and the motion transferred to a potentiometer through a cable and pulley system. In another the float is made from iron and rides on a copper tube. Inside the tube is an iron core with variable pitch winding. As the float rides up and down, the effect of having an extra core section (the float) at different winding sections changes the inductance of the winding.

More directly electronic are the conductance and capacitance methods of level indication (Figs. 1108 and 1109). Almost every liquid, except transformer oil which is a very good insulator, is conductive to some extent. If we immerse a set of rods in the liquid and measure the resistance between them, the resistance is an indication of how much of the rod length is inserted in the

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liquid, and thus is a measure of level. Often the tank serves as one electrode.

Capacitive level indication can be done two ways, one for conducting liquids and one for insulating types. In the conducting kind, we simply insert an insulated (coated) rod in the liquid, while the liquid forms the outer "plate" of the capacitor. For insulating liquids, we must insert two concentric electrodes, and
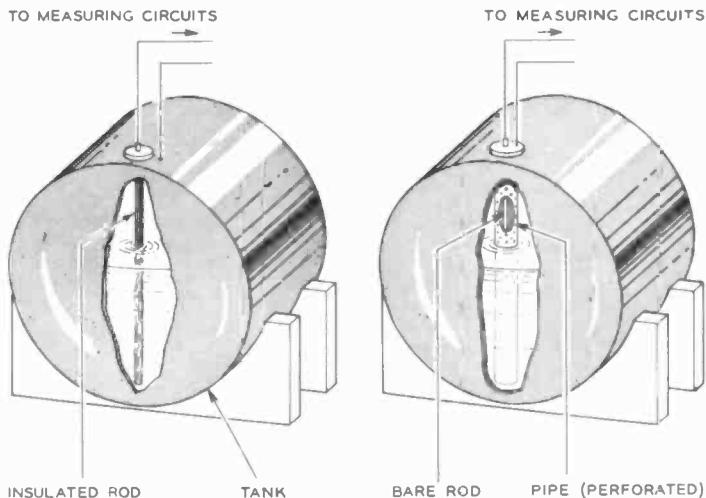
Fig. 1109. *Capacitive methods for measuring level. The insulated rod inserted in the conductive fluid at left serves as one "plate" of a capacitor. At right, the concentric electrodes (insulated from each other) act as a capacitor with changing dielectric when a nonconducting fluid rises between them.*

the capacitance between them is changed by the variation in dielectric as the liquid rises between the electrodes.

More sophisticated are the sonic level indicators. These depend on the principle that, if we send a sound through a boundary layer, a considerable portion of it will be reflected. Thus if we send a sonic pulse from a transducer down onto the surface of a liquid (Fig. 1110), the time needed for the echo to return to the transducer is a measure of the depth of the air space above the liquid. We can, of course, turn things around and send the pulse down through the liquid, but the first method is more accurate. The pulse of sound takes longer to travel through the vapor than the liquid, and therefore it is more accurate to measure the longer time interval through the vapor.

Radioactive level indicators depend on the amount of radiation absorbed by a liquid from a very weak source of radiation (Fig.

1111). A Geiger counter measures the radiation passed through, again a measure of the thickness (level) of the liquid.

The conductance method can be used for solids if the material is finely divided and has some conductance. Often we are merely interested in whether a bin or hopper is full or empty. In that case, we can get by with a simple indicator which has a flexible

TRANSMITTER-RECEIVER

POWER SOURCE

TO INDICATOR RECORDER OR RECEIVER
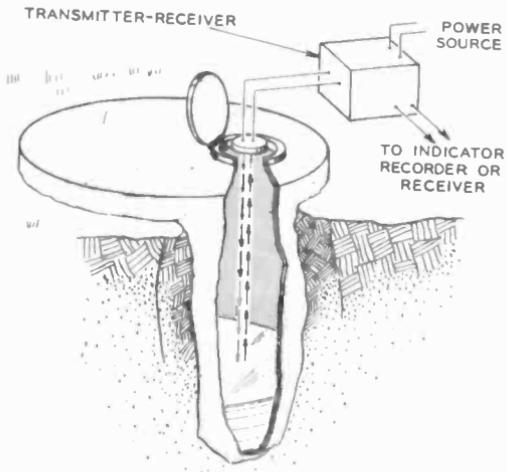
Fig. 1110. *Sonic level indicator sends high-frequency sound pulse to boundary layer where it is reflected. Time difference between pulse and echo is measurement of level. Sound can also be sent through liquid but this is less likely to be accurate.*

diaphragm operating a microswitch as the pressure of the material moves the diaphragm.

Another way to tell the level of solids in a bin is to weigh the bin, and for this we sometimes attach load cells with a strain gage in some structural member of the bin, and read the weight as a function of the strain on the load cells.

Moisture

Moisture can be measured in several simple ways. One uses a resistance electrode formed from a cup with an insulated section of grid inside it, and the entire cup filled with ordinary table salt to just above the grid. Salt will absorb moisture from the air, and the wetter the salt, the greater the conductivity. A simple bridge circuit can be used to measure moisture this way. The salt transducer has the disadvantage that it must be dried out periodically or the salt replaced.

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In place of the salt cup, a moisture-detecting element can be used. A conductor pattern is printed on a special absorbent plastic material. It does not absorb much moisture and it does not need to be dried out with heat.

Another way to measure moisture is to compare the temperature difference (by resistance measurement) between two thermistors,

COUNTER
INSTRUMENT
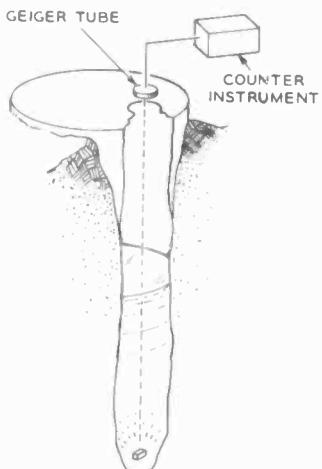
Fig. 1111. *Radioactive level measurement uses low-grade radioactive source, measures absorption by column of liquid.*

one in the air and a second near the first but surrounded by a sleeve which absorbs water from a reservoir. The dry thermometer indicates room temperature. The wet bulb, as it is called, shows a temperature which is dependent on the evaporation of the water from its sleeve, which in turn is dependent on the relative humidity of the surrounding air (Fig. 1112). Error is introduced in the last method by moving air currents, and the wet bulb must be kept out of drafts.

Industrially, if we wish to measure the moisture content of a product, numerous methods are available and the choice depends mostly on the shape, size and average moisture content of the product.

One method is to measure the dielectric constant of the material. For this we must know the moisture content of various samples of the material and make a graph of the dielectric constant vs moisture. After that, we can pass the product between two capacitor plates and measure moisture content that way. This is a particularly handy method when the product is in the form of large or continuous sheets, such as textiles, paper, rubber sheet, plastics, thin wood veneer, etc. If the moisture content of such a product

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is high, a better job can be done by measuring its conductance. For this we use a set of prong electrodes, rugged but small, which are spaced a fixed distance apart. To measure, the small prongs are inserted into the material all the way, and the resistance between them measured. Again some previous calibration is needed. This can easily be done on standardized samples by weighing them: measure a completely dried out sample and weigh with a delicate
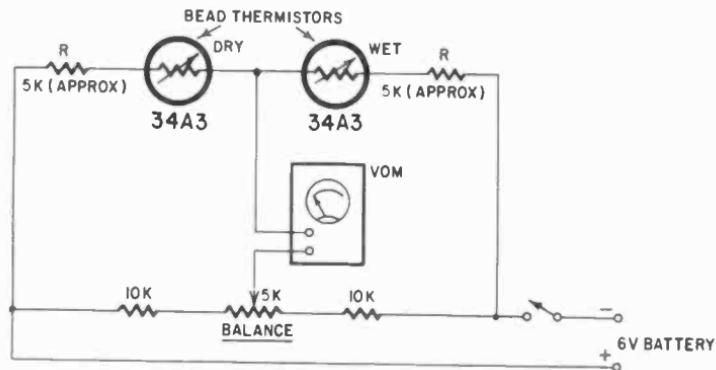
Fig. 1112. *Wet and dry bead thermistors replace thermometers in this humidity test.*

balance the increase in weight with moisture absorption, measure the sample's conductance, and thereafter work with conductance only. Periodically, weighed samples, taken to assure uniformity of other factors in the process, are sufficient to make the measurement reliable.

Viscosity

The viscosity of a liquid or semi-liquid in industry is an extremely important factor. Viscosity tells us, so to speak, how well a liquid will flow. There are easy ways to measure this. Take a paddle on a motor driven shaft, rotate the paddle in the liquid, always at the same depth and we can measure the viscosity in two ways. Either we run the motor at a constant speed and measure the current required to maintain this speed, or we supply a constant current to the motor and measure the resulting speed. Whichever we use, either setup must, of course, be calibrated and measurements would bear a direct relationship to the viscosity of the liquid.

A flow meter (Chapter 6) can tell us about viscosity, if we send the liquid through the meter always with the same "head" pressure. The flow through the meter is then related to the viscosity,

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with some correction for the possible turbulence created by the turbine blades in viscous fluids.

Chemical factors

Numerous chemical factors are important in industry, and there are many ways of measuring them. One of the most important is
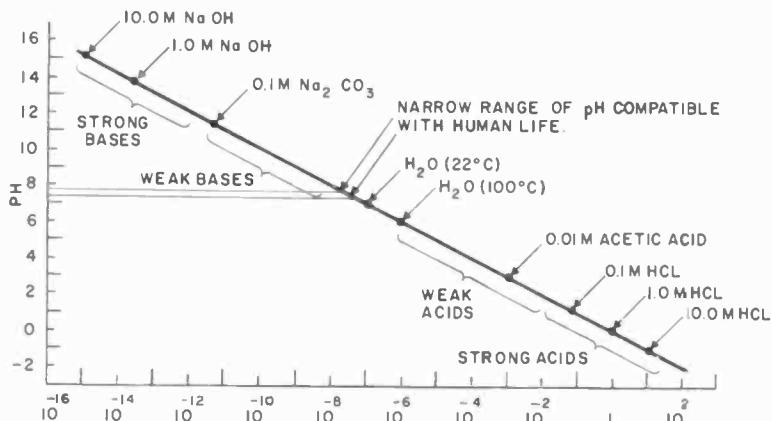
Fig. 1113. *A pH scale is a logarithmic scale used to indicate acidity or alkalinity. A mole (M) is the number of grams per liter as indicated by the substance's molecular weight. Note the extremely small range of pH we can tolerate in our body fluids and stay alive.*

the acidity or the alkalinity of a liquid. The importance of this is dramatically obvious if we look at a pH scale, a scale which logarithmically represents the number of free hydrogen ions in a solution, which is a direct measure of the acidity or alkalinity. On this scale we have arbitrarily called 7 a neutral solution. Numbers larger than 7 indicate alkalinity, smaller numbers acidity. Only a very small variation can be tolerated in our body fluids. We have a pH of 7.3 to 7.5 with an average of 7.4 (Fig. 1113). Beyond this lies death, through coma and the resultant cessation of functions in the acid region, and through convulsions in the alkaline region. Small wonder then that pH measurements are important in industry, very particularly in the food industry.

The pH factor is measured with glass electrodes (Fig. 1114-a). The principle of the glass electrode is sufficiently complex that an entire book has been devoted to it. For simplicity we will use analogy, and try to convey the idea without going deeply into the theory.

If you dip a piece of steel in a solution of copper sulfate crystals, the steel comes out copper-plated. What happens is that some of

the copper sulfate solution dissociates, leaving the solution slightly acid and some copper ions floating about. These copper ions are positive ions. Some of these will get together with the free electrons
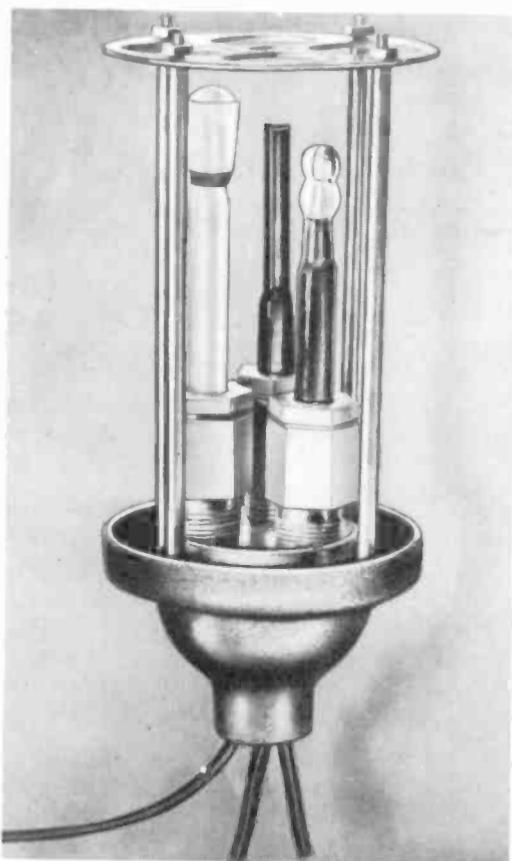
Fig. 1114-a. *Glass electrode assembly used in pH measurements.*

at the surface of the steel, and will form copper atoms and molecules there. You will note that the layer is never very thick, nor is it continuous, as you can see under a microscope. The steel is also partly unplated, and in these places some of the free hydrogen ions in the solution have combined with the iron electrons to form hydrogen. In other words a sort of migration of ions takes place on the surface of the steel.

The glass electrode consists of a very thin glass bulb in a weak

acid (usually hydrochloric solution). Inside the glass bulb is another bulb with a strong potassium chloride solution in which a mercuric electrode is making contact. At the surface of the mercury, mercuric chloride is created, which is very high in free hydrogen ions. Thus anything happening in the outer glass bulb, as

HIGH IMPEDANCE POTENTIAL MEASURING INSTRUMENT CALIBRATED IN pH UNITS

CALOMEL REFERENCE ELECTRODE

GLASS ELECTRODE

PLATINUM WIRE

MERCURY

BUFFER SOLUTION

MERCURY

CALOMEL

pH SENSITIVE GLASS BULB

MERCURY-CALOMEL PASTE

SATURATED KCl

GLASS WOOL

LIQUID JUNCTION

ASBESTOS FIBER
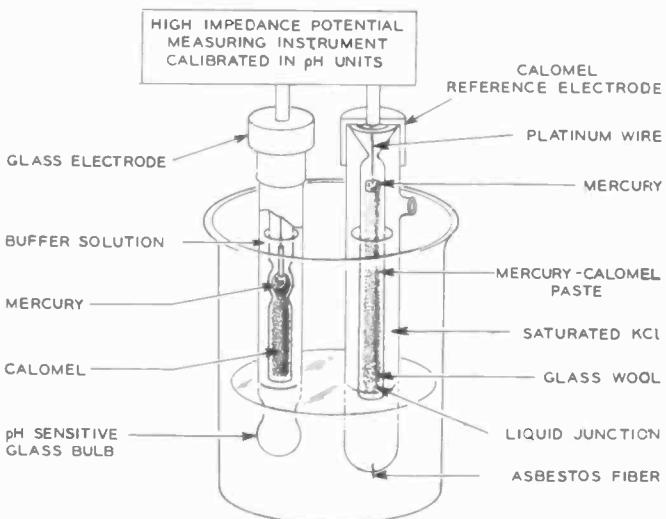
Fig. 1114-b. *The glass and calomel electrodes used in pH measurements are shown here in diagrammatic form.*

far as ions migration is concerned, does not affect the electrode contact.

The electron–ion combination (remember our example of the steel dipped into copper sulfate) releases some energy and this energy appears as a potential across the boundary layers of the electrode. Thus if we could (this is of course impossible) put another electrode in the solution which would not have any potential created at its surface, we could measure the potential at the active electrode. In the glass electrode (glass is permeable to ions) a potential is created by the ion migration taking place. The resistance of even such a very thin glass bulb is very high, and we must use special electronic means to measure it. But more than that, we must do something about the other electrode in the system. Rather than try to find an electrode which is completely inert, which we would probably never find, we go the other way and select one which always can be depended upon to produce the same potential at its surface. Such an electrode is the calomel electrode (Fig. 1114-b).

Calomel is KCL, potassium chloride, mercuric. This is so rich in hydrogen ions that whatever happens in the solution is not going to affect it particularly. The contact to the solution is made through the little asbestos fiber in the bottom of the electrode, which will soon be saturated with the solution we dip it in. The

LEADS   SEAL   AIR VENT   PLATINUM ELECTRODES
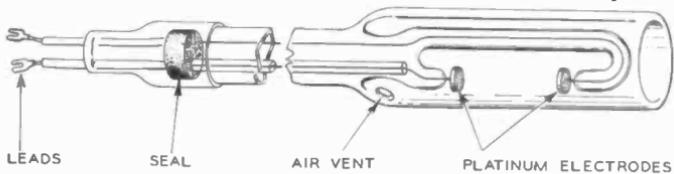
Fig. 1115. *Conductivity-measurement electrode. Distance between platinum electrodes is fixed. Vents assure that the cell fills with solution when immersed. Conductivity is characteristic of solutions of certain concentration and also is a factor in the purity measurement of water.*

calomel electrode always produces 0.282 volt of potential at 22°C, slightly more at higher temperatures, and this gives us a handy reference for pH measurements. We now have our other electrode.

To measure the voltage developed by the electrodes we must use a very sensitive vtvm, since the resistance of the electrode is as much as 100 megohms or more and "loading" the electrodes will polarize them (the cell will act as a battery) and they recover from this very slowly. We use a vtvm which is similar to an electrometer in which the tube appears to be inverted. This circuit can measure currents on the order of 10^{-13} ampere, (.0000000000001 ampere), and this current across a very high resistance will provide the potential for measurement. Potentiometer type recorders can be used which are so designed that their input does not load the circuit, simply by comparing the potential in a bridge circuit. With the bridge carefully adjusted to null, no current can flow.

The pH measurement is important in many industries beside the food, paper and textile, chemical, oil, cosmetics and drug industries, as well as medicine and biology.

Potentiometric measurements also characterize solutions other than acids and bases, and are made in a similar manner, often with the calomel electrode for reference and a silver—silver chloride one as the active element. Glass electrodes are also used.

Another measurement which will chemically classify a solution is conductance, and it is also used extensively in industry. Any organic material in the purest water will raise the conductivity. Conductivity measurements, alongside of pH measurement, are important in analyzing both drinking water and liquid coming

from sewage disposal plants. Fig. 1115 shows the electrode used for this.

To make the conductivity measurement meaningful we must either control temperature or make corrections for it. Conductivity measurement is also very important in the evaluation of steam boiler water, for too many solids or salts in the boiler would clog tubes. Special "salinity" meters, which are in effect

Fig. 1116. *Fuel-vapor detector is characteristic of a class of these instruments used to detect gases and vapors by cooling effect on a heated electrode.* (Heath Co.)

conductivity meters, are installed in all boiler installations where water is "hard." Chemicals can be added to the water to offset the hardness, but we must first have a measurement of how much to add. On any steam vessel, the salinity indicator is an important item in the engine room where boilers are fed with evaporated salt water, which may yet contain a goodly percentage of salt even when it is considered "fit" for the boilers.

Other chemical factors we can establish with transducers include the composition of gases and vapors. Gas or vapor, particularly in the hydrocarbon group, can often be identified by the cooling effect it exerts on a heated electrode wire. Thus, by immersing a hot platinum wire in the gas or vapor, we can determine

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its composition by measuring the resistance of the hot wire. Again, humidity and temperature will have their effect, but this is usually a qualitative measurement. Elaborate apparatus can be designed for quantitative measurement in this manner.

This is the principle of operation used in the Heath gasoline-vapor detector shown in Fig. 1116. Numerous industrial vapor detectors operate on a similar principle.

Another method of analyzing gases and vapors is with the infra-red spectrograph. There we pass a certain range of frequencies in the infrared region through a container or transparent pipe filled with the gases, and measure by optical methods which of the frequencies were absorbed most. Fig. 1117 is a set of typical infra-red spectrograms of hydrocarbons. Each gas has a "picture" in in-frared which is as characteristic and as different as fingerprints of human beings.

A third method of gas analyses is quite similar except that it uses ultraviolet light to give a characteristic spectrum. A fourth method uses microwaves in the same fashion.

Also used for gas analysis is the mass-spectrometer. Briefly, a mass spectrometer creates ions of the gas and accelerates them down a bent tube, uing a magnetic field to bend the ion stream. Since the ions have a considerable velocity, ions of different weights will bend more or less, with the same magnetic bending forces, and will strike the wall of the tube in different places. In several places we will have collectors, where we can measure the relative numbers of ions of different weights, and thus we can establish the composi-tion of the gas.

Gases which often need to be analyzed particularly include exhaust gases of a furnace, oven or any other process using high temperature. The presence of carbon monoxide and carbon di-oxide should be known in many cases. These can be detected with devices similar to the hot-wire platinum detector, except that in the place of the hot wire we use a heated thermistor; with a com-parison thermistor protected from the gas, which is at the same temperature. The difference between the thermistor resistances will indicate the presence of certain gases.

We have discussed only a few transducers; there are many others; There are several books devoted entirely to transducers, none of which succeeds in treating *all* transducers. There is one for meas-uring practically any physical and chemical quantity from the consistency of paper pulp to the impact required to break alumi-num foil or the tension that can be sustained by a nylon thread.

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Every industry has its own particular measurement and control problems, and each of them may develop some special transducers for their purposes, although many will use a group of standardized types such as we have shown.

In general, the transducer applicable to a given problem must be capable of producing a varying electrical signal with sufficient accuracy and repeatability to be useful for measurement or control. The signal need not be large; we have very sensitive and accurate recording instruments. But, preferably, it must be linear
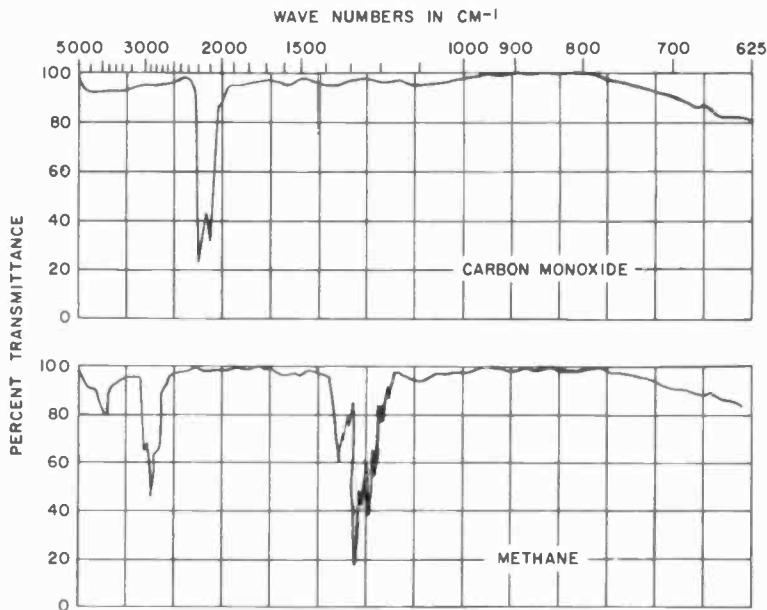
Fig. 1117. *Infrared spectra can identify a great number of substances accurately. This is particularly true of hydrocarbon gases and vapors. Many other substances have characteristics in the microwave and ultraviolet spectrums.*

with respect to the variable to be measured, or follow some definite mathematical relationship to make the recording as meaningful and as simple to read as possible.

Generally transducers are designed to require a minimum of service and maintenance. However, remember that, in effect, the transducer is like an extension of the instrument, and that the accuracy of the instrument can be no greater than the accuracy of the transducer. Transducers containing delicate parts such as crystals should not be subjected to mechanical shock. Delicate mechanical parts can also be damaged quite easily. Transducers

must be kept clean, particularly their sensing surfaces. A photocell sooted up on the outside is not going to function properly, light just won't get through. A diaphragm thickly encrusted with salt will not give you an accurate pressure reading. So cleanliness is important, as is protection from unwarrented mechanical damage. Other than that, not much need be done to keep transducers working.

Keeping them calibrated is another matter. Most transducers will need periodic calibration if high accuracy is to be maintained. For example, strain gages will "creep," meaning that the cement holding the gage to the structural member may be elastic to a certain extent and may cause the gage to take a "set" so that after a particularly heavy load the gage will lose calibration. A Bourdon tube or bellows after a certain number of expansions and contractions will show a very slight change in the characteristics of the metal bellows, with the resulting in change in calibration. Most transducers are subject to wear. It depends to a great extent on the mechanical wear and chemical forces the transducer is subjected to daily. Those using wirewound potentiometers will after a time show enough wear on the pot to require recalibration, and so on. Common sense will dictate what must be done.

Miscellaneous industrial applications of electronics

We have tried to give you a cross-section of industrial applications, most of which are different from the more familiar communications practices. Items such as electronic counters, photoelectric static controls, and thyratron circuits are different enough to occupy separate chapters. However these do not embrace all of industrial electronics by any means.

Many instrumentation and measurement practices in industry are directly borrowed from communications applications. Thus telemetering is a very common thing in industrial electronics. Often, available wires are used for telemetering purposes, and this is akin to the well known wireless intercom systems. We may even use such systems for control of equipment, although usually, when we start investing enough money to automate equipment, we can also afford the extra wires needed. But it is not always practical. For example, one need of most industries is water. If a source of water supply is many miles from the main plant, it may be more profitable to handle the well-pump control by radio rather than by wire. The opportunities opened up by the new FCC rules which allow 30 watts of control power on 27.255 mc may well change the balance between the economics of wire and radio control in such instances.
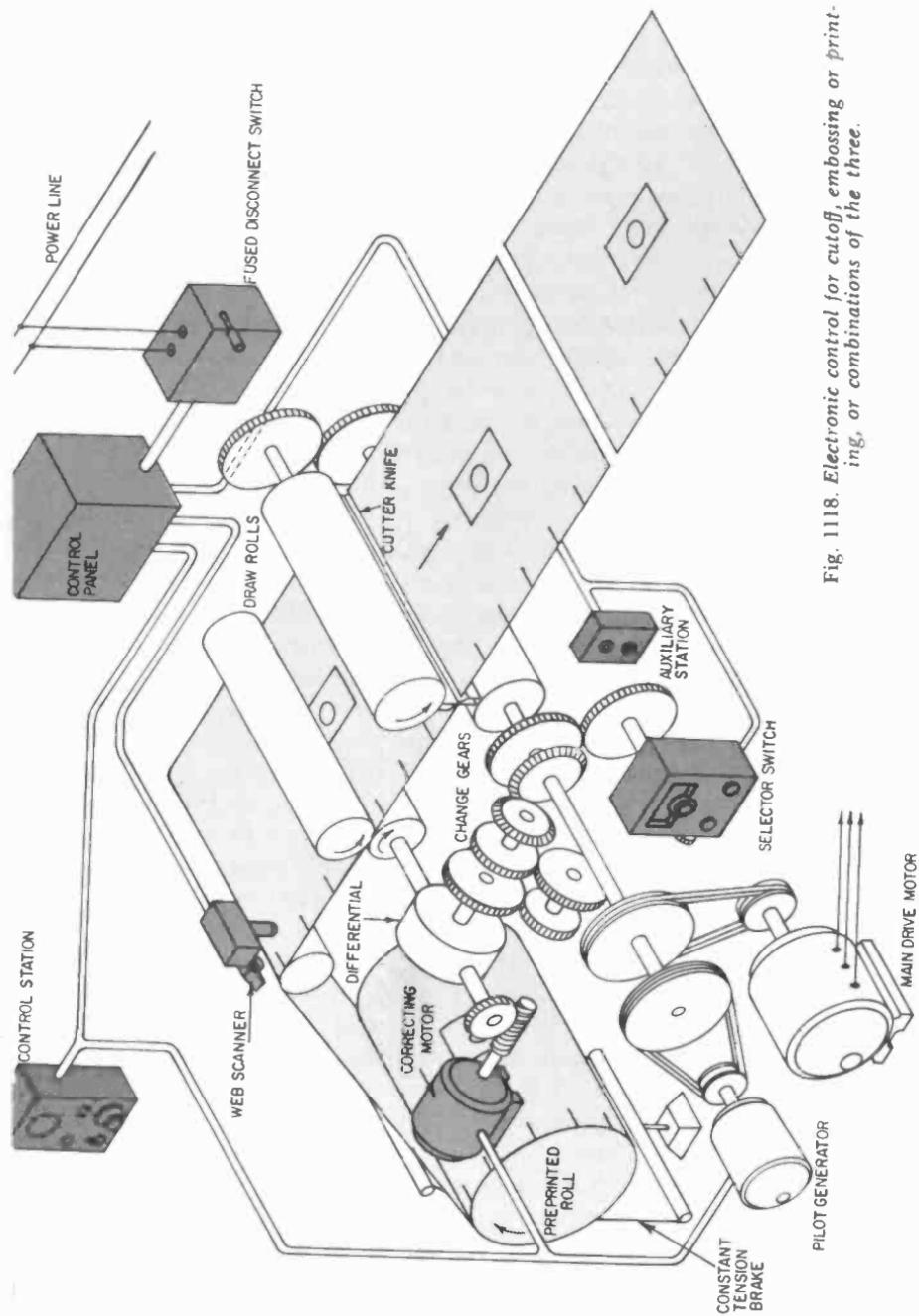
Fig. 1118. *Electronic control for cutoff, embossing or printing, or combinations of the three.*

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One very common application not yet specifically discussed is welding control. This is the control of welding current by thyratrons or ignitrons. It is similar in many ways to the Thymotrol motor-control circuit of Chapter 7. For arc welding, we use dc generators capable of delivering very high currents at a relatively low voltage. The voltage and the current *both* are important to the quality of the weld. Thus with the type of motor control represented by the Thymotrol we can control both the driving motor (often a three-phase wound-rotor induction type) for the generator and the dc circuits of the generator.

In contrast to arc welding, resistance welding is usually done with ac. Here the weld is made by passing a very high current through the limited section of the materials to be welded, which is contacted by the electrodes, and the I^2R losses that are developed weld the material by heating the joint to a liquid state. The pressure of the electrodes help complete the fusion. The current is obtained from a transformer, often with but a single turn in the secondary. The secondary current is controlled by controlling the current flow in the primary of the welding transformer.

Thyratrons and ignitrons are used as switches in this case. As long as the thyratron fires with each cycle of 60-cycle current, we have a maximum current through the transformer. By controlling the firing cycle of the thyratrons or ignitrons, we can control the average current through the transformer primary on each half-cycle. By timing the firing so that the thyratron will fire on only some specific number of cycles per second, we can control the *duration* of the welding current. Thus for some applications such as spot welding, which is a form of resistance welding, we may use just a single pulse, depending on the material, the thickness of the work, etc. For seam welding, when the electrodes are likely to be a pair of wheels, we have a series of pulses which keeps on as long as there is material in the electrodes. In "stitching," the pulses are widely spaced; in continuous seam welding, the pulses come fast in relation to the motion of the material in the electrodes.

Electronic control in welding is an important application of industrial electronics, and one of the earliest. We cannot treat the subject in detail here, but many publications are available from manufacturers which tell the story adequately, and these can be obtained on request.

There is hardly a major industry which has not felt the impact or has not embraced joyfully the possibilities of electronics. One example is printing. There, speed and accuracy are two major requirements for the adjustment of position, pressure and tension of

type, rollers and paper. This the industry has in common with many others which involves the imprinting of figures, the punching of holes, the stamping of shapes out of continuous strips of material.

Fig. 1118 shows an arrangement for accurate registry of pieces of a roll of material to be cut into sections. The system input is the printed marks on the roll, which are scanned by the "web" scanner for the accurate positioning of the material to be

Fig. 1119. *Lens turret on this camera allows rapid selection of field of view.*

cut. Similarly, the positioning of material for printing and embossing could be handled by this kind of a system. The lateral position of the material on the rolls can also be checked and corrected by such a scanner system. If the light reaches the photocell after being partially blocked by the web, the output of the photocell will be a continuously varying signal, which can be used for the control of the web position. Another way to do the job is by turning on the cell only or obtaining from the cell a signal when a register mark passes the photocell. If the register mark does not cover the entire "seeing" area of the cell, the signal will be in proportion to the amount of register mark that passes by—a pulsed system, in other words. Such side and longitudinal position photoelectric controls are also used in printing presses, where registry must be extremely accurate when three or four colors are printed successively on the same sheet of paper.

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Such register controls are also used in the printing of etched-circuit boards when the image to be left after the etching is first printed in resist type ink. The sheets of laminate are usually printed with numerous copies of a circuit to be etched, and is not cut into individual circuit boards until after the etching has been done. Registry is required not only for the multiple printing job but also for the cutting process. For mass production, the manufacturer cannot rely on the accuracy or the "squareness" of the raw sheet, and register marks are often provided on the laminate to position it properly for printing and sawing.

An entire electronic printing process, xerography depends on the depositing of charged carbon particles on a negatively charged electronic "image." The image is put on the paper by exposing it to ultraviolet light. The paper is specially treated. The process can be used for more permanent printing by fusing the carbon particles into solid "type."

Another way that electronics is used in "typesetting" is in a photographic process for producing "typeset" material. In this equipment, photographic records of many type fonts are stored on film. The proper font and letters, are selected electronically as the operator "types" out copy.

Electronics is also used in engraving. A machine has been invented which photoelectrically scans a color image, and electronically selects the portions of the image which belong on the various (three or four) color plates from which the final image is to be printed.

Industrial television

One of the important subjects in industrial electronics, but one which is fortunately not far removed from the average technician's experience is ITV, industrial television.

Two basic systems are in use. In one, the camera or its control unit generates the necessary signals, and impresses them on a carrier, which can then be received by any standard television receiver, but the signal is supplied to the receiver over a coaxial cable. Considering the sensitivity of the average TV receiver, it is obvious that the signal level in such a system can be very low. This is in one sense an advantage, and in another sense a disadvantage. We can work with low signal levels, but we must be very meticulous about shielding out any unwanted noise which could amount to a significant part of the signal.

The other system uses a special camera and control unit connected directly to monitors designed to work from the camera and
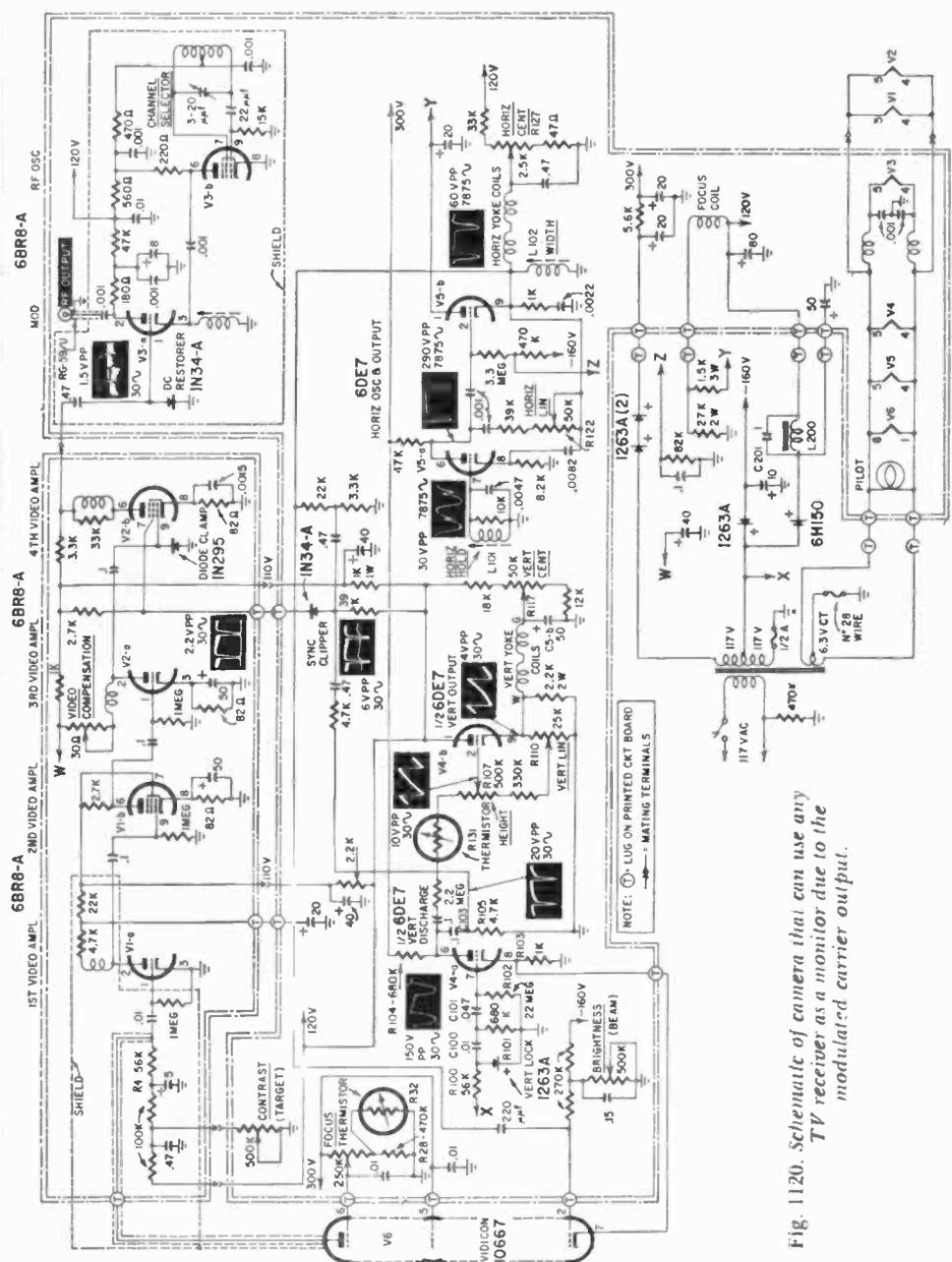
Fig. 1120. Schematic of camera that can use any TV receiver as a monitor due to the modulated carrier output.

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control unit only. In this system, no rf carrier is generated. The sync and video signals may be transmitted over a single coax or over separate cables. This system has the advantage that it can be used in an area of interference with greater impunity, but it demands special monitors.

However, the monitors are not as complicated as a TV receiver,
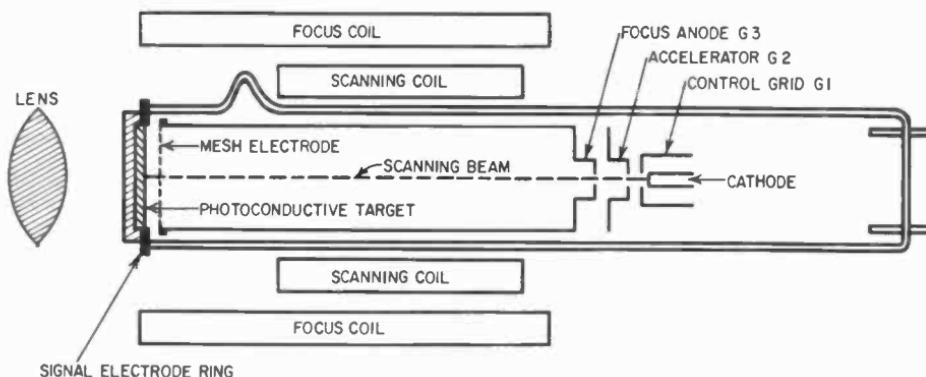
Fig. 1121. *Diagram shows the basic construction of vidicon camera tube and the positioning of the associated components.*

for the entire tuner, if and sound sections are left out. If the sync signals are applied over a separate cable, even the sync separation circuits are not needed, and the monitors become more simple. Another advantage of the system is that the synchronization between the camera and the monitors is direct and positive, and we can use a system with more lines to get greater definition—if we so desire. The number of horizontal lines used in commercial television is a compromise between definition and economy, and, although definition and clarity are acceptable for entertainment purposes, some scientific work could require greater definition. For example, where we use the ITV system to broadcast (for purposes of instruction) the image seen by a camera through a microscope, definition becomes a crucial factor.

ITV is not complex in terms of circuitry compared with the normal home TV sets; in fact, it usually is simpler. Fig. 1119 shows a typical camera of the type that can be used with any TV receiver, and Fig. 1120 is the schematic diagram of one of them. In this diagram we have a video amplifier and an rf oscillator which is modulated with the video signal. The oscillator produces a carrier which can, usually, be received on the lower channels (2 to 6) of the TV receiver. In addition, there are cir-

cuits to generate the vertical and horizontal deflection for the camera tube (Fig. 1121) which also serve to provide the sync and blanking signals for the carrier. The camera tube can be one of several types. The one shown in Fig. 1121 is a Vidicon, a photoconductive tube. As the light hits the photoconductive layer in the tube, the current at that point from the beam is greater, and consequently the signal across the load resistor is created. The rf composite signal from the camera unit is like the one produced for commercial TV transmissions.
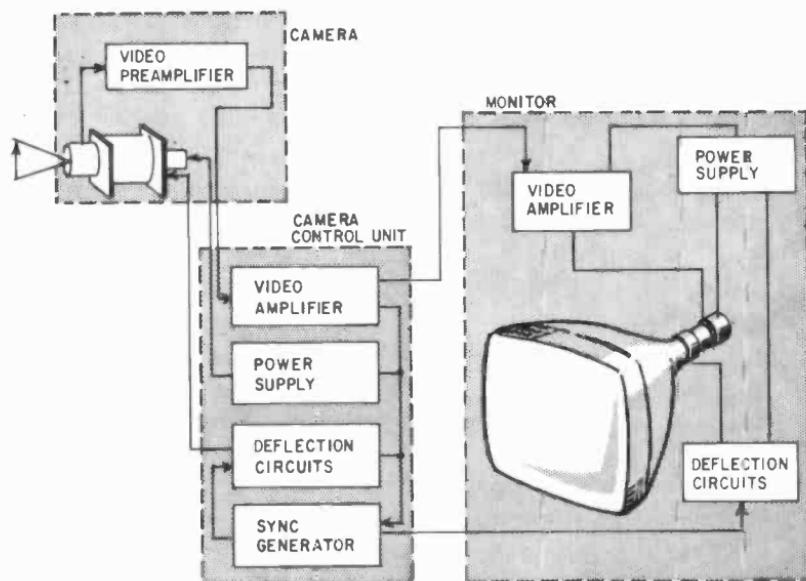
Fig. 1122. *This block diagram shows the simplification when rf carrier is eliminated.*

The other system, using no rf carrier, is shown in the block diagram of Fig. 1122. This system contains a video amplifier, the horizontal and vertical sync and deflection circuits for the picture tube, and the power supplies that are all relatively conventional. There is no rf section, no if section, etc. The camera contains only the preamplifier, while the control unit contains the necessary sync pulse generators, deflection circuits and the main video amplifier.

This kind of equipment has been developed to include all

kinds of circuits to make the image a more precise reproduction of what the camera sees. Thus correction is made automatically for aperture of camera lens, which in effect means that electronically we compensate for the amount of light falling on the object we are looking at. A wide latitude of light intensity is provided for, so that the image on the monitor will be clear under many different lighting conditions, without becoming blotchy or all white—in other words, without loss of detail. In scientific work particularly, but also in industrial applications, this can be of extreme importance.

Maintenance of an ITV system is not greatly different from TV service work, but remember that you are now dealing with something that is not merely entertainment, but something that is depended on by the owner to provide him with certain necessary functions and that interruption of these functions may be costly to him.

Maintenance and troubleshooting data are always supplied with the equipment, and will vary so much from one environmental situation to the next that we cannot reasonably generalize about it. Be familiar with the equipment maintenance procedures *before* something happens.

Another area of industrial electronics not entirely foreign to the communications technician is the intercommunications network. Here special requirements are demanded by the industrial situation, which is often noisy and sometimes very hard on the equipment. But apart from special enclosures and sometimes more power, the equipment is very similar to the commercial variety. Where the system is to be used only for voice, (paging and instructions), a frequency response of 300 to 3,000 cycles is quite adequate for intelligibility. But where the system is also to be used for music—and it will be in many industrial situations, particularly those involving a great deal of monotonous work— the frequency response should range from 100 to 8,000 cycles. All the factors of coverage, installation and protection of public address equipment will apply here, and the well known constant-voltage system is as popular for industrial systems. As you can see from these few examples, industrial electronics is an enormous field indeed. There are so many applications that we could fill many volumes trying to describe them all. Control of railway signals, radio communications within and around a plant, industrial X-ray controls, special instruments in the automotive industry, truck weighing, frequency changing for high-frequency

lighting, textile mill controls, thickness gaging and fault detection in many materials of many types, wood gluing, automatic door openers, automatic elevator controls, fire and intrusion alarm systems, detection of underground pipes, automatic gas detection in mines, the automatic production and testing of electronic equipment, just to grab a handful out of the bag. All are part of industrial electronics. You will find, however, that each industry has uses for a relatively limited kind of equipment, and that complete knowledge of all equipment is almost an impossibility anyway.

The sanest approach to getting into the electronics servicing business on an industrial level is to survey carefully the area in which you wish to operate. Find out what equipment is being used, what kinds are likely to be used in the near future, and what should be used for modernization. If you are prepared to deal with most of them, you will probably have few difficulties in carrying out your plans.

Microwave cooking

The use of these ovens solely for the rapid cooking or reheating of food removes this application of electronics from the group of industrial dielectric and induction heaters of Chapter 3. Often new devices get their names from some similarity to a previous product or process. The trade name of a device may often become a popular reference name for all like units simply because it was the first or most advertised. For instance, the common refrigerator was long referred to by a popular trade name. Here we find *radar* led to *radar* cooking and *Radarange*.

While microwave cooking is a small field at the present time, there is much room for expansion. The oven is primarily a dielectric heating device since the heat occurs internally. This presents an entirely new problem in cooking. Microwave-cooked food has been compared to boiled food. Roasts do not brown. Cakes and breads do not have the familiar crust. Steaks and roasts are always well done.

The advent of completely frozen meals on a tray is a perfect application for microwave cooking, or rather reheating. Solid frozen frankfurters can be converted to steaming hot food in less than 2 minutes, and other foods take about as long. Conceivably the familiar steamtable could be replaced with a deep-freeze chest. Menu items could be preformed into portions and frozen. When all the items had been assembled on a serving dish, they would be inserted into the oven, to emerge thoroughly reheated. The problems of keeping food palatable on a steamtable would be a thing
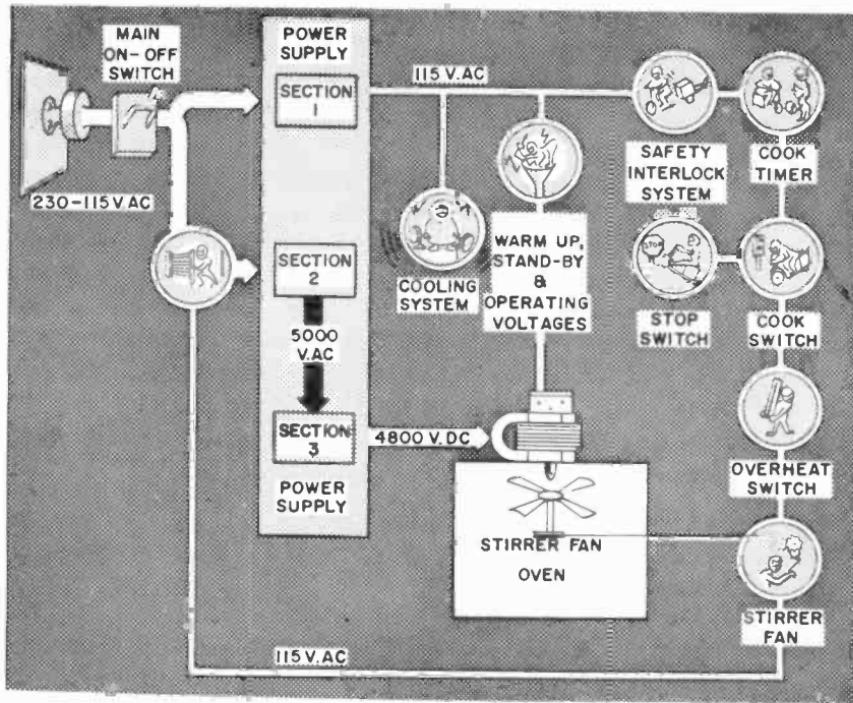
Fig. 1123. *All microwave cooking devices have circuitry similar to this, outlined in block form.* (Raytheon Corp.)

of the past. There would be no waste in unserved foods. Menus could be expanded to include many additional treats. The "daily special" would no longer exist except for merchandising and advertising purposes.

Radar cooking equipment utilizes the same band of microwave frequencies as radar equipment, and has similar generating circuits and components. There are a number of radar type ovens, but, since all of them operate on the same principle (Fig. 1123) we will use the Radarange as a typical example. Fig. 1124 shows the schematic diagram. The heart of the circuit is the magnetron.

The magnetron is complicated in function although simple in appearance. The symbol for it shows a diode (although it has two or more anodes) and a single cathode, and sometimes the anode has a number of cavities built into it. An electron traveling through a magnetic field will have its path altered in relation to

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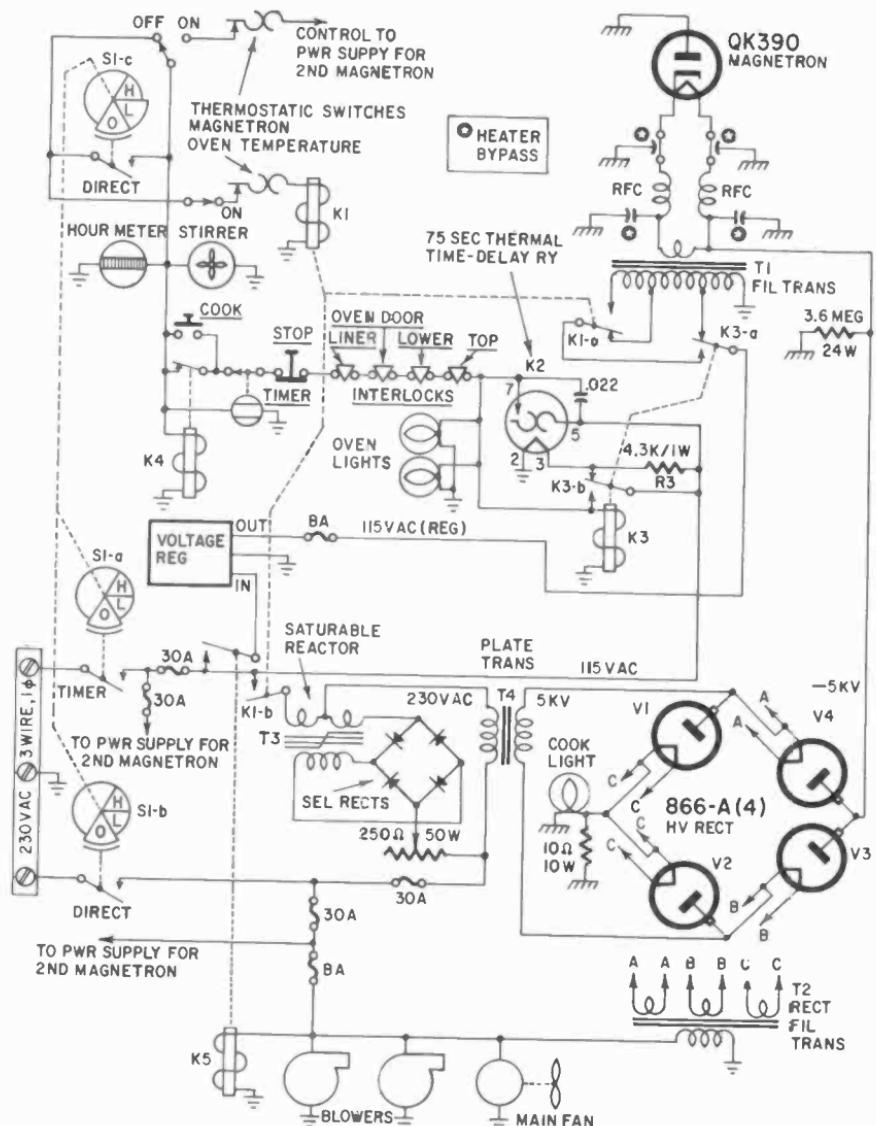
Fig. 1124. *Circuitry of model 1161A Radarange is simple when compared to TV receiver.* (Raytheon Corp.)

the velocity of the electron and the strength of the magnetic field. In the magnetron, specially shaped to fit easily between pole pieces, a magnetic field with lines of force parallel to the cathode of the tube, is established—in other words, an axial magnetic field. Fig.

1125 shows, symbolically, a magnetron with two anodes. The lines of force of the magnetic field would be perpendicular to the paper, with the North pole above and the South pole below it.

Note what happens to an electron starting out from the cathode. If the field is strong and plate voltage (and thus electron velocity) low, the path of the electron will curve most (Fig. 1126). The next curve is the result of a very high plate potential. Then is shown the path of an electron traveling in a little stronger field (with less plate potential), and, finally, if we make the field strong enough or the plate voltage low enough, the electron never gets to the anode and instead circles the cathode. In this case, no electrons reach the plate, and the tube is in a "cutoff" condition. In opera-
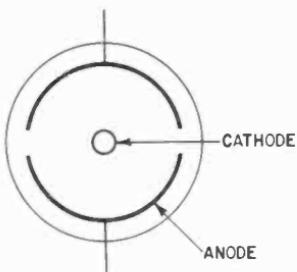
Fig. 1125. *Basic structure of magnetron is simple, with two plates and a heated cathode.*

tion, the tube is actually in this cutoff condition, although some other factors must be taken into account, as will be shown.

If we have an equal plate voltage on the two anodes, the potential at any point between the plates and the cathode is the same as at any other point located at the same distance from the cathode. If we connect these points graphically in a diagram, we would show so-called equipotential lines, concentric circles about the cathode with each corresponding to a given potential. This is, of course, an imaginary concept since the potential change is smooth and continuous.

If we lower the voltage on one of the anodes, the equipotential lines would be distorted as shown in Fig. 1127. An electron now setting out from the cathode will start with a relatively high potential pulling it out, while the magnetic field tends to curve it back. When an electron returns to the higher potential part of the field, it will not penetrate as deeply and will again be curved away. Instead of getting closer and closer to the plate toward which it started, it keeps drifting farther and farther, and finally ends up on the anode with the lower potential.

By lowering the plate potential of one anode, we increase the current to it. In other words, we have a negative resistance characteristic which we can exploit for oscillation purposes. This is usually done by using a resonant circuit, which could be a *Lecherwire* system but a cavity type resonant circuit is more practical at higher frequencies. In another method, referred to as "electronic" operation, the electrons, in the cutoff condition, orbit the cathode (Fig. 1126). The electrons are orbited around the cathode at a velocity which brings them past each anode resonant cavity under
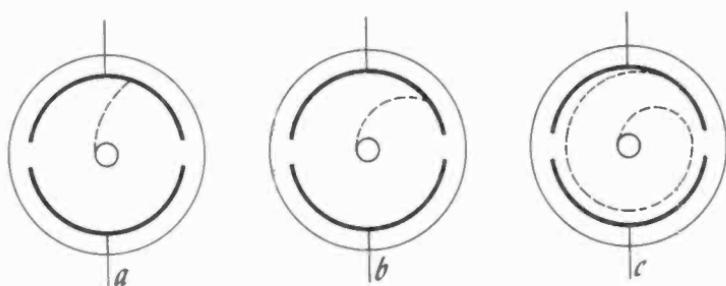
Fig. 1126. *Three conditions of electron path in magnetron. Variations are due to changes in magnetic field or applied voltages.*

the same magnetic field conditions (in other words, the transit time is exactly one full cycle of the cavity's resonant frequency), the electron will induce a field change in the cavity at each turn, thereby exciting it. In a multi-cavity anode, an electron excites each cavity in turn.

The orbit of the electron will be affected by the field in the cavity, since the electron gives up kinetic energy to the cavity field, which is, in effect, "lessened" by the electron and the latter is then more easily deflected from the anode. Thus, we have a multitude of asymmetrical orbits around the cathode, and a continuous interchange of energy between the fields in the cavities and the circulating electrons.

This type of oscillation, named "dynatron," can take place in different "modes." The relationship between the lopsided orbits and the cavity fields can be arranged in different ways by changing the magnetic field and the plate potentials. The energy in the cavities is taken off by stubs, which in turn excite a short waveguide. In the Radarange, this energy is emitted directly from the waveguide to the food being cooked.

Note that the voltage of the power supply at the lower right

of Fig. 1124 is regulated by magnetic amplifier T3. The magnetron is extremely voltage sensitive. As in dielectric generators, no filtering is required. In fact, a 60-cycle input is intentionally introduced into the circuit by T2 to prevent the magnetron from oscillating continuously, which would overheat it and might even melt the glass.

The schematic diagram (Fig. 1124) shows power is supplied to the unit through the terminal block and oven control switch S1. When this is turned on, power is first supplied to the rectifier filament transformer T2, time-delay relay K2 and magnetron filament transformer T1. The thermal element of K2 (supplied with 115 volts) delays the rest of the cycle by 75 seconds to assure properly heated filaments. When K2 finally closes its contacts, relay K3 is energized and latches in. The filament voltage on the magnetron decreases to 9 volts (it is 11 volts during warmup), and K3 applies 115 volts (through all the safety interlocks) to the stop switch, cook

CIRCULAR
EQUIPOTENTIAL
LINE

DISTORTED
EQUIPOTENTIAL
LINE
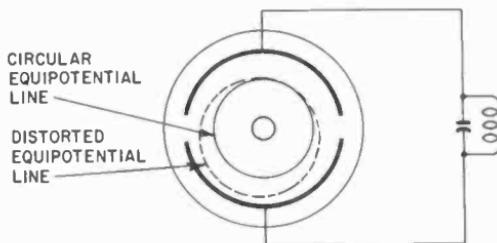
Fig. 1127. *Distortion of equipotential lines by lowering the B-plus on one anode will cause electrons to "fall" toward that anode.*

switch and cooking timer. This puts the range on standby, ready to cook with blowers running, all filaments warm and oven lamps lighted. When the timer is set, 115 volts is applied to the timer motor and the coil of K4 closes its contacts. The stirrer motor is now running.

On the LO position of switch S1, only one of the magnetrons is used. In the HI position, both magnetron power supplies are energized. In both positions, relay K1 is energized. This reduces the magnetron filament to 7 volts during operation. Also, power transformer T4 is energized through saturable reactor T3. The secondary of this reactor, which is in series with the 230-volt supply voltage, is also energized. Voltage from T4 is automatically regulated by the reactor.

Notice that the rectifiers have no filter capacitor on the output.

The power supply thus provides 4,800 volts dc, pulsed at 120 cycles. When K1 closes, the 4,800-volt supply is connected to the magnetrons, which then generate 2,450 megacycles.

Notice also that the supply is 4,800 volts negative, allowing the anodes of the magnetron to be grounded. Because these anodes project, inside, through the top of the oven, this is a safety feature — an operator putting his hand in the oven to insert and remove food will never contact the fatal high voltage from this supply. The magnetrons are cooled by blowers. Failure to cool the magnetron would almost certainly destroy it through overheating. Each magnetron produces 800 watts of power, and the entire range, 1,600. (On LO we have just half, or 800 watts).

When initially installed, the range is tested by heating a quart of water in a plastic container. If the range raises the water temperature 45° to 47° in 2 minutes, it is working at full power. Anything more or less than that calls for readjustment.

The service manual which comes with the range is very clear and explicit about maintenance, and no purpose would be served in treating it in detail here. Only some of the highlights will be discussed.

The interlock switches particularly need a periodic check, for a sticking switch might keep the range from operating. Or, worse, it might allow the range to operate with the door open, spraying the operator with rf energy. Although this is seldom fatal, it can cause nasty burns. If the energy can cook a steak from the inside out in minutes, it can certainly raise the temperature of human tissue dangerously.

Operation with the oven empty is likely to raise the temperature of the magnetrons glass top to the breaking point. Never operate such an oven empty. Even a plastic bag of water is better than nothing.

Periodically, the cooling-air filter must be cleaned. Other cooking besides that going on in the range will not take long to foul up the filter with grease. Filters are cleaned with warm water, soap or detergent and a stiff brush.

Three kinds of magnetron trouble can develop: a gassy, a nonstarting or a runaway magnetron. Gassiness may result from a minute leak in the glass-to-metal seal. A gassy magnetron will not generate microwaves and can be recognized by its using 500 ma of cook-light current rather than the usual 320 ma. This is measured at the cook light, as the instructions will make clear. Gassy magnetrons must be replaced.

A runaway magnetron may be caused by insufficient cooling and will be detected in the same way, by measuring the current.

A nonstarting magnetron may result from insufficient filament voltage possibly due to poor filament connections. Cleaning the connections and refastening is often a cure.

Unstable readings on the milliameter indicates arcing, and causes an audible buzz in the oven. This calls for replacement of the magnetron, if the arcing is internal.

Apart from the magnetron, the oven contains no service-prone parts. Rectifiers should be checked periodically. The magnetron is quite voltage-sensitive, and any drastic reduction in B-supply causes failure. Be particularly alert to proper operation of cooling fans. Nothing could do damage, more quickly, than inadequate cooling, and it, like the overheating of the magnetron glass, is the kind of damage no fuses can protect against.

For other than the magnetrons, routine electrical equipment maintenance applies to the Radarange.

12 *

<div align="right">

service
instruments
and
practices

</div>

INDUSTRIAL electronics servicing has many things in common with regular communications and radio—TV servicing. But there are also some very important differences. If you service a TV set or a radio and the set subsequently conks out, it becomes merely a recall. This will cause a certain amount of annoyance to the customer, and it may cost you your profit. Too many recalls is poor public relations, and will reflect on the business. But in industry you may never get the chance for a recall.

An industry uses electronic equipment in its processes when it is a necessity, a time and money saver, or a safety device which is depended on. The equipment will often be rugged and reliable to begin with. When it becomes defective, it is likely to hold up production. Thus speed is essential in practically all cases. The technician who gets four or five pieces of equipment behind in his work may cause a substantial loss in production which will hurt the manufacturer where he is most vulnerable. He will take a dim view of repeated failures. Reliability and quality of workmanship must be especially high in servicing industrial equipment. If a particular unit is used in many places in a plant, it is practical to have at least one spare on hand which can be substituted rapidly, so that production can be resumed almost immediately. Unless the equipment is extremely bulky, heavy or expensive, this is a worthwhile investment.

Instruments and tools

Tools in industrial electronic servicing will not differ much from those used now, except that you may have to have some special ones for relay adjustments; also the range of sizes of wrenches and pliers may need to be a little greater. A set of box and socket wrenches is often needed to handle the bolts on the special enclosures used in industry.

Actually the array of tools and instruments needed will differ from place to place and whether you are permanently attached to some industrial company as their technician or are an independent service technician. The company employee soon knows
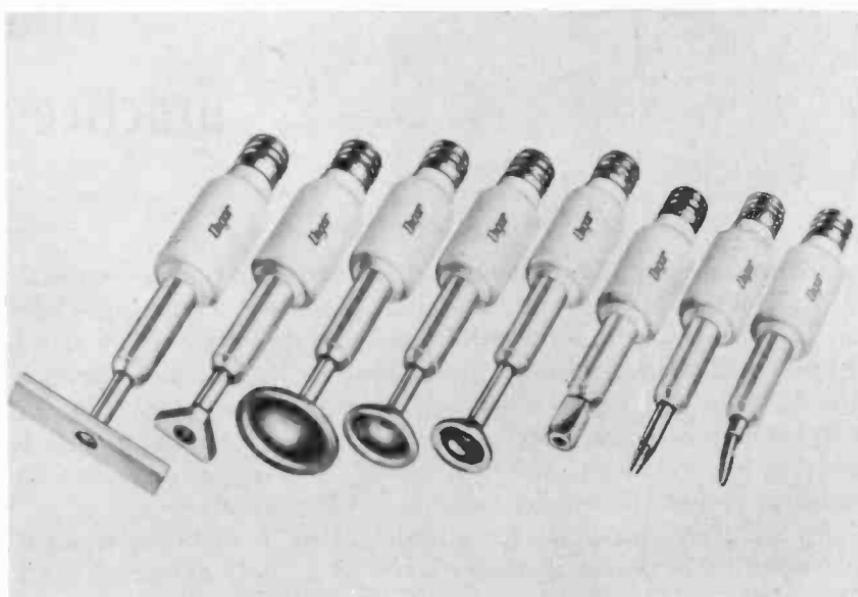
Fig. 1201. *The special tips of the desoldering kits are useful for printed-circuit repairs.* (Ungar Electric Tools, Inc.)

the requirements of his instruments, while the latter must be prepared for almost anything.

Devices which include printed circuits, as for example electronic counters, will require appropriate soldering tools. These will include a low wattage soldering iron and a small wire brush, for replacing parts on printed-circuit boards. Special kits are marketed for printed-circuit desoldering (Fig. 1201). To remove sockets without damaging the circuit board, such tools are very handy to have, but the removal of sockets is also a relatively

rare event. Not as rare as in radio and TV servicing, however, since in industry the chance of severe vibration is much greater, and fatigue in small metal parts, such as socket prongs, can occasionally occur. A set of cleaning solvents, protective insulating varnishes, phenolic cement and similar service aids are also needed.

Choice of instruments will depend for the most part on the type of industrial equipment with which you will be involved. The volt-ohmmeter is going to be one of your most constant companions. Volt-ohmmeters vary all the way from the inexpensive and somewhat limited kit type instrument (Fig. 1202) to

Fig. 1202. *Small and inexpensive instruments of the kit type have limitations but are useful in industrial work.* (Allied Radio Corp.)

the more expensive and more sensitive test instrument of Fig. 1203. The first may have resistance as low as 1,000 ohms per volt and will do well enough for approximate measurements on low-impedance circuits, while the latter will be able to do almost any measuring job on electronics circuits without seriously loading the circuit with its 100,000 ohms-per-volt resistance.

Probably your vom will not be able to do all the jobs that need be done in industry, although there are many ways of extending and improving the versatility of the meter. Ac current ranges are not included on most volt-ohmmeters. Many other jobs will be more adequately handled by separate meters. For example, a set of meters with interchangeable scales (Fig. 1204) allowing a single basic movement could be used with a number of scales. An assort-

ment of movements and scales for different ranges will be a useful thing to have on hand.

A unique approach to the meter problem, and one which would

Fig. 1203. *The 100,000-ohms-per-volt sensitivity of this instrument allows it to be used for tests that would normally require a vtvm.* (Simpson Electric Co.)

seem to offer a number of advantages in an industrial situation, is the Add-adapter group manufactured by Simpson (Fig. 1205, on pages 275 and 276.) These adapters are used with the model 260 or
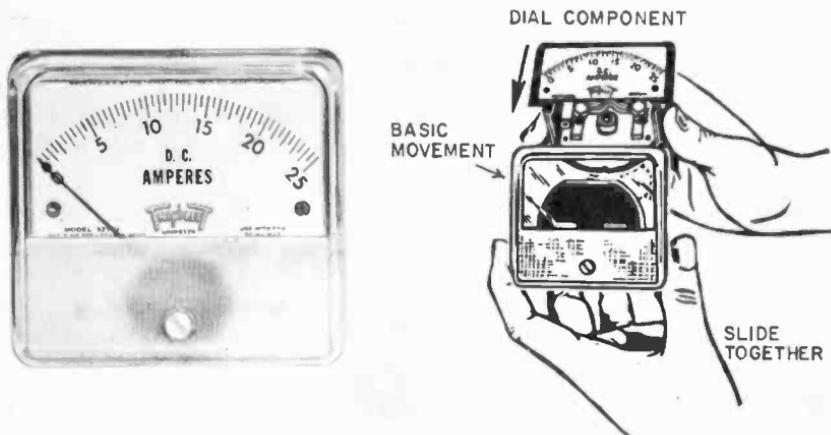
Fig. 1204. *Handy for laboratory and bench test setups, the interchangeable units are useful in industrial electronics servicing.* (Triplett Electrical Instrument Co.)

Fig. 1205. *The vom (a) is used as an ac ammeter with adapter (b), audio wattmeter (c) and transistor beta tester (d). Similar adapters are available for temperature, microvolt and battery tests. Another unit converts the vom to a vtvm.* (Simpson Electric Co.)

270 volt-ohmmeters, and adapt them to the functions of an audio wattmeter, battery tester, ac ammeter, dc vtvm, temperature tester, transistor tester and microvolt attenuator. This is a good selection of instruments, and in service work it is not likely that you will need these instruments simultaneously since they cover radically different measurements.

The audio wattmeter provides the load resistors needed in wattage measurements and, in addition, the case carries a slide rule to convert meter readings of the 50-μa current scale of the vom to wattage for the load resistor used. The battery tester also

Fig. 1205. (continued). *Temperature tester adapter (e) uses thermistors as sensitive elements. The microvolt attenuator (f) supplies calibrated test voltages. The vtvm adapter (g) makes the vom into a sensitive vtvm with more than 10 megohms input resistance. The battery tester (h) adapter for the vom makes the latter into an instrument for testing all batteries, important with the increased use of transistors.* (Simpson Electric Co.)

provides appropriate load resistors for testing A-and B-batteries, and the relative reading can be converted by a slide rule attached to the case to a rating of the battery condition as good, weak or bad. The ac ammeter unit is a transformer which the 2.5-volt ac scale converts. With it you can read from 250 ma ac to 25 amperes in six ranges.

The vtvm adapter is a battery-powered unit using a 1AG4 tube. The complete schematic is shown in Fig. 1206. Input resistance is 10 megohms. The 50-volt range of the vom is used for this unit. The dc and ac microvolt attenuator is an entirely new concept in instrumentation. It provides an accurate very low-voltage source from dc through the audio range by the precision attenuation from a convenient source which can readily be measured
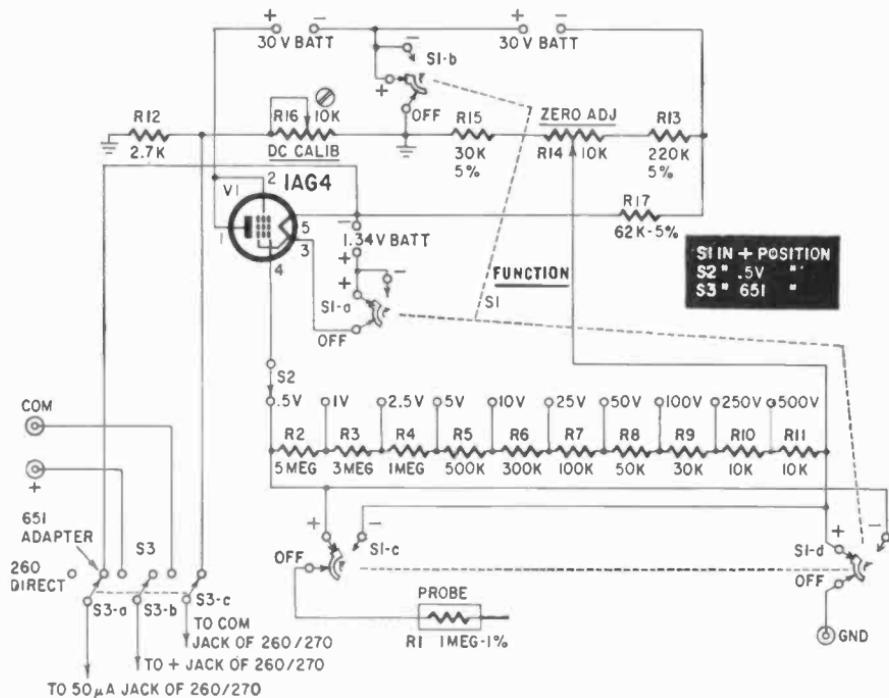
Fig. 1206. *Schematic of vtvm adapter shows single tube and switching circuit that allow vom operation without removing adapter.*

with the vom. Input can be from 2.5 to 33 volts, output can be as low as 25 mv. This is handy to provide a calibrated input signal when making adjustments and tests on amplifying or recording equipment.

The temperature adapter converts thermistor resistance readings to temperature, and is equipped to read three ranges of thermistors. Computations are made with a built-in slide rule.

Last but not least, the transistor tester adapter is a battery-powered unit which provides all the circuitry to make beta and collector-current tests on transistors up to 100 ma. Power transistors cannot be directly checked with it.

In a plant where temperature calibrations must be made regularly, you would expect to have the use of a direct temperature meter such as Fig. 1207. Designed to use thermocouples, it consequently has a low-millivolt type meter movement. A reference junction is built into the meter.

Similarly if you expect to check tubes weekly, a good commercial tube checker (Fig. 1208) is a must. Even at that, it will prob-

ably not allow you to check some of the larger industrial power tubes. These are usually built into equipment provided with meters or metering jacks so that their performance can be checked in place (Chapter 3).

Electronics circuitry will often demand the use of meters with very high input impedance, in which case we must turn to the vtvm. These again come in all ranges of accuracy and price, from the less expensive but quite high-quality general-purpose service instrument of Fig. 1209 to the laboratory instrument shown in Fig. 1210. When the job requires an accuracy beyond the customary gross limits, the more accurate instruments must be used. Not

Fig. 1207. *This millivoltmeter is calibrated for direct readings of Fahrenheit and Centigrade temperature measurements with the proper thermocouple.* (Simpson Electric Co.)

many jobs in industry require such instruments, but those that do will permit little compromise.

The oscilloscope with which you must be familiar, will be high on the list of required instruments. Again, different jobs will demand different scopes, and there are almost as many oscilloscopes as there are drops in a bucket. The kit type instruments (Fig. 1211-a) will adequately handle most of the industrial servicing you may encounter, but occasionally the faster rise time

of the more expensive laboratory scope (Fig. 1211-b) will be needed to judge waveforms accurately. The critical factor in scope specifications then is, not the frequency response or bandwidth, but the rise time.

In dealing with slowly varying voltages, common in industry, a response to dc is essential. Scopes with a dc amplifier tend to be more expensive, since extra care must be taken to avoid drift in the amplifier.

Fig. 1208. *A transconductance type tube tester is essential for preventive maintenance.* (Hickok Electrical Instrument Co.)

Careful consideration must be given to the type of scope which will be most useful. If you expect that most of your service work will be in the field, away from the shop, a small portable scope will be the easiest to work with. But the size is not necessarily the only criterion. If there is no high frequency equipment in the plant and no pulses for which the rise time is critical. a scope with response to dc will most likely be better.

For routine service on electronic equipment, scopes are used much as in communications work. The scope can also be used for such things as frequency measurement, tracing interference, indicating stage overloads (flattening of waveforms), picking up magnetic fields, etc. Measurements of phase shift, for example, will be required when dealing with thyratron circuits. Harmonics in power-line voltages can be caused by faulty transformer windings, and these can be discovered readily with a scope. Contact bounce of relays and internal combustion engine timing points can be shown on a scope. Ignition patterns, ignitron and thyratron conduction patterns, engine-pressure cycles, electric motor armature operation are some of the tests that can be made with the

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oscilloscope. There are many more. You will profit from using the scope and learning to interpret the various patterns and their meaning for circuits you must work with.

Special instruments

Industry is often concerned about the health and safety of the employes. Many times management will turn to the electronic technician when the required measurements involve elec-

Fig. 1209. *This medium-priced vtvm will measure inductance, capacitance, resistance as well as ac and dc voltages.* (Hickok Electrical Instrument Co.)

tronic instruments. Thus, you may be expected to supply data with a sound-level meter, to establish whether sounds and noise in a plant are of a nature that could seriously affect health. One such instrument is shown in Fig. 1212. It is, of course, nothing more than a carefully calibrated microphone and a tunable amplifier to permit analysis of the sound frequencies.

To make sound-level measurements which are not as precise, but which would give a general indication of noise level (without an attempt at frequency analysis), a microphone, amplifier and wattmeter may be used. The noise, being measured in decibels, is an additive function. Thus, you can measure an *increase* in relative noise level by making comparative measurements with the same volume-control setting on the amplifier, since a db *difference* at the input carries through as the same db *difference* at the output of the amplifier, provided the amplifier is reasonably linear and the total frequency content of the

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noises are similar. In one instance the monitoring of the average noise level in a plant has given warning that a machine was about to break down, but this is an individual case.

Another health hazard that calls for electronic instrumentation is radiation, and as we progress in peaceful uses of atomic energy this will become more and more common. Fig. 1213 shows a kit type Geiger counter which would be sufficient for detecting health hazards. If continuous use of radioactive materials is contem-

Fig. 1210. *Laboratory vtvm (a) performs all the familiar functions with greater accuracy while the unit at (b) only indicates voltage.* (Hewlett-Packard Co. and General Radio Co.)

plated, more sensitive instruments such as a scintillation counter may be needed. Radioactive poisoning is cumulative, and a very little above the background level can be tolerated for long periods. Many publications are available which will give tentative safe limits, although even now there is a considerable difference of opinion in the matter.

Other special instruments which might be needed would include such items as frequency meters, when critical frequencies are needed for control systems (Fig. 1214) and in-circuit capacitor testers (Fig. 1215), both of which should be familiar to you from communications work.

Signal generators may be needed, depending on the kind of instrumentation and control devices used. For the calibration of transducers, precision bridges may be required. There are companies that specialize in renting accurate instruments for a mod-

erate fee. Thus instruments needed infrequently might be rented. The cost of rental must be balanced against the cost of purchasing and storing such an instrument. No generalizations can be made as to where the line should be drawn. This will depend entirely on the type of instrument involved and the expected frequency of use, as well as the initial cost compared to rental charge.
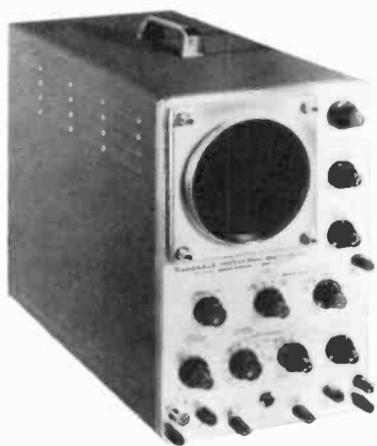
Service practice

Whether you are an employee or a contractor, proper organization of your work is required to do successful servicing. Too much industrial service is on a catch-as-catch-can basis—unfortunately. To call a service technician only after a machine has broken down (or starts to turn out round nuts instead of square ones) is covering the well after the pig has fallen in. Many millions of dollars are lost annually because of lack of preventive maintenance. A machine that works 24 hours a day is going to show wear sooner or later. A control circuit which must operate 24 hours a day under a great variety of environmental conditions is just as likely to need attention, (the wider applications of static switching systems will help minimize this). Preventive maintenance may appear more expensive than repair, but when production is maintained trouble-free for long periods of time, the cost is more than offset.

The industrial service technician keeps odd hours. His best time to work is when no one else is around. When the plant is shut down he can make his routine checks without interfering with production. Sometimes these checks are possible only with the machine operating normally at full capacity.

He should also have a regular schedule for periodic inspections of plant equipment. Relays and contactors should be checked monthly. These should be checked for contact condition, collection of dirt, excess heating of coils and of the metal parts, corrosion on metal parts and terminals, proper contact pressures, excess slam of the armature, loose connections, wear or binding of the moving mechanical parts, excess arcing, noise and hum in the magnetic system, and condition of the oil in dashpots if any, oil leaks in these relays, etc.

Motors and motor-operated devices must also be inspected, monthly at least. Excess heating, vibration and noise are again the most important clues. Dc motors should be inspected for arcing on the commutators. Bearing temperature is an important indication of belt tension. Static control devices should be kept clean, and monthly inspection should include the plug-in buses (look for gummy deposits), metal parts (corrosion) loose con-

a
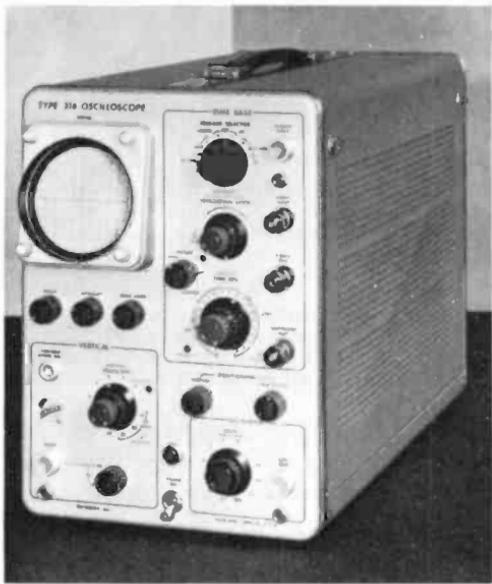
b

Fig. 1211. *Scope (a) built from kit can handle most industrial electronics jobs. More expensive portable 3-inch scope (b) has wide range.* (Heath Co. and Tektronix, Inc.)

nections, etc. A dated record should be kept of the inspection and anything found in less than optimum condition should be noted so that the records may be referred to when trouble arises. This may help you locate its source much faster.

Many electronic devices should be similarly inspected perio-

dically, and the rate of inspection will depend on duty cycles and the environmental conditions in the plant. For example, dry-disc rectifiers should be checked for overheating and for ventilation, high ambient temperature, corrosive atmosphere, etc. The large high-voltage capacitors often associated with them must be checked for moisture and dirt on the insulators, and signs of corrosion on the enclosures.
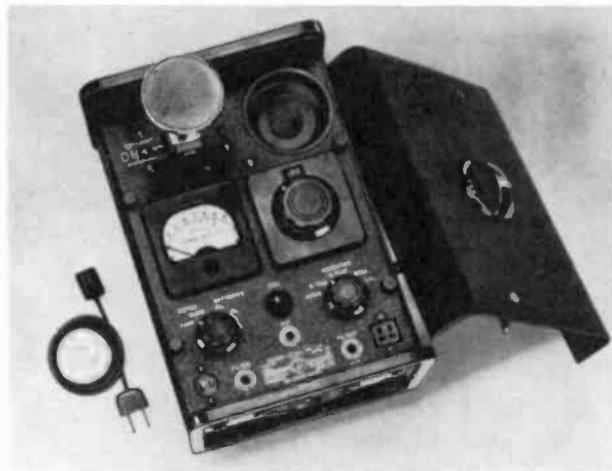
In many industrial situations there is more vibration than

Fig. 1212: *Sound-level meter is an accurately calibrated microphone and amplifier. Some tests may be duplicated with a metered amplifier.* (General Radio Co.)

initially anticipated, and loose or broken wires, terminals, pigtails and even metal supports are a common source of trouble. Vibration will also reduce vacuum-tube life, particularly affecting the filaments. Mechanical vibration isolation mounts may be needed to correct excessive trouble. The electrical equivalent of vibration is fluctuating voltages. It also can drastically reduce tube life and may cause periodic malfunction which appears as an intermittent fault. Any circuits critical of voltage must have some sort of regulation. If it is not designed into the instrument, it may have to be provided externally from a constant-voltage transformer in the ac supply. A thorough check, preferably with a recording voltmeter, should be made for several days to determine line voltage conditions in the plant. If many heavy motors are started and stopped periodically, voltage fluctuation can be expected, no matter how well the electric power system has been designed. Con-

sistently low voltage will not cause damage or wear, but may prevent proper functioning of the equipment. Consistently high line voltage carries its obvious penalty.

Trouble with mercury vapor tubes, such as refusal to fire, may not necessarily be circuit faults; low ambient temperature may be responsible, and some discharge tubes need light to operate mar-

Fig. 1213. *Radiological monitoring may be needed to protect personnel from radioactive contamination.* (Heath Co.)

ginally. On the other hand, too high an ambient temperature may cause arc-back in the tubes. Usually all equipment is protected by fuses, and much of it by time-delay relays, to allow heater warmup before plate voltages are applied. Such timers may be responsible for equipment failure. In general, troubleshooting should start with the simplest most likely cause of trouble. If there are repeated breakdowns of the same nature, the equipment is possibly being misused or conditions are not proper for the equipment.

Specific troubleshooting procedures will almost always be provided by the equipment manufacturer. These procedures have been carefully worked out. It is wise to follow the instructions provided, with, of course, modifications your own experience

dictates. Most problems are not the result of errors or design errors in the equipment, but are due to environmental operating conditions, with dirt and moisture high on the top of the list. Photoelectric types of equipment must be kept particularly clean for optimum functioning.

Safety

An aspect of service practice which is all too often ignored or treated with contempt, after a certain familiarity has been achieved, is safety. Most control equipment contains high voltages and, even though one may think he is immune to 110 volts dc because the last three times he was shocked by it, it did not kill him, the fourth time may be fatal. No individual reacts to electric shock the same way twice, even though the sensation may appear to be about the same. Conditions of the body change drastically, and an electric shock right after lunch is an entirely different thing than one right before quitting time, when the stomach is empty. Contrary to the popular belief that, after one has withstood an electric shock the danger is over, the body may show symptoms of a mysterious nature, sometimes hours, days or even weeks later. Even mild electric shocks leave their mark. The entire human body functions as an electrochemical entity, and an electric shock momentarily interferes with body's signals to the nervous system. A shock may also cause some extrastrenuous muscle contractions. If the muscles contracting happen to include some of the more delicate organs or glands of the body, the results may be drastic. Such contractions have been strong enough in some cases to break bones.

Whenever you are working on equipment which can be turned on remotely, make certain the master switch is pulled, or that all the controls are locked in inoperative conditions, properly tagged with warning tags. If you *have* to work on hot equipment, and usually you will be sitting on concrete floors to do it, carry a rubber mat and rubber gloves to protect you against "moderate" voltage shocks—they too can kill. Take even greater precautions when working with high voltages.

Never take large (or even medium-size) capacitors for granted. *Always* discharge them before touching their terminals. And *never* bypass or jam cabinet interlocks, at least until you are thoroughly familiar with the locations of the high-voltage terminals in the equipment. You will live longer.

Records and supplies

Equipment manuals should be organized and readily available.

But more than that, each manual should have a paste-in card or slip, which tells what modifications, part replacements or service work has been done and when. This will give you and any other technician a history of previous problems. A job well organized is easier to keep that way.

In addition, you should have a log of routine maintenance work. For the contract service technician this is doubly important as a record of his work and for billing. A duplicate should be pro-

Fig. 1214. *Direct-reading frequency meter needs no adjustment or interpolations to determine frequency. Counters are also used for this type of measurement.* (Hewlett-Packard Co.)

vided for the customer's files. Such record keeping will help prevent disputes, and if they occur you will have definite information on which to base any claim or defense.

Inventories must be taken, and it is often a good idea, to include with the test equipment its condition, particularly if it has been shelved for a good part of the year. Many a technician has discovered a piece of useful equipment this way because the records had not been accurately kept. Instruments are valuable and must be treated and stored accordingly.

The storage of replacement parts must be well organized. When you need a part, you need it quickly. How the parts storage is organized depends on the equipment you service. For a great variety, with few parts in common, it would be better to store the spares for each separately, and properly labeled. If there are many parts in common, spare-parts storage can be drastically reduced, and parts stored on a per-item basis. But in any case, keep a record of parts used, and set up some routine for reordering. Parts which are subject to deterioration, such as electrolytic

capacitors and batteries, should be stocked only in minimum quantities. These are items which can be quickly purchased.

A well organized stock room and service area is an asset when the work load gets heavy.

Conclusion

This volume has attempted to present to you a representative selection of industrial applications which are different from the

Fig. 1215. *This in-circuit capacitor checker only indicates open or shorted conditions. Actual capacitance and leakage valves are not normally indicated as such.* (Heath Co.)

run-of-the-mill communications applications. To do the subject complete justice, we would need at least a half dozen volumes, each in its own area of industrial practices.

Today the majority of industrial electronic technicians are employed by the manufacturers of the equipment. The time is not far off when the installations will be spread over such tremendous territories that manufacturers service organizations may become unwieldy, and a liability rather than an asset. With automation growing daily, the need for technicians who understand this particular branch of electronics is going to grow indefinitely. You can grow with the field, and make this a highly satisfactory occupation, as well as a profitable one.