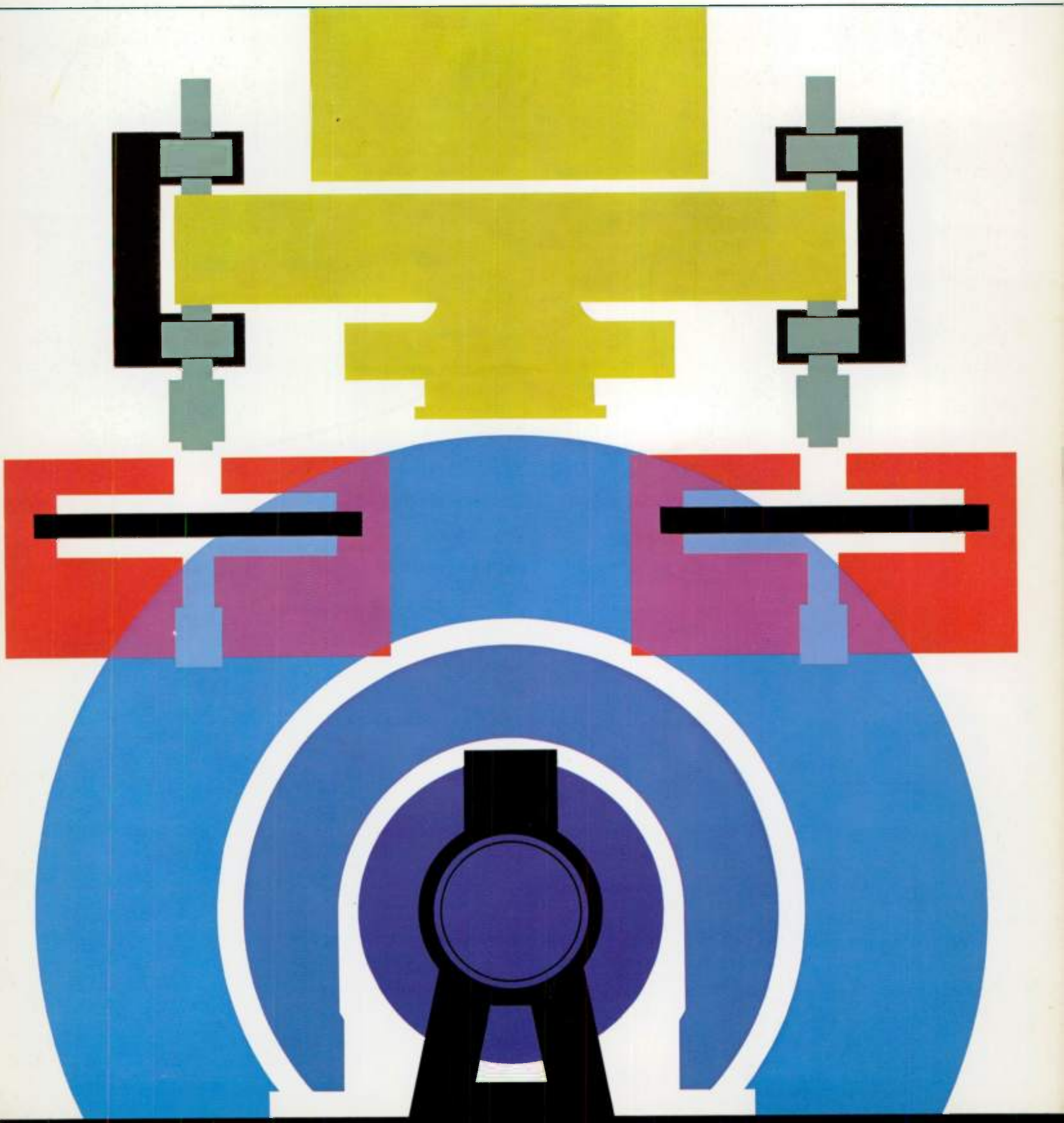
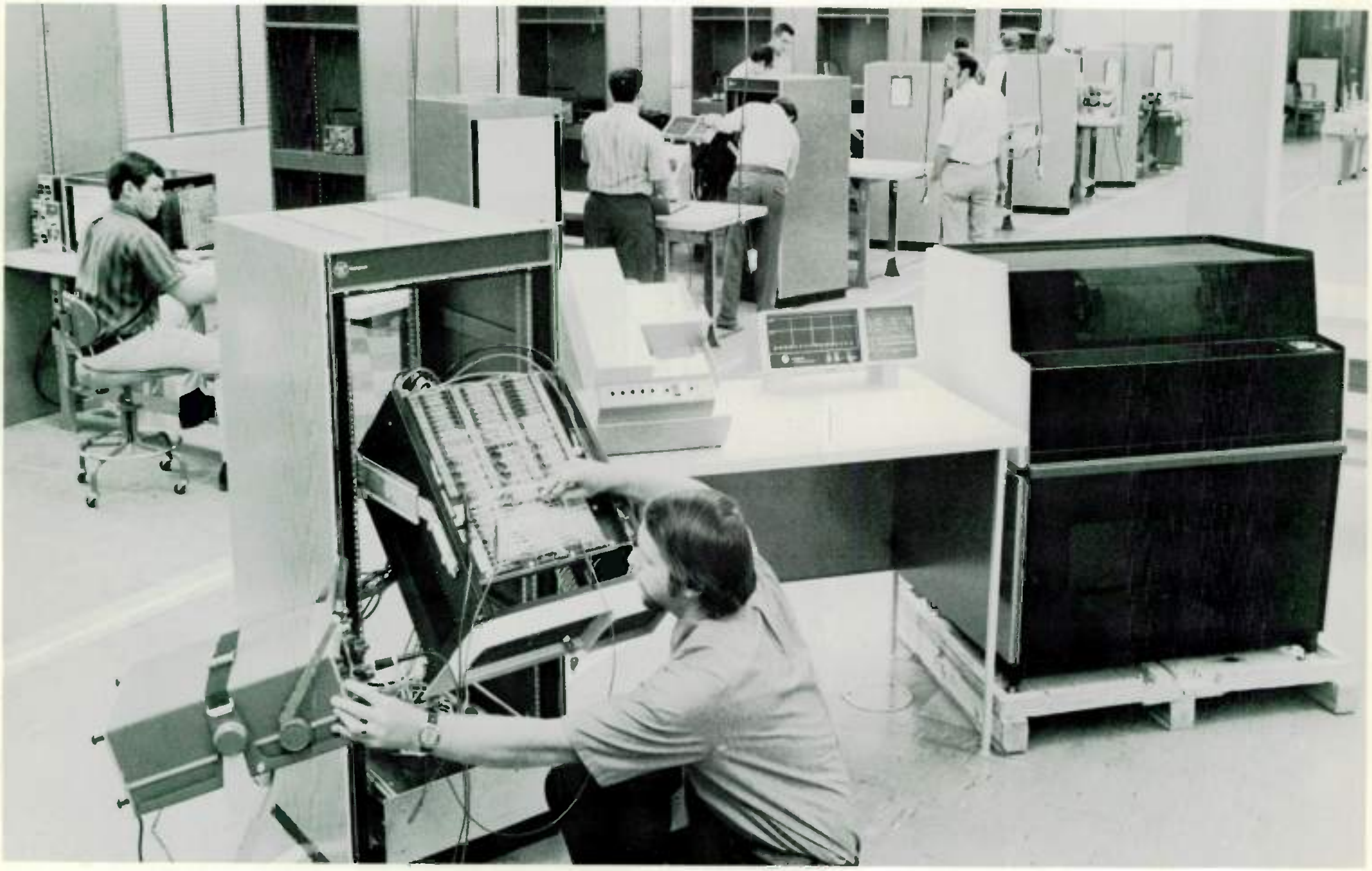
Westinghouse ENGINEER

January 1972





Minicomputer Takes on Data-Processing Jobs

Some minicomputers designed originally for communications, industrial control, and scientific applications have been found versatile enough to serve also in business data processing. Examples are the 13 Westinghouse 2500 and 2550 computer systems being applied by Appalachian Computer Services, Inc., London, Kentucky.

The 2550 system consists of the Westinghouse 2500 minicomputer as a central processor, plus a card reader and operator's console for input, a line printer and teletypewriter for output, and a disc mass memory unit. The systems being supplied to Appalachian Computer Services are able to do much of the accounting and related work themselves, although more difficult tasks may be referred to a larger central computer. The company specializes in data processing for nonmetropolitan areas. Customers include medical doctors, banks and other financial institutions, utilities, schools, municipal governments, engineering firms, wholesale grocers, and public accounting firms.

The Westinghouse 2500 minicomputer is a digital machine employing 16-bit words and having 750-nanosecond memory cycle time, hardware multiply/divide, and power fail safe. It is capable of serving as a satellite processor (a computer that accepts local information, performs some computational work, and transmits the results over a telephone line to a large computer located elsewhere), as a remote batch terminal (a computer that performs calculations on a batch of information it has collected and transmits the results to a large computer), or as a stand-alone computer system (one that does not need to be associated with any other large computer and may actually have smaller computers providing information to it).

The 2500 and 2550 computer systems are made by the Westinghouse Computer and Instrumentation Division. The photograph shows a 2550 system being assembled.

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Front Cover: Drives for large grinding mills such as are used in the mining and cement industries are suggested in this month's cover design and are discussed in the article beginning on page 19. At top is a dual pinion drive; at bottom is a gearless drive of the new wraparound type. The cover design is by Tom Ruddy.

Back Cover: Windings of a stator section for a hydroelectric generator, foreground, and a large steam electric generator, rear, get a final check at the Westinghouse East Pittsburgh plant. Manufacturers shipped a record amount of generation equipment to utilities in the United States last year—almost 42,000 MW of capacity. Installed utility generating capacity is expected to double between 1970 and 1980.

Radiation Monitoring System for Nuclear Power Plants

Stephen A. Lane
Charles Griesacker
Ted Hamburger

Seven types of radiation detection monitors, strategically placed about a nuclear power plant, can monitor all areas of the plant to insure the safety of all operating personnel and the surrounding environment.

The Westinghouse radiation monitoring system (RMS-1000) is a multichannel system employing radiation detection devices and solid-state converters to monitor and indicate radiation levels of selected areas in a nuclear power plant. Use of channels with identical circuitry permits a building-block approach to fit the system to individual plant requirements. Furthermore, it allows the system to be expanded, contracted, or rearranged with a minimum of trouble and expense.

A typical monitoring channel contains a radiation detector, a check source, and the associated impedance-matching network mounted at the sampling point; a remote indicator and an annunciator alarm mounted on or near the detector assembly; and a computer/indicator, power supplies, and controls located in a control console in the nuclear power plant control room.

The radiation detector, which may be one of several types (to be described) is mounted in the area of the radiation to be monitored. It provides a chain of voltage pulses that is routed to the computer/indicator in the control room over a coaxial cable. All other electronic signals between detector and computer/indicator are transmitted over the standard multiconductor cable. Distances between detector and computer/indicator are typically 200 to 600 feet.

The computer/indicator circuitry converts input pulses from each radiation detector to a direct-current signal voltage proportional to the radiation level detected. This signal energizes channel indicating meters, alarms, recorders, and computer output signals.

Radiation Detection

Seven basic types of detectors are used to monitor various points throughout a nuclear power plant: an air-particle detector, in-line and off-line radioactive gas detectors, in-line and off-line liquid-sample monitors, area monitors, and a stack-gas detector assembly. All seven detectors use one of two basic types of sensors—either a Geiger-Mueller tube or a scintillation detector. Several models of these two sensor types are required to match the various levels of background radiation, the beta-gamma activity of interest, and the type or style of mounting required.

Geiger-Mueller Tube—This device is the standard beta-gamma radiation detector that operates on the secondary ionization current principle. Basically, the tube consists of a positive anode wire, coaxially surrounded by a cylindrical negative cathode that usually forms the metallic envelope of the tube. The tube is filled with an ionizable gas mixture.

Beta or gamma rays enter the tube through a foil window or directly through the wall of the tube. They ionize gas molecules, releasing electrons that gain energy as they drift toward the positive anode and thus produce secondary ionization. This process results in an electron avalanche that terminates when all electrons reach the anode. The complete discharge occurs within microseconds, and it is quenched immediately to prevent another discharge. The quenching agent, such as a halogen, is mixed with the ionizable gas; it prevents secondary discharges of electrons from the cathode.

Gas ionization produces a current flow through a load resistor, causing a voltage drop that lowers the potential between anode and cathode. The voltage drop produces the negative pulse that is transmitted to the computer/indicator for processing.

Scintillation Detector—Certain phosphors emit light ("scintillate") when subjected to nuclear radiation. The number of scintillations is proportional to the energy of the light-producing radiation. The emitted light is optically coupled to the photocathode of a photomultiplier tube, causing the release of photoelectrons. These electrons enter the structure of the photomultiplier where their number is increased by a large factor as a result of the secondary-emission processes occuring at the cascaded stages. The scintillation crystal, optical coupler, and phototube are contained in a hermetically sealed light-tight package that forms a simple plug-in type of unit.

The chain of output pulses, the amplitude of which is proportional to the energy of the radiation, is coupled through an impedance-matching circuit to a coaxial cable for routing to the computer/indicator counting circuitry.

Three attributes which make the scintillation detector especially suitable for the detection and measurement of radiation are its high sensitivity, energy discrimination, and very good time resolution.

Radiation Monitoring System

The negative pulse chain produced by the radiation detector is converted by computer/indicator circuitry into a 0 to 10-volt signal, with an amplitude proportional to the logarithm of the pulse rate. Since each computer/indicator channel is electrically identical to all others (Fig. 1), and all detector signals generated are similar in character, the main differences between channels are the type of detector, the radiation sampling method employed, and the meter display, which is either in counts per minute or roentgens per hour. This building-block approach simplifies the problem of accommodating the system to any given plant requirement.

Each computer/indicator channel incorporates the following basic circuits: discriminator, pulse shaper, driver, log-pulse integrator, level amplifier, bistable alarm amplifier, and test-calibrate circuits. All of this circuitry is contained on only three types of printed circuit boards. Like boards are interchangeable, and only seven different active semiconductor components are employed throughout the radiation monitoring system to facilitate maintenance and minimize stocking of spare parts.

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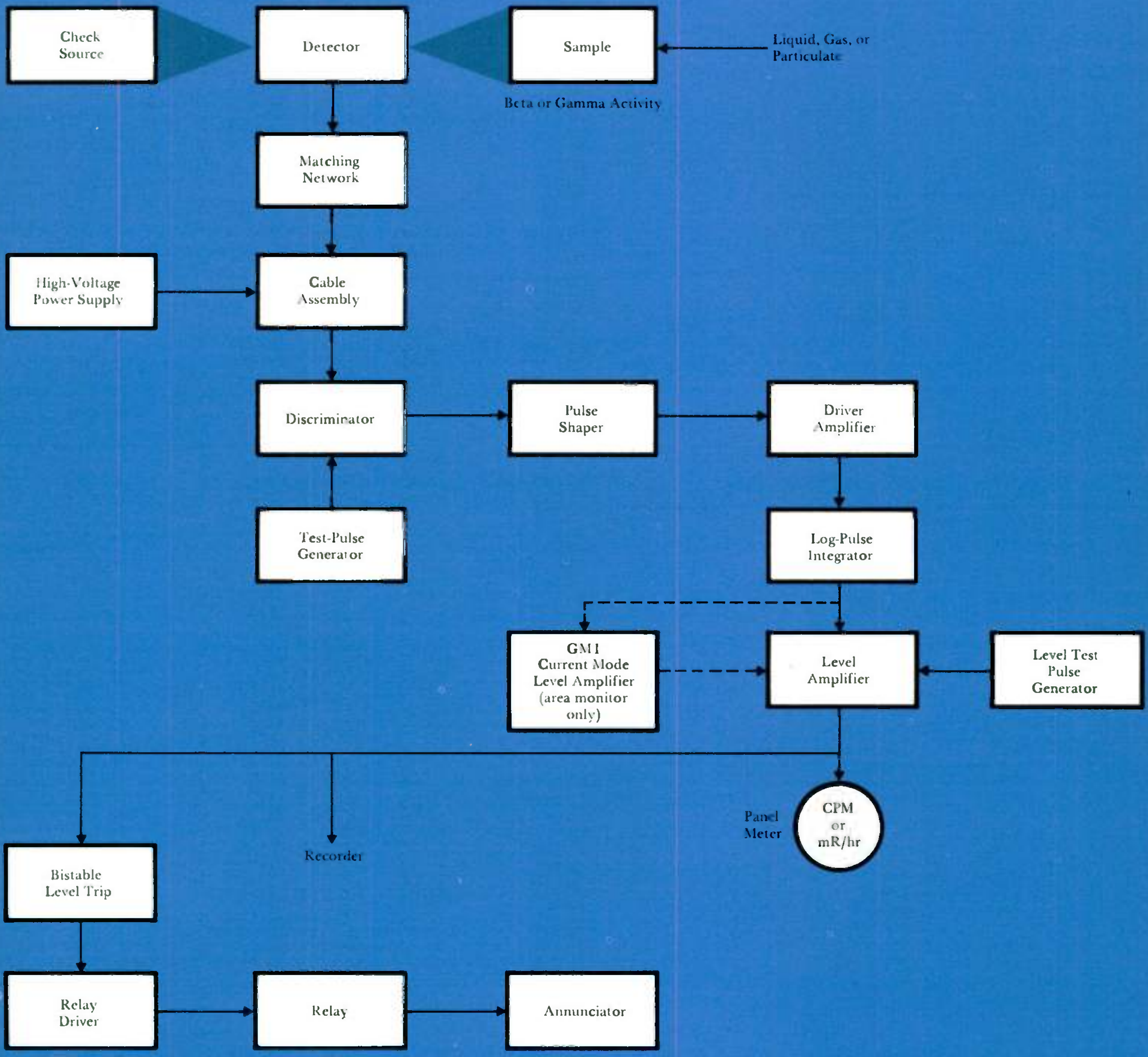


1—A typical channel of the radiation monitoring system is shown in simplified block diagram form.

Modes of Operation

There are five distinct modes of operation of the standard computer/indicator and monitor circuits: the normal-level pulse mode, an extended-range bistable mode, a high-level alarm mode, a low-alarm mode, and a test-calibrate mode.

Normal-Level Pulse Mode—Negative pulses generated at each detector are coupled through a coaxial cable to the computer/indicator circuitry for the channel. When the detector signal (a random-amplitude voltage pulse) exceeds a preset reference level, it is converted to an equal-amplitude square-wave signal with a frequency proportional to the frequency of the input pulse chain. This signal actuates an on-off flip-flop circuit to generate a 3-volt square wave, the duration of which corresponds to the time between detector pulses. This square-wave signal is integrated to produce an output voltage proportional to the pulse rate. The range of response is 10^0 through 10^6 counts per minute.

During the normal count mode (10^0 to 10^6 pulses), the output of the log-pulse integrator is routed to a level amplifier, which matches the signal to indicating panel meters, recorders, etc.

Alpha, Beta, and Gamma Radiation

Radioactive substances are detected by their emitted radiation, which is of three basic types—alpha, beta, and gamma. Alpha and beta radiations are actually fast-moving particles. The alpha particle is the helium-4 nucleus, which has a positive charge and relatively small penetrating power. Beta particles are electrons with about 100 times the penetrating power of alpha rays.

Gamma rays are electromagnetic radiations of very short wavelength, 10^{-8} to 10^{-9} cm. They have great penetrating power, about 10,000 times that of alpha rays. Gamma-ray energies range from 10^4 to 10^7 eV. Although the activation mechanisms are different, energetic particles and electromagnetic radiations produce similar effects in radiation detectors. Gamma activity, because of its greater penetrating power, is the radiation most frequently sensed, especially when radiation levels are relatively low.

At the 10^6 count rate, full current is flowing in the normal-level pulse integrator circuitry. For any increase in pulse count above this high rate, an extended-range (GMI) current mode of operation is initiated.

Geiger-Mueller Current Mode—The GMI bistable circuit is employed in conjunction with the tube-type detectors used in the area monitors to permit extension of their range after pulse-mode saturation occurs (Fig. 1), thereby extending the useful range of the Geiger-Mueller counter tube. When the radiation level drops back to the normal pulse mode level, the channel is returned to the normal-level pulse mode.

Alarm Modes—A bistable level trip circuit (Fig. 1) accepts the output from the level amplifier and operates at a preset trip level. Transistors in the output circuit of the bistable level trip circuit function as driver amplifiers for relay circuits to provide a high alarm and a low alarm. Alarms and relays are operated with a trip accuracy of ±6 percent of full scale.

The *high-alarm* circuit is a latching type which must be reset by the operator. A high-alarm lamp is displayed on the front panel, and heavy duty relays are mounted on a relay rack directly behind the drawer assembly. These relay contacts have a high current capability and are for power plant use to control any required shutdown procedures.

The *low alarm* is similar to the high alarm. The trip level is adjustable over the full range of detection. Unlike the high alarm, however, the low-alarm circuit is nonlatching and automatically resets when the signal rises above the preset alarm level. When used as a low alarm, its prime purpose is to indicate channel malfunction. Any detector or electronic failure results in alarm actuation, and the low-alarm lamp lights on the front panel of the computer/indicator.

Test-Calibrate Mode—When this mode is actuated, a pulse-generator circuit provides a 100,000-cpm test signal to the discriminator (Fig. 1). A level test signal is also provided to the input of the level amplifier for testing the level trip bistable.

To check the complete channel from detector to computer/indicator, the check-source solenoid for the channel is actuated to mechanically position the check source in front of the detector.

When the channel is not operating in the normal monitoring mode, a channel test lamp is energized to indicate that one of the channel tests is being performed.

Control Console

All of the channel computer/indicator circuits and most of the associated control circuitry is housed in a single control console (Fig. 2). Control and computer/indicator circuits are mounted in either dual- or single-channel drawer assemblies. The control console also houses a recorder for permanent historical record of radiation levels, terminal boards, a relay assembly, multirange-voltage power supplies, and all required interconnection circuitry.

Dual-Channel Drawer—The standard dual-channel computer/indicator drawer assembly contains two completely isolated (electrically and mechanically) channels with shield barriers between channels (Fig. 3). Each channel contains the circuits for control and readout of the radiation level for the monitored area.

Single-Channel Drawer—Each air particle detector (to be described) requires additional control circuits for the pumps, filter paper drive, and solenoids required in the detector assembly. A single computer/indicator channel (electrically identical to one of the dual computer/indicator channels) occupies half a drawer, and the switches and indicators necessary for control of the air particle detector are mounted in place of the second channel. The single-channel air particle detector drawer has the same physical dimensions as the standard dual-channel drawer.

Meters—All meters for dual- and single-channel drawers have the same mechanical dimensions and basic movements, but various dial faces are used,

Computer/Indicator Signal Processing

Computer/indicator signal processing can be illustrated for the normal-level pulse mode with this simplified schematic diagram.

Discriminator—The discriminator accepts input pulses from the radiation detector and converts them into negative-going output pulses of fixed amplitude; each time a detector pulse exceeds the adjustable reference level, the output switches from a +3-volt to a −½-volt level. This state is maintained until the trailing edge of the signal pulse falls below the reference. Thus, input pulses with amplitudes above the preset level are converted to equal-amplitude square-wave pulses.

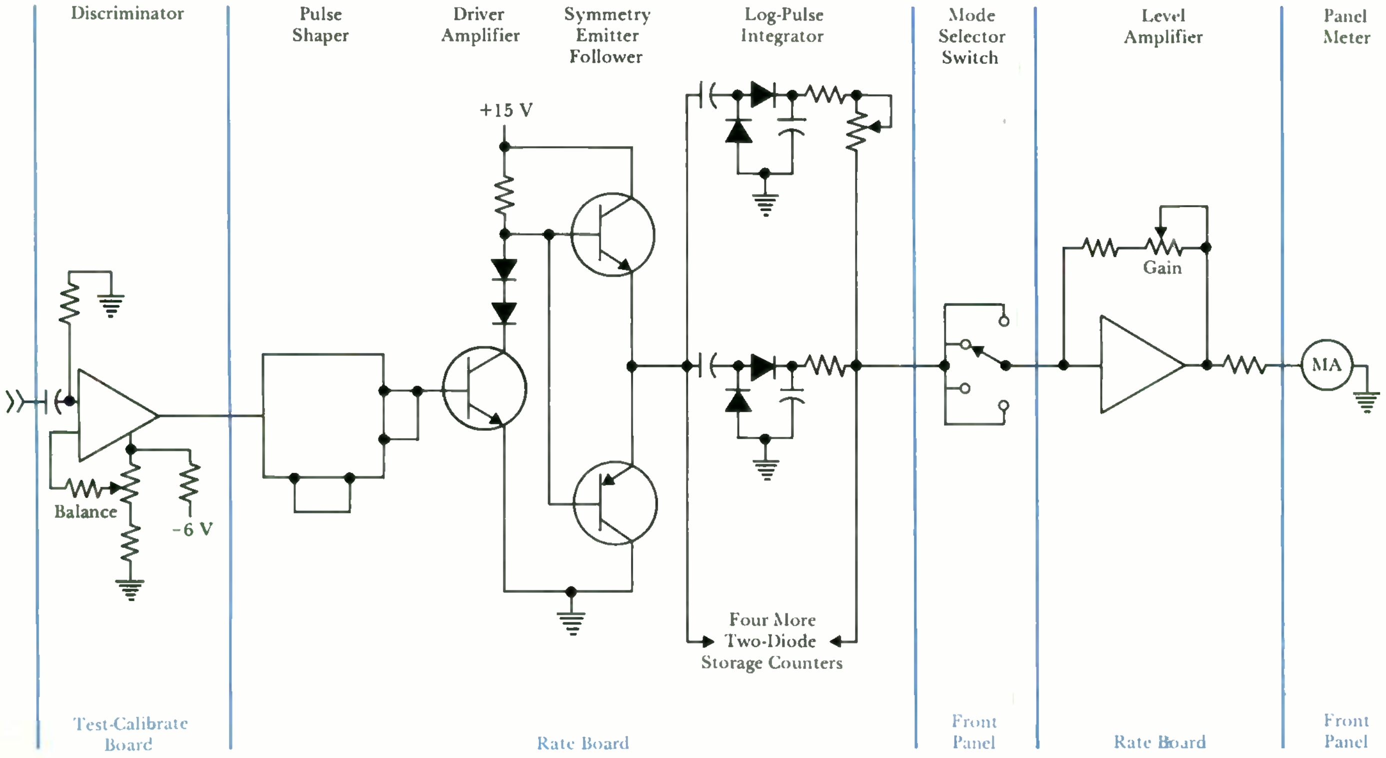
Pulse Shaper—The discriminator output (negative-going pulse chain) is routed to the pulse shaper, which functions as an on-off flip-flop. Each input pulse causes the output to change state and remain in an *on* or *off* condition until the next input pulse again changes the output state. Thus, the output of the pulse shaper is a 3-volt square wave whose duration corresponds to the time between the leading edges of successive input pulses.

Driver Amplifier—The output of the flip-flop is coupled to a driver circuit, where the square-wave amplitude is raised to 12 volts and coupled into the log-pulse integrator.

Log-Pulse Integrator—This circuit integrates the square waves to produce a dc voltage proportional to pulse *rate*.

The log-pulse integrator is composed of six parallel stages of two-diode storage counters, which integrate the square waves and produce an output voltage proportional to the rate at which the pulse shaper changes state. The range of response of the overlapping counters is 10^0 through 10^6 counts per minute. During the normal count mode (10^0 to 10^6 pulses), the output of the log-pulse integrator is routed to the input of the level amplifier.

Level Amplifier—This amplifier has an output proportional to the log-pulse integrator output. The output voltage varies from 0 to 10 volts dc with a maximum linearity tolerance of ±6 percent of full scale. The level amplifier has the following remote outputs: computer (0-5 volts dc), recorder (0-10 mV dc), and two remote meters (0-1 mA). The level amplifier also drives a 0-1-mA meter located on the front panel (as shown) and a level trip bistable circuit.



depending upon calibration and sensitivity range. For example, area monitor meters are marked and calibrated in decades of roentgens per hour (10^{-4}R to 10^{1}R/hr log scale); process meters are marked and calibrated in decades of counts per minute (10^{1} to 10^{6} log scale). The process meters are calibrated for the five decades of scale and for an expanded-range scale for the first three decades.

Radiation Detectors

Seven basic radiation detectors are employed in the RMS-100 system:

Air-Particle Detector—The air-particle detector (Fig. 4) monitors gamma activity that might be carried by particulate matter in the air.

The detector assembly consists of a radiation detector, a filter-paper drive mechanism in an airtight assembly, and a pump capable of delivering ten standard cubic feet of air per minute. The filter paper has a collection efficiency of approximately 99 percent for particles 1 micron or larger.

The detector is a scintillation type (thallium activated) sodium iodide crystal optically coupled to a photomultiplier tube. Crystal and tube are housed in a cylinder 2¼ inches in diameter and 12 inches long. The cylinder also includes the tube socket, a mu-metal shield, voltage divider network, impedance matching circuitry, and the appropriate connectors. Shielding is provided to permit detector operation at a maximum sensitivity in the specified radiation field.

The filter-paper drive normally operates at a speed of 1 inch per hour. The paper supply will last a minimum of 25 days at this speed. The drive also has a fast speed of 28 inches per minute for rapid advance to obtain a clean section of filter paper in front of the detector for true representative readings of the activity level, or to check proper feed of the filter paper.

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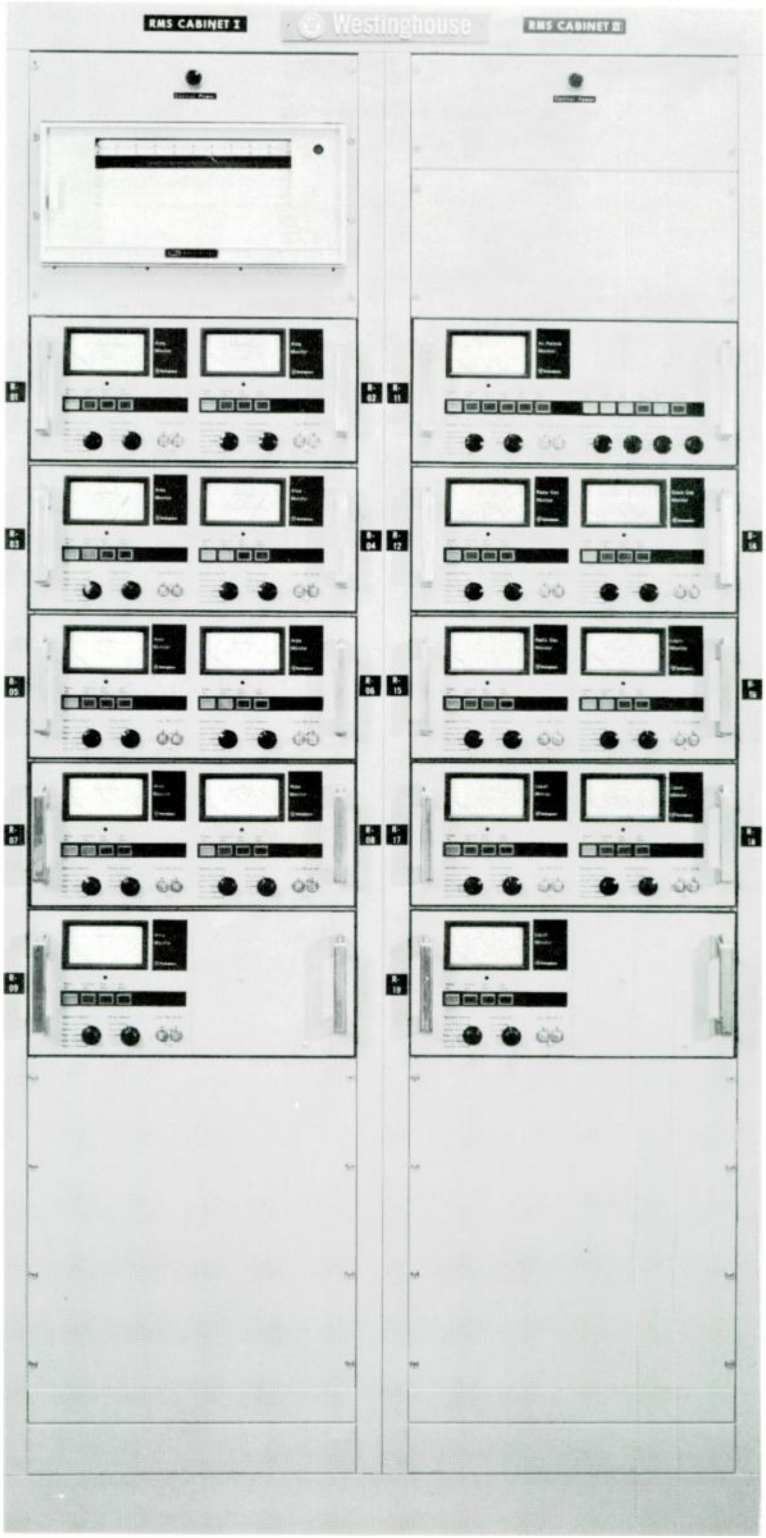

2—All of the computer/indicator circuitry is mounted in a single control console for installation in the plant control room.

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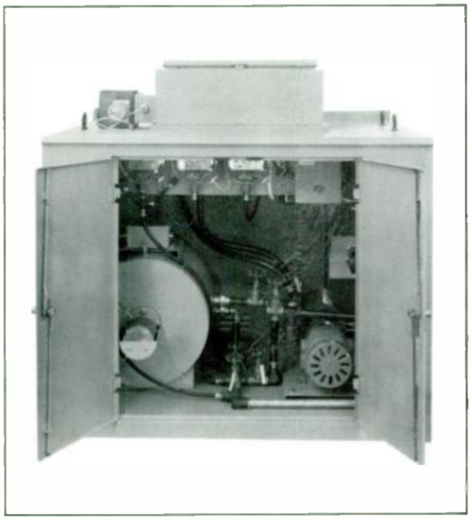

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An isokinetic nozzle is used to draw a sample from a moving air stream. Such a sampling system ensures a representative sample of particles of all sizes. The piping between the nozzle and the air particle detector should be short and have as few bends as possible in order to minimize trapping of particulates in the system.

Radio Gas Detector—The radioactive gas detectors are designed to measure beta-gamma activity in gases that are radioactive. There are two configurations of this detector assembly, an off-line and in-line model.

The *off-line* model (Fig. 5) consists of a welded steel tank, designed for cyclonic flow around the axis of the detector tube. The detector is a beta-gamma-sensitive Geiger-Mueller tube, which is mounted exactly in the center of the tank volume parallel to the length of the tank. The tube is mounted on a cylinder that also houses the high-voltage coupling circuitry.

The unit is designed for floor mounting and is shielded for operation in a specified radiation background. Sample volume is 0.1 cubic foot. Inlet and outlet connections are ½-inch stainless steel pipe. A 100-microcurie cesium-137 check source with actuating solenoid is mounted on the tank.

The *in-line* radio gas detector (Fig. 6) is functionally the same as the tank model except that it is mounted within a pipe that has flanges for mating with the plant piping. The sample volume is 0.5 cubic foot, and inlet and outlet connections are 8-inch 150-pound flanges. Shielding for the detector is provided

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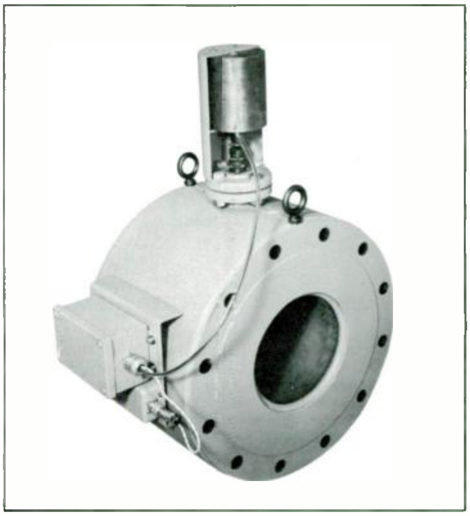

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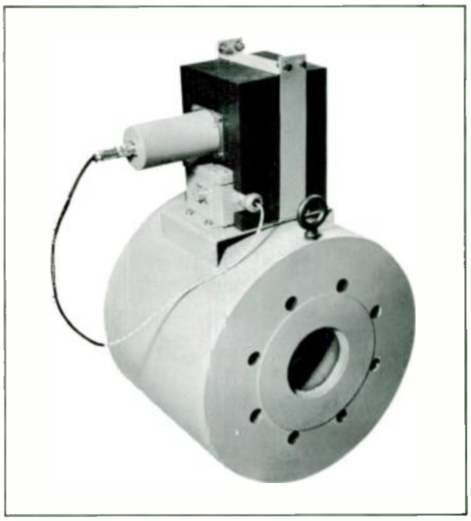

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3—The standard dual-channel drawer contains indentical computer/indicator circuitry for two channels.

4—Air particle detector assembly.

5—Typical tank-type (off-line) radio-gas monitor assembly.

6—Typical in-line radio-gas monitor assembly.

7—Off-line liquid sample monitor assembly.

8—Tee in-line liquid monitor assembly.

as required by the background radiation level. In-line monitors can also be supported with mounts on the detector assembly for floor mounting.

Liquid Monitors—The liquid monitors, in-line and off-line, are designed to measure gamma activity in a liquid processing line. The detector is a scintillation type. Both models operate at 150 psig and have a sample volume of 0.1 cubic foot. Both are shielded for operation in a specified radiation background.

The *off-line* liquid sample monitor (Fig. 7) has a welded noncorrosive sample tank designed for minimum particle drop-out or crud buildup from the continuous sample flow. The inlet and outlet connections are 1-inch socket weld connections. The check source is cesium-137 with a strength of 10 microcuries.

The *in-line* mounting monitor (Fig. 8) is designed to be inserted directly into large-diameter pipes. The mounting is accomplished with a 16-inch 150-pound flange, and the minimum pipe diameter is 20 inches.

Area Monitor—The area monitor (Fig. 9) is designed to measure gamma activity in various locations of the plant over the range of 0.1 milliroentgen per hour to 10 roentgens per hour.

The detector is a gamma-sensitive Geiger-Mueller tube designed for use in relatively high flux areas. A thin lead shield is provided to yield a ±20-percent energy response from 80 keV to 3 MeV. The tube is mounted with high-voltage coupling circuitry, impedance matching, a readout meter, alarm light, and buzzer in an enclosure designed for wall mounting.

The check source is approximately 1 microcurie of strontium-90. Solenoid actuation aligns the check source with the window of the detector to provide a 30- to 50-percent scale deflection.

Stack-Gas Monitor Assembly—The stack-gas detector (Fig. 10) monitors beta-gamma activity in the effluent gases emitted from the exhaust stack. The detector assembly consists of four Geiger-Mueller tubes mounted parallel to the effluent flow. The assembly is fitted into the stack with an 18- by 18-inch square flange. Included are two check source assemblies, consisting of four 10-microcurie cesium-137 sources.

Shielding Requirements—The shielding of the detectors is determined by the background radiation in which the channel must operate and also by the sensitivity level requirement of the channel.

Sensitivity and Background—The sensitivity of each monitoring channel is determined by the system's ability to discriminate between true events caused by the radiation being monitored and background events. In order to keep the sensitivity high, background levels must be kept low as possible. A reduction of the background by a factor of two approximately doubles the sensitivity.

There are two types of background interference: radiation background and electronic noise. Some radiation background is always present due to cosmic rays and other natural radioactivity. Non-natural background is reduced by surrounding the detector with several inches of lead shielding. Electronic background is kept as low as possible by the careful design of low-noise electronic systems.

System Calibration—All monitoring systems have been carefully calibrated. Area monitors are tested for sensitivity and accuracy over a wide range of radiation levels. Liquid and gas monitors are calibrated with prepared mixtures that closely simulate the energies and concentrations expected in a nuclear power plant under normal and accidental release conditions. The calibration is done in background radiation fields that approximate the actual operating environment. Periodic calibration checks of the system can be made by using standard sources in a reproducible geometric configuration.

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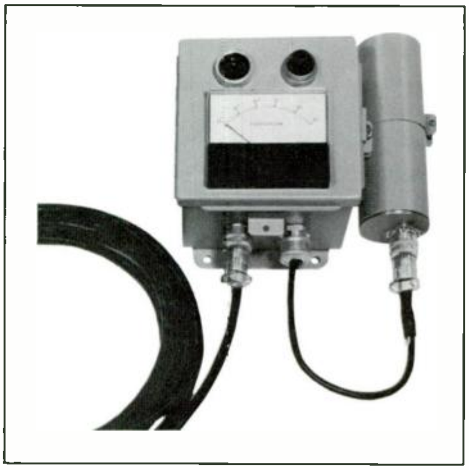

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9—Area monitor assembly.

10—Stack-gas detector assembly.

Modern Applied Mathematics and the Engineer

Robert Hooke

An engineer can increase his effectiveness by recognizing the need, when it arises, for modern mathematical techniques. He may not know how to use each technique expertly, but he can always consult a mathematical specialist.

There was a time when an engineer with a working knowledge of calculus and differential equations might feel that he could cope with most of the mathematical problems encountered in an average job. Times have changed. In the past two decades, the number of new mathematical tools applicable to engineering has grown beyond the capacity of a single person to use them all. Now, part of the engineer's job is to know enough about those new tools to recognize the need for one when it arises, even if he can't use the tool himself.

The rapid introduction of new tools is a big factor in the much discussed increased rate of obsolescence among engineers. One of the simplest and most effective ways of combating obsolescence is to learn to use specialists. The engineer who knows when to consult a mathematician or computer scientist, how to use his help in formulating problems, how to talk to him in general, and how to listen to and evaluate his solutions is well on his way to solving his own obsolescence problem.

The Applied Mathematician's Point of View

Why does "applied" appear in the title when so many mathematicians insist that pure and applied math are indistinguishable? They're right, of course, in the sense that we can never tell when today's pure math will be tomorrow's applied; however, the goals of the applied mathematician are very different from those of his pure counterpart. As applied mathematicians, we want to develop methods that (a) help us identify the client's "real" problem, and (b) help us to handle bigger and more complex problems.

As (a) suggests, the applied mathematician is very much concerned with his client and with the formulation of the client's problem, and the engineer should be aware of this interest. Formulation is the process of describing a physical situation with a mathematical model, using this model to define problems related to the questions the engineer wants answered, and determining whether the solutions really fit the physical situation or if they need some reformulation. (For a more complete explanation of this process, see chapter 2 of reference 1.)

For best results, formulation requires close cooperation between the engineer who understands the physical situation and the mathematician who can compare the various analytical techniques available; together they decide on a procedure that is relevant, yet not so involved as to be impractical or too expensive to carry out. In other words, today's applied mathematician does not, as some seem to think, simply solve equations that people poke under his door. Let's look now at some of the areas in which he works.

Uncertainty, Inference, and Investigation

Situations having uncertain outcomes are studied with mathematical probability. The most common engineering problems involving probability are those in the area of reliability. We can never say exactly how long a particular device will operate before it fails, but the pressure is on the engineer today to make quantitative statements about the overall reliability of his product. Such information might be used to estimate the cost of a warranty for a washing machine or to determine redundancy characteristics of a nuclear energy system that make system failure a virtual impossibility. Since failure is the ultimate fate of almost any device, complex systems consisting of numerous devices should be designed so that components can fail without causing system failure. That means redundancy, which adds further complexities such as possible failures of the required switching elements, need for routine inspection of standby elements, and the danger of having standby elements out of commission too often for inspection. Problems of this sort can't be handled without the use of mathematical probability theory.

Related to reliability theory is the problem of reliability testing. There are, unfortunately, people who think that reliability testing is something that can be negotiated between producer and consumer at a bargaining table, with "mathematical details" worked out later by an engineer.

For example, a producer makes a device with 0.99 reliability, which is satisfactory to the consumer. The device comes in lots of 100, and at a bargaining table it is decided to test 5 of these and, if one failure is seen, reject the lot. The same man who negotiated the test may tell his plant manager that a rejection rate higher than 1 percent is unacceptable. He may have made that decision, however, without full knowledge of its consequences: to keep the rejection rate down to 1 percent under the negotiated sampling plan, the plant manager will have to increase reliability to 0.998. That is, he must improve from the consumer-accepted failure rate of 1 per 100 to 1 failure per 500, which may mean a costly overdesign. (See *Testing and Reliability*, page 10.)

Statistics is the science of learning from data. People have been misled by data for centuries, for the science of statistics as we know it today has been developing only over the past few decades. When data points toward a certain conclusion, we have learned to ask ourselves questions such as these: (a) Could the data have occurred by chance, even though the suggested conclusion is not true? (b) Could there have been some bias in the data-collecting process that invalidates the conclusions altogether?

Answers to question (a) are provided by a host of statistical techniques based on the laws of mathematical probability. As for (b), statisticians have become expert at running down such biases, but once they are found there is often not much that one can do about them. The best thing is to avoid them by consulting

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a good statistician before conducting experiments or surveys. Means of producing data for efficient and unbiased inference have been developed to a high degree by statisticians working in the fields of design of experiments and population sampling.[2]

The term "experiments" just used suggests laboratory work, while the term "surveys" usually implies an interest in learning about people. Although the practical problems involved can be quite different, the basic statistical principles used are pretty much the same. Scientists are much concerned with design of experiments, for obvious reasons, but many engineers feel that they are not in the experimenting business. They may actually be in it, however, because anything called a test, with numerical results, has the problems associated with experiments. (For example, to show that lamps of a certain kind have an average life of at least 800 hours, statistical theory helps determine how many must be tested and under what circumstances.)

Systems and People

Most engineers hardly need to be told about systems. Growing interest in systems over the past 20 years has spurred growth in a number of mathematical areas, and engineers who deal with systems are usually aware of the new techniques that concern the strictly physical aspects of systems. Things change radically, however, if we consider the human users of systems as integral parts of them, and even more so if we go to systems whose working components

Testing and Reliability

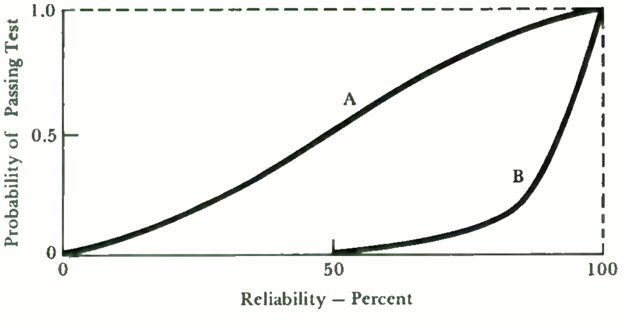
Suppose that 99-percent reliability in a particular product is satisfactory to both the consumer and the producer. Both parties must realize that tests are fallible. Whatever the test is, a product of greater than 99-percent reliability might fail it, and the probability of that happening is called the "producer's risk." Also, a product of less than 99-percent reliability might pass the test, and that probability is called the "consumer's risk." In any case, the greater the reliability of the product, the greater is its probability of passing the test.

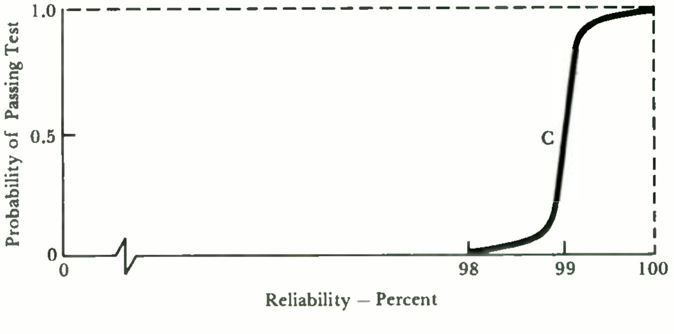
Curves *A*, *B*, and *C* illustrate three ways in which the probability of passing a test may depend on product reliability. Since both the producer and the consumer demand that their "risks" be small, the producer would like a curve such as *A* and the consumer would want a curve such as *B*. A curve such as *C*, however, makes both risks small, but it requires an enormous amount of sampling, an added expense to be shared between consumer and producer. We get a hint as to the difficulty here when we note that we are asking, for example, that curve *C* be close to 1 unit high when the reliability is, say, 99.1 percent, but that it be close to zero when reliability is, say, 98.9 percent; that is, we want a continuous curve to do all its rising in a very small range.

To achieve a more practical arrangement, the producer and consumer must take separate positions on the scale. That is, the consumer must back off and compute his risk at, say, 97 percent, while the producer computes his risk at, say 99.5 percent. In other words, the consumer agrees to a test that has only a 5-percent chance of accepting a product whose reliability is 97 percent, while the producer agrees to accept the test if it has only a 5-percent chance of rejecting a product of reliability 99.5 percent. This still requires a sizeable sample, as indicated by the following.

If a test consists of n items selected at random from a lot, all of which must succeed in order for the lot to be accepted, then the probability of acceptance (p) is $p = r^n$, where r is the true reliability, or probability that an individual item will succeed. This relationship always produces a curve like *B*, which is unlikely to be satisfactory to the producer. In a test where acceptance occurs if there is not more than one failure, the probability of acceptance is $p=r^n + nr^{n-1}(1 - r)$. This equation produces a curve that is flat at $r = 1$ (as is curve *A*), but n has to be pretty large before it appeals to the consumer. For example, if the consumer expects 99-percent reliability, he obviously wouldn't be happy with a value of n less than 100.

There are many ways of approaching this problem, but all we have space for is an introduction. One thing that should be understood, however, is that a destructive test doesn't guarantee a certain degree of reliability in the output. If 99-percent reliability is the goal, and a test is designed for this, what happens if the true reliability of lots is always less than 95 percent? The answer is that most of them will be rejected, but some will be accepted, so the reliability of the accepted product never exceeds 95 percent. A test will improve the reliability of the overall product only to the extent that it will accept mostly the best; if the best is not good enough, the test can't make it better. This fact should help both producer and consumer realize that they have a joint responsibility to see that the design and manufacturing methods produce a satisfactory product; routine tests are made, not to insure that the product is satisfactory, but to catch any deviations of unusual magnitude. If that goal is agreed on, large samples are not needed.





are people, such as schools, hospitals, or law enforcement agencies.

When it comes to people, the engineer is often guilty of declaring them someone else's problem, but that attitude must change. With increased emphasis on consumer protection, side effects such as pollution, and general systems problems generated by our increasing population, people are becoming components of almost every problem. The engineer often hesitates to go into this area, since he feels that he is leaving a region of small variability for one in which the variability is much larger. If it is any consolation to him, he can reflect on the fact that much of the "small variability" was in his own imagination. The lifetime of even a good product varies greatly, perhaps even more than that of people; for example, a single lamp that lasts three times the average is not unheard of, but no people are able to do that.

Products and people both have averages and variability. Finding the averages is a statistical problem. The greater the variability, the larger must be the number of observations to determine the average, but that is not the only problem caused by variability. If we are going to satisfy customers, we must abandon the idea that they are all average. Even if we can't afford to cater to the most extreme people, there are masses of individuals between mean and extreme whose desires can be found by careful study involving good statistics.

The factor that creates a need for a different point of view in systems studies is sometimes called the "stochastic" element, a term used by mathematicians to describe events that are random in nature; in physical problems we usually have to treat events as stochastic if their underlying causes are so overwhelmingly complex that it is fruitless to try to trace the entire cause-and-effect history. A hospital can't be very closely described by a set of differential equations. In concept, perhaps, it could if one knew the mental and physical state, as a function of time, of each hospital employe and of each patient and potential patient from the surrounding area. But even if one could get such information, he would not be able to process it all.

When people become an integral part of a system, the stochastic element becomes an important part of the system description. If the system is simple enough, we may be able to handle it with mathematical probability, but if not we have to use simulation. A typical application of probability theory is illustrated in *Beds for a Hospital*, page 12.

In simulation, we describe a problem situation mathematically and then try to reenact the situation in detail on a computer. How long will it take a rapid-transit vehicle to travel 5 miles, stopping for passengers at four stations? If we assume an average speed and an average stopping time, the answer is obvious, but average behavior is not what causes difficulties in a transportation system. Stops take longer than usual if a few more people than usual are waiting, and, in some systems, that might slow down the progress between stations.

Determination of the vehicle's trip time requires knowledge of the probability distribution of passengers at each stop; this determination should also include the variability, which can be described in terms of the probability distribution of the trip time. In simple cases, this problem could be handled by direct probability methods. However, if there are several transit lines, with people transferring and perhaps with cars waiting for other cars at certain points, then small departures from average behavior can lead to large buildups of congestion. A quantitative study of this phenomenon can be made only by computer simulations. For large systems, computer simulation can be expensive, but, compared with the expense of experimenting with actual systems, the cost is usually trivial. Often the expense of computer simulation can be greatly reduced if a good mathematical analysis of the problem is carried out first.

People who do quantitative studies of the operation of complicated systems, such as transportation, traffic, assembly lines, hospitals, and urban renewal, sometimes refer to their field as operations research, or simply OR. There is some overlap among OR, systems analysis, management sciences, etc., but name tags are not our concern at the moment. The point is that many large systems have about reached their limit in unplanned growth, and, to avoid chaos, we must now plan them with greater consideration of how they will interact with the people who use them. We must get away from the attitude that describes the efficiency of a transit system in terms of dollars per passenger-mile (based on the unrealistic assumption that passengers will be there whenever we decide to pick them up) and learn how to describe the system in terms of how long it takes a passenger to get where he wants to get, starting from the time he wants to leave.

This philosophy has been used in the planning of elevator systems and is featured in the simulator developed at the Westinghouse Research Laboratories to study such systems in high-rise office buildings.^{3} With that simulator, passenger traffic is generated through the use of appropriate mathematical models. Such traffic is then carried on the simulated elevators and a full history of service rendered is recorded. An improved or even optimal system can be achieved by studying the variation of important measures of service, such as the average times for elevators to answer calls, as a function of system parameters that can be controlled.

Looking for the Best

When an engineer is looking for an alloy with maximum toughness, a chemical process with maximum yield, a wire with the smallest number of imperfections, or any of hundreds of similar goals, he is optimizing. Mathematicians express such problems as finding the maximum (or minimum) value of some function of n variables, $y=f(x_1, x_2, \ldots, x_n)$, possibly in conjunction with several constraints that must be satisfied by the independent variables, $x_1, x_2, \ldots, x_n$.

Every calculus student knows that the unconstrained problem can be solved by taking the derivative of y with respect to each of the x's, setting the results equal to 0, and solving the resulting system of equations. A little later he learns that the constrained case can be handled by Lagrange multipliers, and he considers the optimization situation to be well in hand. Then he goes out and finds real problems in which the system of equations can't be solved, or the function doesn't have derivatives, or the function isn't known, or there are so many variables and constraints that he can't find a feasible working procedure. Such real difficulties have led to many developments in mathematical optimization theory in the past 20 years.

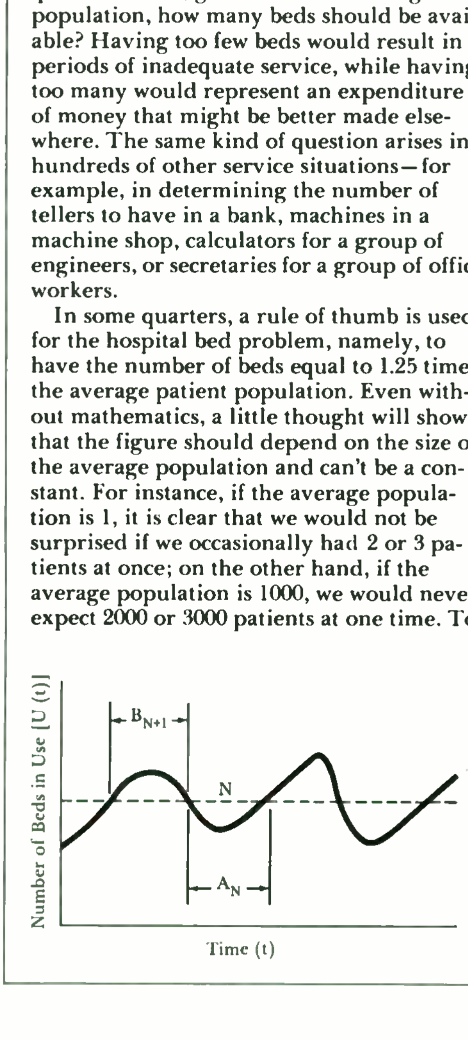
If the function is unknown, but its value can be determined experimentally at any given setting of the x's, then the problem is one of experimentation, and procedures for such "exploration of response surfaces" can be found in books on design of experiments. If the function is unknown but its value can be calculated at any given point (e.g., by solving some differential equations or reading values from graphs), then the problem is a search problem that can be performed on a digital computer. In recent years a number of search strategies have been developed to facilitate the solution of such problems.

If the function and its accompanying constraints are explicitly known, the problem belongs to the general area known as mathematical programming, not to be confused with computer programming. For example, if the "objective function" is linear (say $y=170x_1+200x_2+125x_3$) and the x's are subject to linear constraints (such as $x_1, x_2, x_3>0$; $25x_1+30x_2<400$; and $10x_2+20x_3<200$), then

Beds for a Hospital

A hospital with a given average population of patients sometimes has more and sometimes fewer patients than the average. The question arises, given a certain average population, how many beds should be available? Having too few beds would result in periods of inadequate service, while having too many would represent an expenditure of money that might be better made elsewhere. The same kind of question arises in hundreds of other service situations—for example, in determining the number of tellers to have in a bank, machines in a machine shop, calculators for a group of engineers, or secretaries for a group of office workers.

In some quarters, a rule of thumb is used for the hospital bed problem, namely, to have the number of beds equal to 1.25 times the average patient population. Even without mathematics, a little thought will show that the figure should depend on the size of the average population and can't be a constant. For instance, if the average population is 1, it is clear that we would not be surprised if we occasionally had 2 or 3 patients at once; on the other hand, if the average population is 1000, we would never expect 2000 or 3000 patients at one time. To show how the fluctuations depend on the size requires some mathematics and a mathematical model.



Many different mathematical models are available for problems of this sort, with different physical situations demanding different treatments. Features of any given model are these: (a) A random process that describes the distribution of arrival times, i.e., times when a new customer (in the hospital case, a new patient) arrives. (b) The number of "servers" available (beds, in the hospital case). (c) A priority procedure for determining the order of service and assigning customers to servers, and a description of what happens to a customer if the servers are all occupied. (Does he join a waiting line, receive inferior service, or is he sent away?) (d) A random process that describes the distribution of service times, i.e., the times that tell when a customer has received his service and can be released.

In the hospital problem, the number of servers is treated as infinite. That is, even during periods when patients outnumber beds, some way is found for caring for them though it may not be normal care. Times between arrivals are assumed to have a negative exponential distribution with mean $1/\lambda$. (Also called a Poisson process with rate λ.) Service times are assumed to have a similar distribution with parameter $1/\mu$. Queuing theory shows that the number $U(t)$ of beds in use at time t is a random variable whose distribution is also Poisson. That is,

$$\text{Prob}[U(t)=n]=\frac{(\lambda/\mu)^n}{n!}\,e^{-\lambda/\mu}$$

where $n=0, 1, 2, \ldots$

Now if N is the number of beds, there are periods of time when there are enough beds (N patients or fewer) and periods when there are not. The length of a period of the former type is called A_N, while one of the latter type is called B_{N+1}. These are illustrated in the figure, which shows $U(t)$ as a function of t. Clearly, we don't want to be in periods of type B_{N+1} too often, but it isn't too bad if they don't last too long.

Queuing theory produces values for the mean (expected value) and variance of A_N and B_{N+1}. For example, if the average number of new patients per day is 20, and if the average stay of a patient is 9 days (i.e., $\lambda=20$, $\mu=1/9$), then the average number of patients in the hospital is 180. The expected values of A_N and B_{N+1}, written as $E(A_N)$ and $E(B_{N+1})$, depend on N as follows:

N—Beds	$E(A_N)$—Days	$E(B_{N+1})$—Days
180	0.9	0.81
200	4.8	0.34
220	117.5	0.20

For 180 beds, the periods (A_N) when there are enough beds are short, and barely longer than the periods (B_{N+1}) when there are not enough. Twenty additional beds make a big difference, as the table shows. The probability of having enough beds at a given moment is approximately $E(A_N)/[E(A_N)+E(B_{N+1})]$, so, in the case of 200 beds, this probability exceeds 0.93.

Many different kinds of problems can be stated and solved through queuing theory. The example just described was a simple one for illustrative purposes; additional complexities due to constraints in real situations can often be handled with simulation if necessary.

finding the maximum value of y is called a linear programming problem. Linear programming is an appropriate way of looking at many situations, especially, for example, those that involve allocation of limited resources. Computer programs are available to solve such problems even though they may involve hundreds of variables and constraints. (For more information, see chapters 9 and 11, reference 1.)

As the objective function and constraints become nonlinear, the problem, of course, becomes more difficult. Various methods have been devised to take care of these more complicated cases. One that has proven most useful in optimizing engineering designs, and which was initiated and developed at the Westinghouse Research Laboratories, is called geometric programming.[4,5] The functions used in geometric programming are called "posynomials," and they permit all products and powers of the variables. This class is general enough so that most engineering design problems for minimizing cost, weight, volume, etc., subject to constraints, can be put into posynomial form and solved by geometric programming. Because of this generality, the method is now widely used in a variety of application areas.

The Traditional Tools

Meanwhile, of course, classical analysis and algebra haven't been standing still. The production of new techniques in those fields has filled a growing number of mathematical journals around the world. Possibly the most radical developments have taken place in numerical analysis.

Numerical analysis is the study of numerical approximation methods that can be used when exact, or "closed form," solutions don't exist or are too clumsy to use. Horner's method for solving equations and Simpson's rule for evaluating definite integrals are simple examples that readers may recall from their elementary courses. The overall subject has developed into a complex science with batteries of procedures available for use in solving algebraic, differential, or integral equations, inverting matrices, interpolating and smoothing, inverting transforms, optimizing, etc.

Numerical analysis has been around as long as mathematics, since we have always needed useful approximations to solutions that couldn't be found exactly, and mathematicians have always been interested in finding ways of determining how good these approximations are. The big impetus to the growth of the subject, though, came with the development of the digital computer. Ability to do calculations so much more rapidly meant that many problems could now be tackled that were too big or too nonlinear to have been considered before.

The speed of modern computers is so great that one can easily fall into the trap of believing that they can do anything in a few seconds. Actually, once we begin to see how the computer enables us to set up more realistic models for complicated problem situations, we find that it is easy to set up problems that the computer can't solve within a lifetime. It thus remains important to use the most powerful mathematical tools available before we set up the problem for computer processing.

Consider, for example, the "traveling salesman problem." Here there are N cities, with a given travel distance from each city to each other one. A salesman wants to visit all the cities, returning to the one from which he started, with a minimum amount of travel. Traditional mathematics considers the problem to be solved by noting that there are $[(N-1)!]$ different routes; the distance involved in each can be easily computed by addition and the results compared to see which is the minimum. Each of these computations involves N additions, so the total number of additions is $N!$. When it comes to doing this work, though, we find that the size of N is crucial. For instance, if $N=3$ we can solve the problem by hand. If we could perform, say, 30 additions per minute on a desk calculator, we could solve a 7-city problem in a little under 3 hours. A digital computer that could perform each addition in 10 microseconds could solve a 10-city problem in about a half a minute, but it would take about a hundred years to work a 17-city problem in this crude fashion.

Clearly, if the problem involves much over 10 cities we must find mathematical ways of reducing the problem, since we don't have time to do it by brute force. The traveling salesman problem is an example of a combinatorial problem, a category of algebraic problems involving large numbers of discrete cases that has received much attention in recent years. Many combinatorial problems are unsolved, but enough is known about them to show that some well-placed mathematical analysis in solving them may save some enormous computer bills.

Summary

Any technical person can delay his obsolescence by learning how to use specialists, and the time to bring in mathematical specialists is during the formulation of a problem. Good applied mathematicians are concerned not just with solving mathematical problems, but with finding out what the crux of a situation is and with using mathematics to make the situation more favorable for the people involved in it.

Increasing concern for interactions with people means increasing attention is necessary to the really difficult aspects of problem situations. Doing something useful with these complexities requires that we make sure we don't, from ignorance, neglect the tools that can help us. The computer is a tremendous aid in solving large problems, but it is still not a substitute for thought.

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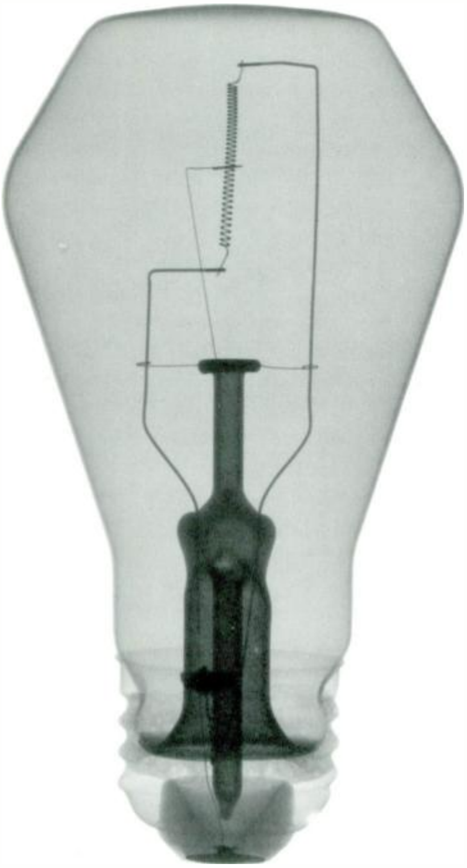
Strengthening Metal with Bubbles

H. G. Sell
R. Stickler

Great strength is imparted to tungsten for incandescent lamp filaments by a sequence of alloying, heating, and working steps. New insight into how those steps produce a dispersion of tiny bubbles, and into the strengthening role of those bubbles, holds promise for even stronger filaments and other metal structures.



1—A lamp filament is a coiled or double-coiled tungsten-alloy wire, supported in a glass bulb as revealed by this radiograph of a Westinghouse Krypton lamp. The filament needs great strength at high temperature to maintain its shape under the influences of gravity, shock, and vibration.

The tungsten-alloy filament of the common incandescent lamp is a unique material, without an equal so far as strength at high temperature is concerned. Lamp engineers have known since 1922[1] how to produce the alloy by combining tungsten with very small amounts of aluminum, potassium, and silicon, but they haven't known why those elements impart such strength—a strength all out of proportion to their concentrations in the alloy.

Recent research at the Westinghouse Lamp Division and at the Research Laboratories has provided the answer to the mystery. It turns out that the alloy's great high-temperature strength comes from submicroscopic bubbles (formed by the alloying elements) in conjunction with filament fabrication steps that combine heavy deformation with intermittent heat treatments. The new insights raise intriguing possiblities for further controlling the properties of alloys for lamp filaments and other applications.

Lamp Filaments

Strength at high temperature is necessary for a lamp filament because it enables the filament to retain its initial shape (Fig. 1). A filament is not a straight wire but instead is coiled into a helix, and the helix itself is frequently coiled to make a "double-coiled filament." Retaining that initial shape is important for two reasons.

First, if the filament were to sag enough it could touch the glass bulb and melt a hole through it. Second, the coiled configuration reduces heat losses, and thereby increases efficiency, by promoting interturn heating through radiation and by reducing the effective surface area from which heat is lost. Even minor sagging would decrease lamp efficiency by causing the windings to open up.

The natural tendency to sag under the effects of gravity, vibration, and high temperature is what is prevented by "doping" tungsten with aluminum, potassium, and silicon. AKS doping, as it is often called, is so effective that a double-coiled filament made from wire of approximately 50-micrometer (μm)* diameter, operating at 2500 degrees C, remains dimensionally stable for more than 1000 hours.

The mystery has been that the concentration of doping additions in the wire is much too low to account for the observed strengthening by any of the classical mechanisms.

Strengthening Metals

Metals are normally polycrystalline materials, made up of individual crystallites (also called "grains") that are regions of a relatively high degree of perfection with respect to the arrangement of atoms in the crystal lattice. The areas where the crystallites are in contact with each other are called grain boundaries.

Some imperfections, primarily subboundaries and dislocations, are always present within crystallites. Subboundaries are features that separate portions of slight orientation differences (a few degrees) within the crystallites; dislocations are defects of linear extension in the otherwise regular atomic arrangement of a crystallite.

Because of this crystalline structure, there are two main strengthening mechanisms for metals. One consists of making it harder for grains to slide over each other under an applied stress. The other consists of making it harder for dislocations and subboundaries to move through the crystallities when stress is applied. Movement of dislocations is impeded when two or more meet and "entangle" each other; consequently, one way of hardening and strengthening a metal is by increasing the number of dislocations, as by working. Another is by adding other barriers, such as dispersed particles, to impede movement of dislocations.

A metal hardened by working can be softened (to facilitate further working, for example) by annealing, that is, by heating it to a temperature at which dislocations and other defects disappear. This "recovery" process is most thorough when the heating temperature is high

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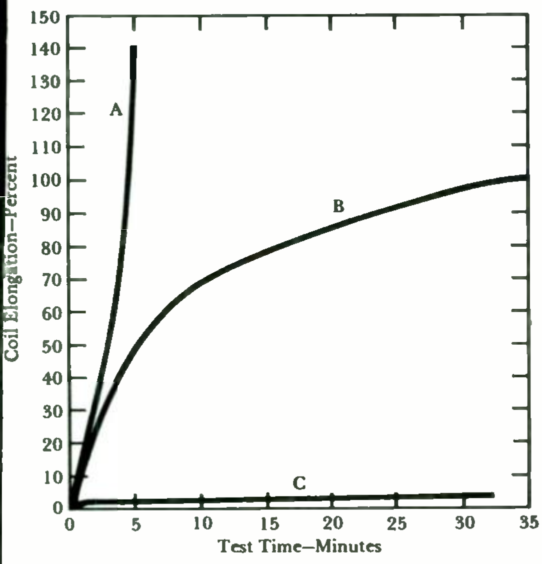
*25.4 μm=0.001 inch.



2—The required strength is provided by AKS doping of the tungsten. Its effectiveness is illustrated by this comparison of the sagging of undoped (A), thoria-doped (B), and AKS-doped (C) tungsten coils at 2500 degrees C when subjected to identical stress. In the pure tungsten coil, grain boundaries can slide over each other and dislocations are relatively free to move, so sagging is rapid. In the thoria-doped coil, dispersed thoria particles prevent grain boundaries from sliding as readily as in the pure tungsten coil, and they also pin dislocations to some extent. In the AKS-doped coil, dislocations are practically immobilized by the tremendous number of very small bubbles; in addition, grain boundaries interlock for further strengthening.

enough to cause complete recrystallization, which transforms the grain structure distorted by working back into a more perfect strain-free structure of new grains. The more dislocations there are in the structure initially, the lower is the temperature at which recrystallization starts; the more barriers there are to dislocation movement, the higher is the temperature that must be reached to cause recrystallization.

In practice, two common methods of strengthening a pure metal are by alloying with other elements and by adding fine particles of such materials as oxides, carbides, or nitrides. The first method produces a single-phase alloy, which is an alloy that has only one type of crystal structure, such as body-centered cubic. (A "phase" is a homogeneous physically distinct and mechanically separable portion of a mixture.) A single-phase alloy is stronger than the pure metal because the atoms of the constituent elements differ in size, and the difference creates lattice strains (distortions) that make it more difficult for dislocations to pass through under stress.

The other method, adding fine particles, produces a dispersed-second-phase alloy, which is one that has material of one crystal structure dispersed in material of another. Dispersed particles strengthen the alloy in two ways: they "pin" dislocations and subboundaries in place even when the wire is raised to high temperatures, effectively raising the recrystallization temperature; in the recrystallized material, dispersed particles again impede the motion of dislocations and also that of grain boundaries when a stress is imposed, thus preventing plastic deformation.

However, AKS-doped tungsten is not a single-phase alloy. Neither is it a conventional dispersed-second-phase alloy; particles have rarely been observed in it, and, although the dopants are initially added to the tungsten as oxides, they are reduced to elemental form by subsequent processing.

Clearly, something other than particles or the alloying elements per se must be responsible for the tremendous strengthening effect observed in wire of AKS-doped tungsten. That "something" is now known to be the presence of tiny bubbles, brought about by the fabrication process, and their effect on recrystallization temperature and recrystallized grain structure. In particular, an interlocking grain structure in the heavily worked and recrystallized wire distinguishes AKS-doped tungsten from pure tungsten and other alloys (Fig. 2).

AKS-Doped Tungsten

AKS-doped tungsten is produced by powder metallurgy techniques. Oxides of the doping elements are added to tungsten trioxide powder, and then the latter is reduced to tungsten metal powder by heating in hydrogen. The resulting alloy powder is pressed into a bar, which is consolidated into an ingot by sintering at about 2800 degrees C.

Although the dopant oxides are added in rather large concentrations (about 1 weight percent), only potassium remains in significant concentration in the sintered ingot—0.007 to 0.01 weight percent, as compared with aluminum and silicon with 0.001 to 0.002 each.

The retention of potassium at even that level was a startling finding, since potassium is a very volatile metal. Theoretically it should not be retained at all; potassium boils at 760 degrees C, and sintering exposes a tungsten ingot to 2800 degrees C for about 20 minutes. However, we know now that, in a fashion not yet fully understood, potassium is trapped in pores during processing and that the other two doping elements, aluminum and silicon, are needed to make this possible. Thus, a sintered ingot of AKS-doped tungsten is not a single-phase alloy and yet not really a dispersed-second-phase alloy. The most we can say is that it is a material that has pores containing potassium.

Why is potassium trapped and not also aluminum and silicon, which are much less volatile? It is because potassium is essentially insoluble in the tungsten matrix, even at temperatures as high as 3000 degrees C. The potassium atoms are so much larger than the space between the tungsten atoms that they cannot diffuse from the interior to the surface and

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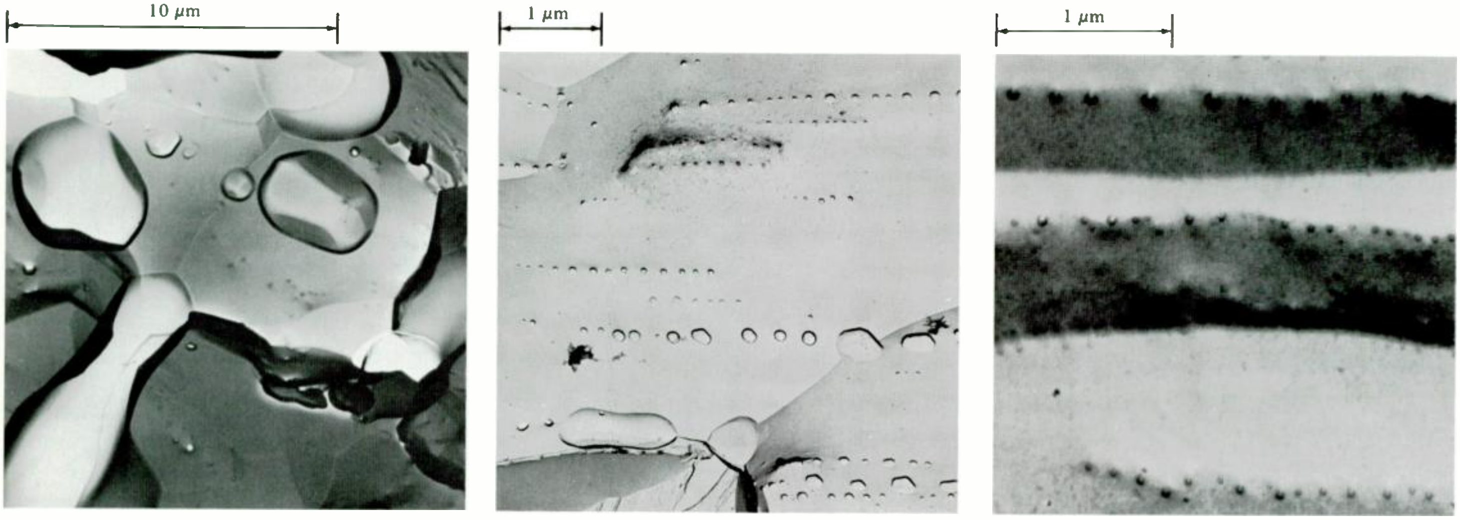
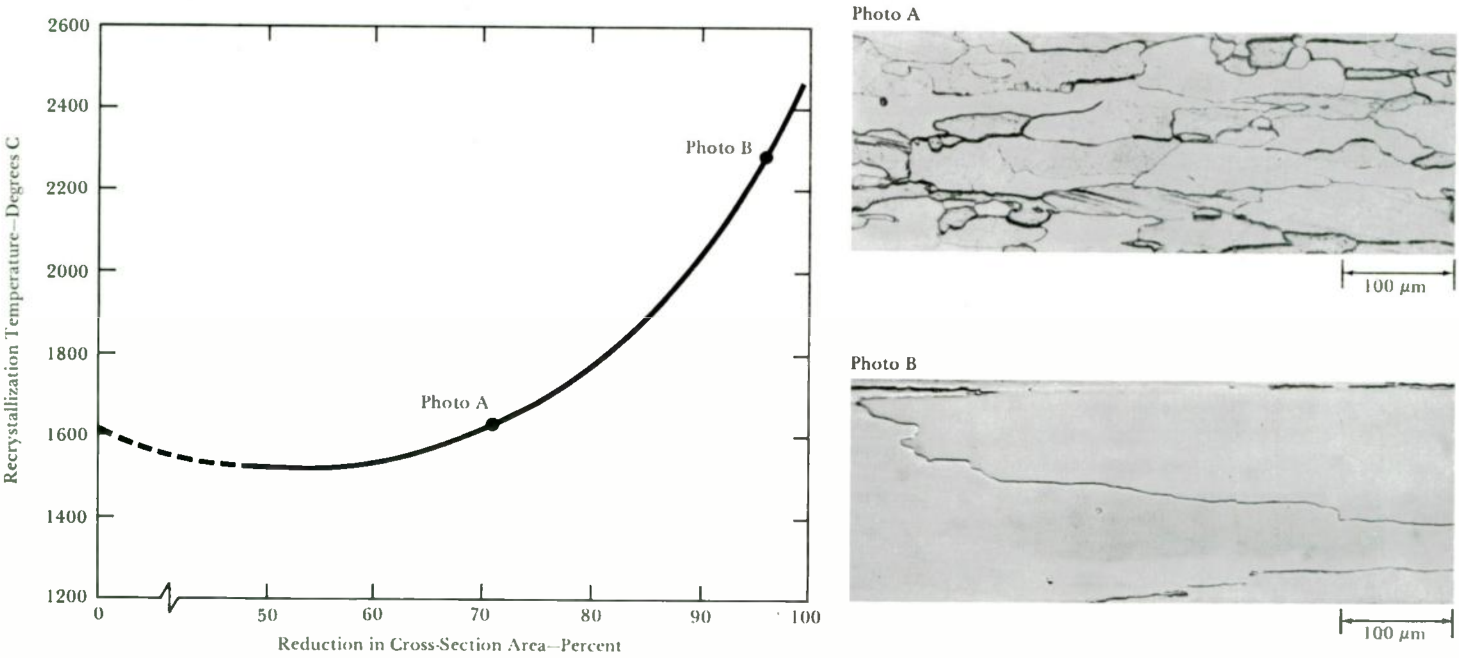


Sintered Ingot

Drawn Wire (880 µm diameter)

Drawn Wire (180 µm diameter)

4



thus must remain as vapor bubbles distributed throughout the ingot. When the ingot cools, the vapor condenses into droplets of potassium metal inside the bubble cavities.

The next step in wire production is swaging and rolling the ingot into rods of smaller and smaller cross section. For swaging or rolling, an ingot must first be heated to about 1600 degrees C to make it workable. As the cross section decreases in successive steps, the heating temperature is decreased (until it is about 1200 degrees C at 5-mm diameter) to increase the amount of cold work and thereby achieve the desired potassium distribution and grain structure.

A further and much more fundamental requirement to produce high-quality tungsten filament wire is periodic recrystallizing of the rod, at various stages of working, to facilitate further reduction. The rod is recrystallized by heating to temperatures of 2000 to 2200 degrees C. The final such heat treatment must be performed at a rod size that, upon further reduction (primarily by wire drawing, which starts at about 2.5-mm diameter), assures a very high degree of deformation in the wire of final size. To this end, the working temperature is further decreased, first to 1000 degrees C and then gradually to about 600 degrees C (below the boiling point of potassium) as the wire approaches final diameter (approximately 25 to 200 μm).

3—Potassium bubbles provide the basic strengthening mechanism in AKS-doped tungsten. Working, with intermediate recrystallizing, disperses the potassium and thereby brings about a finer and more effective dispersion of the resulting bubbles with increasing reduction in wire cross section. The photographs show bubble size and configuration in three fabrication stages.

4—The role of working in dispersing the potassium is verified by the effect of deformation on recrystallization temperature and recrystallized structure of doped tungsten rod and wire. Recrystallization temperature decreases at first but then increases as the bubbles become increasingly effective in impeding movement of dislocations and in promoting the elongated interlocking grain structure. (The reduction in wire cross-section area is after the last recrystallization anneal in the process.)

The effectiveness of those processing steps springs from their action on the pores containing trapped potassium. Fabricating the ingot into a rod, that is, reducing its cross section and increasing its length, also elongates the pores. Further working first deforms the pores into needlelike shapes and then pinches them off into segments, with each little segment having some of the potassium of the parent sintering pore.[2] Thus, working serves to disperse the potassium (Fig. 3). The greater the deformation, the finer is the dispersion.

Further convincing evidence of the importance of potassium dispersion by working is the effect on the recrystallization temperature. Up to about 50 percent reduction in cross section, AKS-doped tungsten has the normal recrystallization behavior of pure metals or of single-phase alloys, in which the recrystallization temperature decreases with increasing amounts of deformation. However, when the degree of deformation exceeds about 50 percent, and the working temperature is low enough to prevent recovery (less than 1000 degrees C, as in wire drawing), the recrystallization temperature increases contrary to expectations and the recrystallized grains assume the characteristic stable interlocking structure that is shown in Fig. 4.

Even in the drawn condition at any wire size, however, AKS-doped tungsten is not a dispersed-second-phase alloy in the true sense. The minute globules of potassium in pinched-off pore segments are simply too small (less than 0.0025μm) to be effective strengtheners.

To transform this worked AKS-doped tungsten into a dispersed-second-phase alloy, the wire must be heated to a temperature in excess of about 1400 degrees C. Then the magic occurs: billions of bubbles nucleate and grow to a size of 0.01μm, the interlocking grain structure forms, and tungsten has been converted to the strong material required for lamp filaments.

On first impulse it is hard to see how bubbles can form and persist in tungsten, a metal so hard that it requires a stress of more than 1000 psi even at 2500 degrees C to undergo any deformation within reasonable time. However, bubbles can form in *any* solid if a bubble-forming element is present as a globule and if it can develop a sufficiently high vapor pressure by being heated to the required temperature.[3] Potassium does have a high vapor pressure (about 600 psi at 1400 degrees C), and the processing of AKS-doped tungsten does involve such temperatures.

The bubbles are stable because, as pointed out before, the tungsten lattice is not permeable to potassium vapor at normal filament operating temperatures (2000 to 3000 degrees C). Bubble stability is essential, because the continuing presence of bubbles is what makes doped tungsten filaments useful.

The Strengthening Mechanism

How can submicroscopic bubbles in a metal matrix perform like hard particles in strengthening the metal? For tungsten, the answer is found in the fortunate fact that the properties of potassium and tungsten are uniquely matched. Tiny globules of potassium embedded in the drawn tungsten wire vaporize and form bubbles in the same temperature range in which recovery of the worked tungsten structure takes place, that is, in the temperature range in which dislocations and subboundaries anneal out. Without invoking fundamental concepts about recovery, nucleation, and recrystallization mechanisms, we can simply say that at some point in the recovery process the bubbles have grown to a size at which they effectively pin the remaining dislocations and subboundaries.

Pinning interrupts the recovery process, so the bubbles make it immensely more difficult for complete recovery, or recrystallization, to take place. Whereas an undoped tungsten wire 250 μm in diameter recrystallizes completely at 1400 degrees C in less than 30 minutes, the same size AKS-doped tungsten wire must be heated to 2200 degrees C to recrystallize it.

Another important factor is the distribution of the bubbles. They are aligned in rows parallel to the wire axis, i.e., in the working direction (Fig. 5). This dis-

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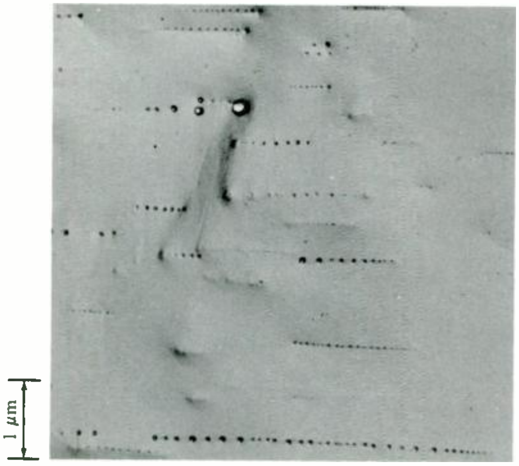

5—The bubbles form in rows oriented in the working direction, and therefore they tend to force the same directionality on grain growth when the wire is recrystallized. The illustration shows bubble rows parallel to the wire axis in an 880-µm AKS-doped tungsten specimen annealed in vacuum at 2500 degrees C for 5 minutes.

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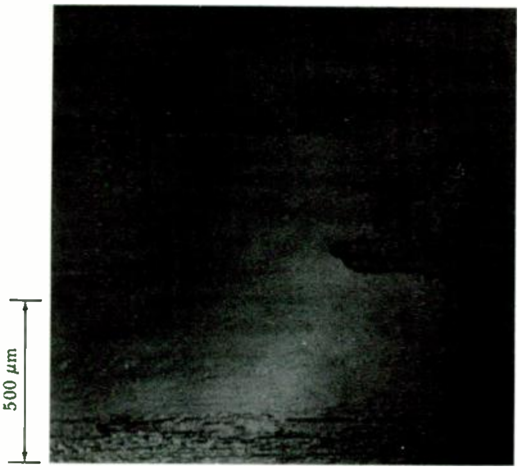

6—The grains mesh with each other as they grow, creating the interlocking grain-boundary structure that strengthens recrystallized AKS-doped tungsten wire. Boundaries of two recrystallizing grains are shown here.

tribution forces on the recrystallization process a directionality that is absent in undoped tungsten: the grain boundaries are discouraged by the bubble rows from migrating in a radial direction but are relatively free to move *parallel* to the bubble rows, that is, parallel to the wire axis.

We can now rationalize how the elongated interlocking structure comes about. Boundary segments of grains expanding in opposite directions move into each other like the fingers of our two hands, which mesh when they are folded (Fig. 6). And like the strong grip of folded hands, the interlocking of the grains tends to prevent grain boundaries from sliding over each other and thus gives the filament much greater strength at the grain boundaries than it otherwise would have.

One further important point must be considered. The recrystallized grains are frequently long, 10 cm or more, and they often extend over the whole cross section of the wire. Those grains are single crystals, which are intrinsically weaker than a polycrystalline matrix. What makes the large individual grains resist deformation? The answer is that the bubbles provide a dispersion-strengthening effect in the same manner as particles do in a dispersed-second-phase alloy. Dislocations moving under an imposed stress are pinned by the bubbles, preventing other dislocations from moving. Thus, creep deformation is prevented.[4]

To summarize, it has been apparent all along that the interlocking recrystallized structure is a consequence of the doping additives. What was not realized until now is how the interlocked grain structure is formed and that the strengthening mechanism within grains is a kind of dispersed-second-phase strengthening by a fine dispersion of bubbles.

Future Outlook

Like all new insights and developments, the possibility of strengthening metals (and solids in general) by bubbles will lead in due time to new applications. The application most immediately related to the discovery of the strengthening mechanism in AKS doping is, of course, development of longer-life lamps in which life is not extended at the expense of luminous efficiency as it is if operating temperature is merely lowered.

In the future, filament wire may no longer be doped in the conventional manner. As pointed out, bubble strengthening requires a vaporizable element distributed in fine globules or a gas that is insoluble in its host metal and thus cannot diffuse out and must form bubbles. A technique that has been used successfully to produce helium bubbles in tungsten is bombardment by alpha particles (which are helium nuclei) in a cyclotron. The effect of those bubbles on the recrystallization behavior has been very much the same as that of potassium bubbles.

Other potential opportunities lie along the lines of nuclear transmutations, especially by reaction with neutrons. Many nuclear reactions leading to bubble-forming reaction products are possible, although not all of them are feasible from a practical point of view because of the radioactivity that might result and prohibit handling of the irradiated metal.

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Evaluating Drives for Large Grinding Mills

J. G. Trasky
A. H. Hoffmann

The increasing size of grinding mills for the mining and cement industries makes the choice of drive system more difficult than it was in the past. Nonconventional systems, including low-speed gearless drives, may be more economical now than the more familiar types.

Grinding-mill drives for the mining and cement industries are rapidly increasing in horsepower because provision of fewer but larger units improves productivity for a given capital cost. A few years ago, a 4500-hp drive was the talk of the industry; now drives of 12,000 hp and larger are being considered. This increase in horsepower, however, makes application problems more complex, mainly as a result of gear limitations and power system limitations. The usual types of mill drive may no longer provide the optimum performance and cost, so nonconventional drives should always be included in an evaluation.

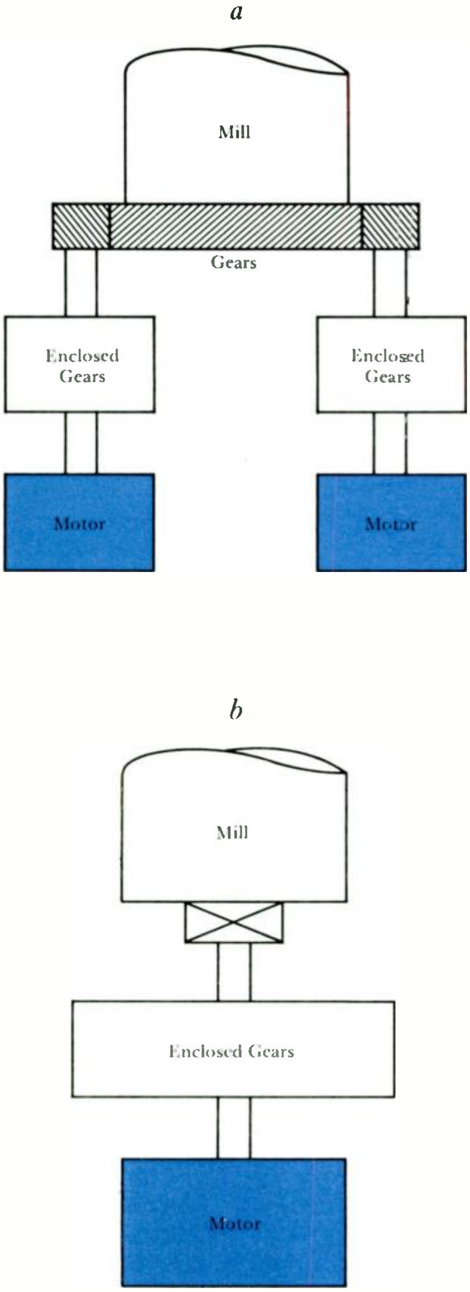
Among the factors that affect the choice are the drive arrangement, mill requirements, cost, maintenance considerations, electrical system characteristics, and motor type, voltage, efficiency, power factor, and starting limitations.

Drive Arrangements

The many variations in drive arrangement that are available can be grouped as pinion, in-line, and gearless. The first two have gearing to reduce motor speed to the required mill speed. Gearing is not included in the cost comparisons here but must always be considered.

Pinion—The pinion type has one or more motors, each with a pinion gear engaging a large ring gear mounted on the mill (Fig. 1a). It has been most popular in the mining industry but is receiving increasing recognition for cement mills because of its low first cost. However, since its gearing isn't completely enclosed, it requires more maintenance than the in-line type.

Single-motor drives are applicable on mills up to 5000 or 6000 hp. Above those ratings, gearing limitations usually dictate dual pinions. Triple, quadruple, and even more unit drives could conceivably be applied on large mills, but problems of load sharing and motor mounting could be very serious.



1—Pinion type of drive arrangement (*a*) employs either two motors, as shown, or a single motor. If low-speed motors are used, the intermediate enclosed gearing is not needed. In-line arrangement (*b*) employs one motor driving the mill through enclosed reduction gearing. Both arrangements can have high-torque motors coupled directly to the gearing, as shown, or low-torque motors with clutches between motors and gearing to permit the motors to be started with no load.

In-Line—This arrangement is traditional in the cement industry. It is a single line-up of mill, gearing, and motor (Fig. 1b). The mill is coupled directly to the gear output shaft through its trunnion bearing, and the motor is coupled directly or through an air clutch to the gear. Only single motors are used. Theoretically, there is no horsepower limit on gear or motor size. All of the gearing is enclosed.

Gearless—Three different types of drives make up the gearless group—wraparound, overhung, and direct connected. Each has its special features that affect mill and millroom design, but all employ a low-speed synchronous motor energized by a low-frequency power supply. Gearless drives are new because of the relatively recent development of efficient semiconductor low-frequency power supplies.

The wraparound type has the motor encircling the mill, with its rotor attached directly to the mill head or shell (Fig. 2a). Thus, it requires the least linear space of all the arrangements. The large motor diameter and the unusual design require a split stator and rotor for shipping and mounting purposes.

The overhung type has the motor rotor overhung on the mill drive shaft (Fig. 2b). The arrangement eliminates one outside motor bearing, but it necessitates a larger mill bearing to support the weight of the motor rotor.

The direct-connected type is conventional in motor construction, consisting of a motor mounted on a standard pedestal bedplate and connected directly to the mill drive shaft (Fig. 2c).

Drive Types

The main features of drives suitable for grinding mills are given in Table I. Motor horsepower and torque requirements are imposed by the mill; they are outlined in *Mill Requirements*, p. 23.

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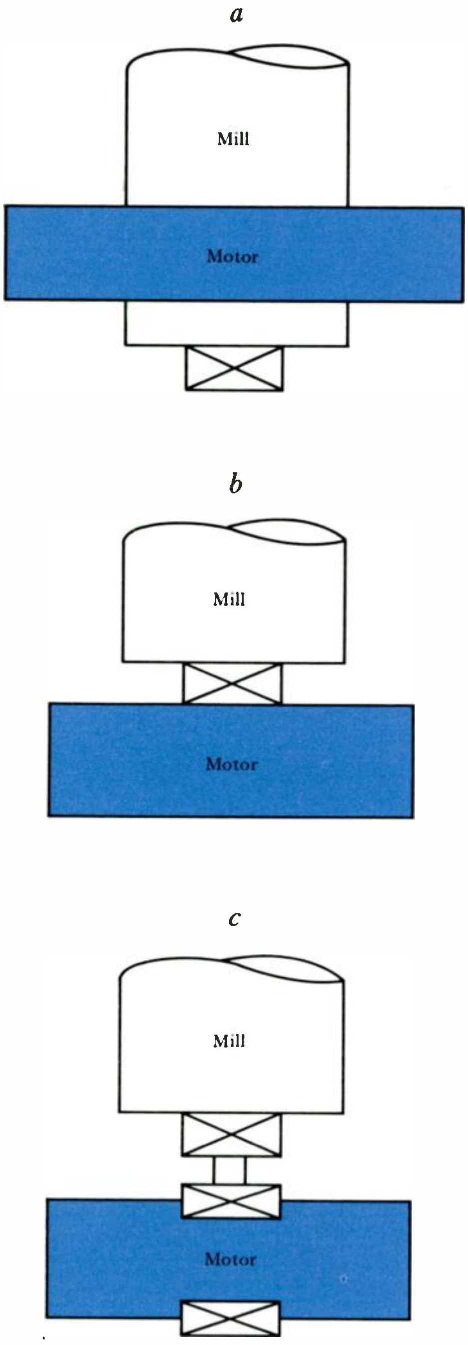

2—Gearless drive arrangements have a very low-speed motor, thus eliminating the need for reduction gearing. The motor can be wraparound (*a*), overhung (*b*), or direct-connected (*c*). It is energized by a low-frequency power supply.

Squirrel-Cage Induction—This is the simplest type, but it is not desirable for mill drives because the high starting torque needed causes high current inrush—about 900 percent for direct drive. The very high starting currents generally cause voltage drop problems. Use of a high-resistance rotor winding to lower the inrush isn't feasible because it would also result in higher losses and poor efficiency.

Moreover, the operating power factor is lagging and generally cause for concern. Power-supply and distribution equipment would have to be larger than it otherwise would be to accomodate the large amount of reactive kVA. Also, electrical power costs increase with kVA demand.

Squirrel-cage motors do not permit electrical inching (operation at very low speed for mill positioning). If inching is required, a mechanical means must be considered.

Finally, the cost of an induction-motor drive is equal to or greater than the cost of the equivalent synchronous-motor type of drive.

Synchronous (Geared)—This type has been the most popular because it meets most mill and power system requirements at reasonable cost. It has a better torque/current ratio during starting than the squirrel-cage induction motor and, above all, has power-factor correcting capabilities up to 0.80 leading. For the large mills, however, the synchronous motor isn't necessarily the optimum choice because it, also, might require more starting current than the power system can accomodate.

Typical speed-torque curves are shown in Fig. 3. The synchronous motor can be inched electrically by use of a separate power supply and control.

High-torque synchronous motors are used with direct drive. They usually have current inrush of 600 to 650 percent of rated current, assuming a motor power factor of 0.80. It may be 700 percent for voltages of 6.9 kV and above.

Most synchronous motors for mill drives, whether they are for high- or low-torque applications, are rated 0.80 power factor. The cost of such a motor is only 20 percent over that of a unity-power-factor machine, so it is a most economical way of providing plant power factor correction.

Voltage drop on the power system during starting must be determined, along with its relationship to net starting torque. The inrush kVA permitted by a given system may be too low to allow the motor to develop sufficient starting torque for the mill. If a motor is selected with higher full-voltage torque, it takes higher inrush; higher inrush causes greater voltage drop and less net torque. It is conceivable that higher full-voltage torque will not provide the best overall solution.

Both starting and pull-in torque affect motor inrush. A check with the motor manufacturer may be beneficial when specifying torque and inrush to determine the best combination. Quite often the relationship of *net* torque to *full-voltage* torque is misunderstood, creating problems. All motors have performance specified on a full-voltage basis, with no allowance for system voltage drop. If the motor were connected to an infinite bus, torques of 150 percent starting and 120 percent pull-in could be specified and the mill safely started. In practice, of course, power-system line impedance, transformer impedance, and sometimes cable impedance cause a significant voltage drop when motor starting current is drawn. This dip reduces the motor's full-voltage torque by the square of the voltage, so the actual developed torque is what an application engineer must consider. It is known as net torque and should always equal or exceed the torque required by the mill. Net torque is calculated from the motor rating and the various power system parameters.

One could choose to specify 225-percent starting and 150-percent pull-in torque rather than the usual 200 and 140 percent, in hopes of assuring mill start-up. However, the increase in net torque would be less than half the increase in full-voltage torque because of the higher starting voltage drop caused by the higher inrush associated with the higher-torque motor. Furthermore, the motor with higher torque would cost more. It

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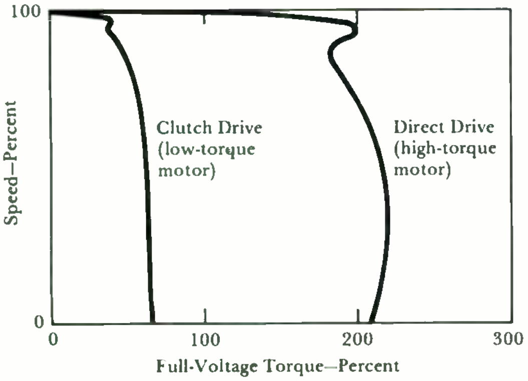

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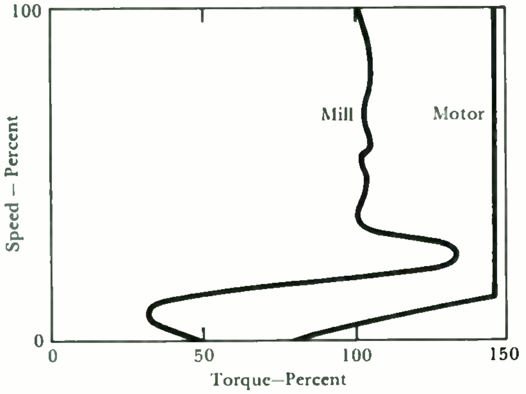


3—Typical speed-torque curves for synchronous-motor drives. Use of a clutch permits application of a low-torque motor, thereby reducing starting current inrush to about 300 percent as compared with about 625 percent with direct drive and a high-torque motor.

4—Wound-rotor induction motor has low inrush, its main advantage. Torque is controlled and inrush limited by varying resistance in the rotor circuit; use of a liquid rheostat for that purpose provides the stepless acceleration illustrated.

often is practical to consider increasing system starting capacity by installing a larger transformer or by rearranging the system.

Typical direct-drive full-voltage motor torques are: starting, 200 percent; pull-in, 140 percent; pull-out, 200 percent. Typical inrush is 625 percent, on the basis of a motor with 0.80 power factor rated 4 kV or less; it can vary with motor speed.

Low-torque synchronous motors (used with clutch drive) are useful when the starting inrushes of high-torque motors cannot be tolerated or when first cost must be minimized. They have a starting inrush (full voltage) approximately half that of high-torque motors. The low inrush virtually eliminates voltage drop problems at starting and, if necessary, lends itself to reduced-voltage starting.

Typical full-voltage motor torques are: starting, 40 percent; pull-in, 30 percent; pull-out, 200 percent. Typical inrush is 325 percent, on the basis of a motor with 0.80 power factor rated 4 kV or less; the inrush can vary, depending on motor speed.

The most critical period in mill acceleration occurs when the clutch is engaged, after the motor is synchronized. The motor must have sufficient pull-out torque, as outlined in *Mill Requirements.*

Wound-Rotor Induction—This type of motor has a cylindrical rotor, with three phases of the winding brought out to three slip rings for connection to starting resistance. It has one very apparent advantage—low inrush. Adjusting the starting resistance in the secondary (rotor) circuit controls torque and limits inrush to not more than 225 percent.

Two types of secondary control for starting can be furnished: stepped resistors or a liquid rheostat. The liquid rheostat provides stepless acceleration (Fig. 4). Submerged electrodes, which are motor driven, continuously change the rotor resistance and thus yield smooth speed-torque and speed-current characteristics. The control can be modified to provide soft start and to accelerate the mill under a current limit.

Power factor and efficiency diminish rapidly with decrease in speed. Therefore, application of wound-rotor motors below 450 r/min is not practical.

The wound-rotor machine has inherent ability to inch with only a small change in secondary control. The control can be designed to utilize the first or the first and second starting points for this function.

Simplex—The simplex motor combines features of the wound-rotor and synchronous types, so it has low inrush and

Table I—Typical Characteristics of Grinding-Mill Drives

Motor Type[1]	*Torques*[2] *(percent full voltage)*	*Inrush (percent full voltage)*	*Operating Power Factor*		*Efficiency (percent)*
			Lag	*Lead*	
Squirrel-cage induction	S 200 PO 300	900	0.85		94
Synchronous, low torque	S 40 PI 30 PO 200	325		0.8	95
Synchronous, high torque	S 200 PI 140 PO 200	625		0.8	95
Wound-rotor induction	PO 200	225	0.9		94
Simplex	Ind PO 200 Syn PO 200	325		0.8	93
Synchronous-induction	Ind PO 200 Syn PO 200	275		0.9	94
Gearless synchronous	150	175	0.85[3]		92[3]

[1] Four kV and 60 Hz; all but gearless are 514 r/min. This note applies also to Table II.
[2] S=starting, PO=pull-out, PI=pull-in.
[3] Motor, cycloconverter, and transformers.

power-factor-correction capabilities. It is a salient-pole synchronous machine with an insulated three-phase starting winding brought out to three slip rings, which are in addition to the two slip rings that carry current to the pole-mounted field winding. A stepped resistor or liquid rheostat control can be used in the starting winding circuit. The field winding is shorted through a resistor during the starting period as in a synchronous motor. Synchronization occurs after the motor reaches full speed as an induction motor.

Since the motor has features of both the synchronous and wound-rotor motor, some compromises of each feature have to be made. For example, inrush is not as low as it is with the wound-rotor machine: it is usually 325 percent. Furthermore, because of stress on the insulated starting winding of the rotor, speeds below 450 r/min are preferred. Power factors of 1.0 and 0.8 are available.

The simplex motor requires secondary control like that of the wound-rotor motor, and also an exciter and field-application panel. It can be inched like the wound-rotor motor. Two large drives are in existence in the United States today, both in the cement industry.

Synchronous-Induction—This motor is a wound-rotor machine with the rotor winding designed to function as both a starting three-phase ac winding and a dc field winding. It is like the simplex motor in having relatively low starting current and ability to correct plant power factor.

The motor's starting current is approximately 275 percent, and it operates at 0.90 power factor leading. It is not recommended for drives of less than 3000 hp because of its relatively high cost, nor for speeds less than 450 r/min because efficiency and power factor diminish at lower speeds.

The synchronous-induction motor requires field excitation and application equipment as well as secondary starting resistance. Inching is the same as with the wound-rotor motor. Two large drives, of 4500 and 5000 hp, are in service.

Gearless Synchronous—This type operates at very low speed to eliminate the

Table II—Drive Cost Comparison[1]

Type	*Cost—Dollars per Horsepower*			
	2000 hp	*4000 hp*	*6000 hp*	*8000 hp and up*
Squirrel-cage induction	25	25	23	23
Synchronous, low torque	23	20	20	18
Synchronous, high torque	30	25	25	23
Wound-rotor induction	55	40	35	35
Simplex	50	40	35	35
Synchronous-induction	60	45	45	40
Gearless synchronous	170	140	125	110

[1] Includes primary and secondary control; gearless drive includes the cycloconverter.

Table III—Cost Comparison by Drive Arrangement, 5000 Horsepower

Single Motor, 514 r/min[1]	*Relative Cost*
Squirrel-cage induction	0.9
Synchronous, low torque	0.8
Synchronous, high torque	1.0
Wound-rotor induction	1.7
Simplex	2.0
Synchronous-induction	2.0
Gearless synchronous	6.0

Dual Motor (each 2500 hp)	*Speed (r/min)*	*Relative Cost*
Squirrel-cage, air clutch	720	0.7
Wound-rotor, high speed	720	1.6
Wound-rotor, low speed	200	2.7
Synchronous, high speed	720	1.3
Synchronous, low speed	200	1.9

[1] Except gearless.

Table IV—Cost Comparison by Drive Arrangement, 8000 Horsepower

Single Motor, 514 r/min[1]	*Relative Cost*
Squirrel-cage induction	1.0
Synchronous, low torque	0.8
Synchronous, high torque	1.0
Wound-rotor induction	1.5
Simplex	1.5
Synchronous-induction	1.8
Gearless synchronous	5.7

Dual Motor (each 4000 hp)	*Speed (r/min)*	*Relative Cost*
Squirrel-cage, air clutch	720	0.7
Wound-rotor, high speed	720	1.5
Wound-rotor, low speed	200	1.2
Synchronous, high speed	720	1.2
Synchronous, low speed	200	1.8

[1] Except gearless.

need for gearing. When the rated speed of a given motor is reduced, its diameter must increase to provide space for more magnetic poles in the winding. At the low speeds needed on gearless mill drives, 60-hertz machines would require many poles and a very large diameter. Therefore, gearless drives employ a power supply with a low-frequency output—about 5 hertz—to optimize the size of the motor and the number of poles.

Advances in high-power solid-state technology have made possible low-frequency power supplies (cycloconverters) at kilowatt ratings, capable of driving mill motors of 7000 hp and larger. Little special instruction is needed to acquaint the plant's operating personnel with the use and maintenance of cycloconverters.

The principal advantage of the gearless drive is elimination of gear operating and maintenance problems. Also, the power-supply frequency is adjustable from zero speed, enabling the motor to be synchronized at very low speed. By starting at low speed, starting inrush current can be limited to less than two times rated current. Mill speed can be adjusted easily and efficiently by cycloconverter control, with constant volts per cycle, over the full speed range. Speed control can be used to match mill speed to changing characteristics of the mill charge, a feature that can improve grinding efficiency. The large air gaps permissible on the motor allow for rotor thermal expansion.

Efficiency of the drive is estimated at 92 percent, including the motor, cycloconverter, and supply transformers. When comparing that value with the efficiency of a conventional motor-and-gear drive, the efficiency of the latter's gearing and transformer should be included to provide a fair comparison.

A lagging average power factor of 0.85 to 0.87 can be expected on the input side of the cycloconverter transformer. This figure is based on use of a motor of unity power factor and a square or trapezoidal output wave from the cycloconverter. Such a waveform improves power factor on the input side of the cycloconverter. If power factor correction is required,

Mill Requirements

Motor Horsepower—The mill builder establishes the required brake horsepower, and then the drive supplier must fit that horsepower into a standard available rating. All of the larger standard horsepowers are available in 15-percent steps, and they are supplied with either 1.0 or 1.15 service factor. However, the percent starting and pull-in torque of the 1.15-service-factor motor must be larger to deliver the same pound-feet torque as the 1.0-service-factor motor, and the larger motor costs more. The following tabulation lists typical minimum net torques required for both service-factor ratings:

	Percent Torque	
Service Factor	*Starting*	*Pull-In*
1.0	140	115
1.15	150	120

Torque (at 1.0 service factor)—For *direct drive* (no clutch), the usual breakaway torque is 50 percent. Breakaway torque is the net torque required at zero speed to overcome friction in the mill, motor, and gear bearings.

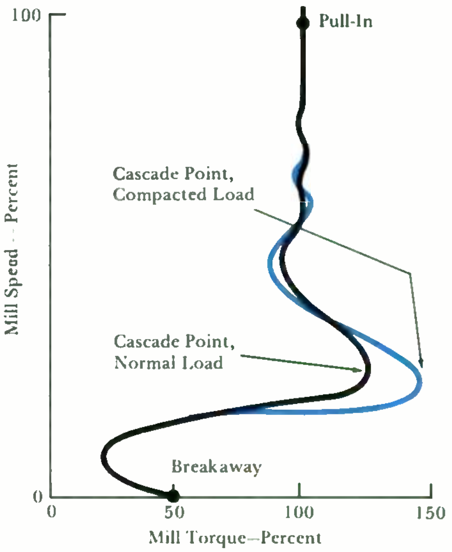
Starting torque must be sufficient to rotate the mill, with its unbalanced weight of charge materials, to the angular position at which the charge cascades (starts to tumble). Normal torque requirements (charge not compacted) at the cascade point do not exceed 125 percent. However, a maximum peak torque of 140 percent is required when the mill contains a compacted charge; it is this torque that determines the starting torque required of the motor. (See figure.) The motor speed at which cascading occurs is a function of the mill's acceleration.

Motors that have to synchronize and operate at synchronous speed (synchronous, synchronous-induction, and simplex motors) require a minimum pull-in torque of 115 percent. The torque must be available at the actual slip at pull-in, which is usually less than the nominal value of 5 percent. This slip at pull-in is a function of the mill, gear, and motor inertia.

A minimum of 150 or 175 percent pull-out torque is adequate, because the running load on a mill drive is steady and not subject to unusual transients.

For *clutch drive*, the motor must only overcome its own breakaway torque, friction, and windage because it starts up and synchronizes before the mill is engaged. A maximum of 15 percent breakaway torque is required for a motor with normal self-lubricating bearings. With oil lift, it could be reduced to approximately 5 percent, but most motors develop sufficient starting torque to make oil lift unnecessary. After breakaway, the accelerating torque required of the motor is approximately 1 percent.

Pull-in torque requirements for synchronous machines are negligible because the motor reaches full speed before the clutch is engaged. Pull-out torque requirements are established on the basis of a clutch-caused load transient. Torque during the engaging period exceeds 175 percent, so motors with 200-percent pull-out torque should be applied. If a motor with 150- or 175-percent pull-out torque is applied, the clutch should have provision for gradual engagement, or field forcing during engagement should be considered.



Typical speed-torque curve for a grinding mill illustrates why a direct-drive arrangement, as illustrated in Fig. 1, requires a motor with a starting torque of at least 140 percent. That much torque is needed to start the mill rotating if its charge has become compacted.

capacitors can be added to the 60-hertz input power system.

Gearless drives have little application below 7000 hp because of the relatively high first cost of the cycloconverter and the special motor construction. When comparing the wraparound type with conventional drives, the additional motor installation costs must be compared with gearing costs of the conventional drives.

Cost Comparison

Drive costs are compared, on the basis of dollars per horsepower, in Table II. In addition to those costs, gearing costs and performance should be considered when evaluating a total drive system.

Motor speed affects cost, because motor prices are inversely proportional to speed.

The way in which the drive and mill are arranged, as discussed in *Drive Arrangements*, also affects cost. Comparisons, utilizing drive costs from Table II, are given in Tables III and IV. In general, a conventional synchronous-motor drive is best when the electrical system permits its use; if a dual drive is needed, it should include load-sharing control as discussed later. Gearless drives should always be considered for large mills because, while their first costs are greater than that of any other, they may be less expensive in the long term because gear problems are eliminated.

Application Considerations

Motor Enclosures—Many types are available, but generally only two are considered: open and totally enclosed water cooled. Where the atmosphere is dirty, the totally enclosed type is recommended. An enclosed motor costs from 10 to 25 percent more than the standard open type. The gearless motor, because of its low speed, necessitates totally enclosed force-ventilated construction for cooling purposes.

Voltage—Primarily, initial cost and operating cost of the drive and all the electrical equipment serving it determine which voltage is best. The main factors are motor voltages available, motor efficiency, plant size (total kVA), and switchgear.

Standard motor voltages are 2.3, 4, 6.9, 11, and 13.2 kV. Motors of a given horsepower increase in size with stator winding voltage, so cost also increases with voltage (Table V). For the larger motors, 2.3 kV is seldom used because of the higher cost of low-voltage switchgear, cables, starters, and transformers.

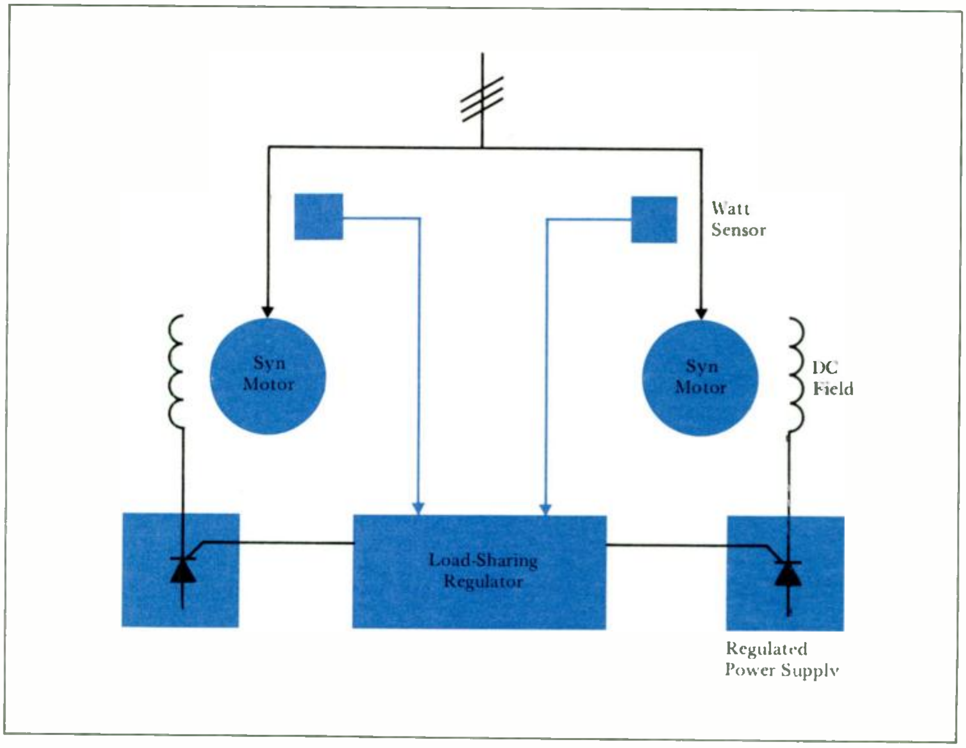
Motor efficiency, however, decreases at higher voltages because heavier dielectric barriers are needed, leaving less space for the copper conductors. The efficiency reduction is small, so only long-term power costs need be included in the economic comparison of motor voltages.

Total plant power requirements determine service voltage and distribution voltages. Generally, 13.2 or 4 kV is available. A 13.2-kV motor would cost more than one at 4 kV, but the higher cost of a 4-kV distribution system might exceed the motor cost difference.

Table V—Motor Cost Comparison by Speed and Voltage

Type[1]	720 r/min			180 r/min		
	4.0 kV	6.9 kV	13.2 kV	4.0 kV	6.9 kV	13.2 kV
Synchronous, low torque	1.0	1.2	1.3	1.7	2.0	2.2
Synchronous, high torque	1.2	1.4	1.5	2.2	2.5	2.7
Simplex	2.3	2.5	2.6	3.4	3.7	3.9
Wound-rotor induction	2.3	2.8	3.0	3.9	5.0	5.4
Synchronous-induction	3.0	3.6	3.9	5.0	6.2	6.8

[1] Comparison is for 3000-hp motor with primary and secondary control.



5—For dual synchronous-motor drives, load sharing between the two motors can be assured by varying field current on the basis of power input sensed at the motor terminals.

Voltage ratings of available switchgear must be considered. In some instances, a 6.9-kV motor might require use of 15-kV switchgear. Moreover, at the higher kVA ratings, 4-kV switchgear might not be available.

In summary, four motor voltages are available, but the choice usually is between 4.0 and 13.2 kV. The higher cost and lower efficiency of the 13.2-kV motor do not alone decide the ultimate choice; the distribution-system configuration also enters in. As drives increase in horsepower, more consideration will be given to 13.2-kV systems.

Inching—This can be done best with special equipment, because jogging the motor from the normal power supply is destructive to motor and starter.

Mechanical inching utilizes a small high-speed motor, reduction gear, and air clutch mounted on a separate bedplate and coupled to the main motor. It adds to the length of the mill lineup, which must be considered in building planning.

Electrical inching with a dc m-g set and sequenced contactors is most common. The contactors commutate the dc in such a manner that, in effect, low-frequency ac power is applied to the motor.

This type is only suitable for synchronous-motor drives. It is most suitable for multiple-mill inching because the power supply and control can be made common to all motors by providing a switch for each motor from a common bus. Motors as large as 5000 hp are successfully being inched by this method, but above that rating it could be difficult because of the high currents that must be switched. This type costs more than a single mechanical incher; when more than one motor is to be inched, however, it is always less expensive than mechanical inchers because the latter must be duplicated for each motor.

A more recent kind of electrical incher has the m-g set and contactor arrangement replaced by a solid-state cycloconverter. Thyristor switching makes a direct three-phase conversion from 60 hertz to a low frequency (0.6 hertz) at a horsepower approximately 1/75 that of the motor.

This type will find more use in the future because it requires less maintenance than the m-g-set type, carries more current than contactors can, and allows higher inching speeds. It has the same ability as the m-g-set type to be switched to any number of motors. Its use will increase as it becomes more competitive in cost.

Load Sharing—If dual-drive gearing is to have long life and minimum maintenance, load must be shared between the two pinion drives; that is, each pinion must have uniform contact against the bull-gear teeth at all times regardless of slight misalignment, gear runout, and tooth wear.

The wound-rotor motor delivers a torque related to its slip speed. Average speed of both motors in a dual drive is constant, because both are geared to the same mill; therefore, regardless of wear, alignment, and variations of the gear teeth, the motors deliver sufficient torque to insure uniform contact of gear teeth at all times and proper load sharing.

The synchronous motor, however, delivers torque at rated speed in proportion to the position of the rotor poles with respect to magnetic poles developed by the stator winding. If dual-drive synchronous motors are to share load equally, the motors must be so designed that, at synchronism, the rotor-stator pole relationship can be adjusted to divide the load between the two motors.

Initially, mechanical adjustments are made until load sharing is as balanced as possible. However, gear runout and variations in tooth wear can cause cyclic shifting of the load; that is, the torque and power delivered by each motor pulsates. This pulsation causes cyclic shifting of the motor rotors from their balanced load positions. From 10 to 20 percent power pulsation can be expected.

A recent test on a mill has shown that those power pulsations can be reduced by continuous cyclic variation of motor excitation. This method can be considered as an electrical input to adjust the strength of the rotor magnetic poles, thereby maintaining the same angular position between rotors and insuring division of load between motors. Solid-state circuitry has been developed to monitor kilowatts at the motors and to vary motor field current accordingly (Fig. 5). Excitation power requirements are slightly higher than those for constant-current applications.

Capacitor Starting—When motor starting current exceeds system capacity, shunt capacitors paralleled with the motor during starting can substantially reduce the current drawn from the system. Most of the starting inrush is reactive (approximately 35 percent power factor); the capacitors supply the motor with this reactive kVA, reducing demand on the power system. Inrush reduction also reduces voltage drop, thus improving net torques. This type of starting is very economical.

Power-Factor Correction — Capacitors can be added to an induction-motor circuit to improve system power factor. The amount of capacitance used is limited to the magnetizing kVA of the motor, which is approximately 20 percent of the motor kVA rating. However, the motor manufacturer should always be consulted to determine the exact amount. That amount should never be exceeded lest it cause overvoltages when the motor circuit is opened for shutdown.

Conclusion

When a large mill drive is to be selected, many application questions must be answered to arrive at optimum performance and cost. However, regardless of mill size and power-system configuration, a suitable drive is available.

Additional Measures of Generation Reliability

P. B. Shortley

The Westinghouse capacity model program was originally developed to determine adequacy of generation reserves, expressed as loss of load probability. The program is a computerized approach that uses continuous probability distributions of daily peak load and available capacity. Now additional information regarding the degree of system reliability can be generated by the program for the use of system planners.

Two additional reliability indices—*period excess capacity* (or deficiency) and the expected value of *unavailable capacity due to forced outages*—have been developed in response to requests by utilities using the Westinghouse capacity model program[1] for their generation planning. These indices can provide a useful complement to the loss-of-load probability (LOLP) that is used as a criterion for planning the utilities' required generation installations.

Period Excess Capacity

During utility system peak periods (or "months"), the chances are that the system will have little excess capacity. In fact, the reserve may be just enough to protect against possible machine forced outages and load uncertainties. However, during off-peak months there may be considerable extra capacity even after outages for scheduled maintenance. It is useful to know how much excess capacity is available during these periods.

The Westinghouse capacity model program determines loss of load probability by convolving daily peak load and available capacity density functions. System daily peak loads for a given period are assumed to have a normal distribution, so they can be described in terms of a mean daily load peak ($\overline{P}$) and a standard deviation (σ) of load peaks from this mean (Fig. 1). This distribution changes from month to month, depending on seasonal variations in level and fluctuation characteristics. An estimated or forecast peak load (F) and standard deviation for each month can be derived from analysis of historical load data. The mean of the daily peaks can be derived using the estimated peak and sigma values.[1] Since the total area under the distribution curve represents 100-percent probability, the shaded area to the right of the estimated peak in Fig. 1 is the probability of a load occurring above the estimated peak value.

Available capacity distribution represents generation availability in terms of a probability density function that extends from zero to the total installed capacity (I) for the units in service during the period represented (Fig. 2). The area under the curve to the left of any chosen value (P) represents the probability of having *P megawatts of available capacity or less* to meet the load.

The relationship between daily peak load and available capacity density functions determines the loss of load probability. It is found by convolving the two distributions with probability mathematics to get a margin distribution (Fig. 3). The probability of negative margin, represented by the shaded area in Fig. 3, is the probability that there will be a deficiency of available capacity to meet the peak loads.

A utility accepts a certain loss of load probability in establishing the system reliability criterion. Therefore, the *period excess capacity* is the amount by which peak loads can be increased and still maintain the system reliability constraint. Period excess (and required reserve) is determined with the capacity model program by iteratively moving the load distribution to the right, as shown by the curves in color (Fig. 4), to the position where period risk equals the system risk criterion.

Since reserve is generally measured as the difference between the available capacity and the period forecast peak load, the required reserve (R), as shown in Fig. 4, is the amount of capacity over and above the period peak (F) that gives exactly the required reliability for the period being studied.

Forced Outage Capacity

The second index of system reliability that can readily be provided by the capacity model program is the expected amount of generation capacity that will be unavailable due to forced outages over and above the scheduled maintenance outages.

The capacity outage density function (Fig. 5) is derived by the capacity model program during its development of the available capacity density function (Fig. 2). The outage function is calculated from a particular combination of individual unit sizes and forced outage rates and is completely independent of forecast load and load uncertainty. The area under the curve (Fig. 5) represents probability and is unity. The *mean forced outage* ($\overline{L}$) is the expected value of capacity that will be unavailable due to forced outages. (It is equal to $\Sigma p_i c_i$ where p_i is the forced outage existence rate for the ith unit and c_i is the megawatt capacity of the ith unit).

Summary

System excess capacity and required reserve by period, and the weekly expected amount of capacity that will be unavailable due to forced outages, have proved to be useful tools for utilities doing generation planning. Although these parameters are related to the loss-of-load probability, the most frequently used criterion for generation installation, they provide significant additional information regarding the degree of system reliability. They also provide reliability measures more meaningful to generation planning functions that are subsidiary to scheduling actual generation installation, such as planning for generation purchases and sales, scheduling maintenance, and comparing planning data against actual system operation.

P. B. Shortley is a Systems Analysis Engineer in Advanced Systems Technology, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania.

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[1] C. J. Baldwin, "Probability Calculation of Generation Reserves," *Westinghouse ENGINEER*, Mar. 1969, p.34-40.

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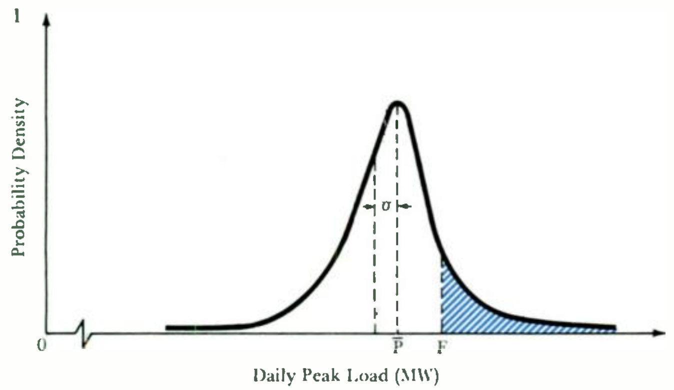

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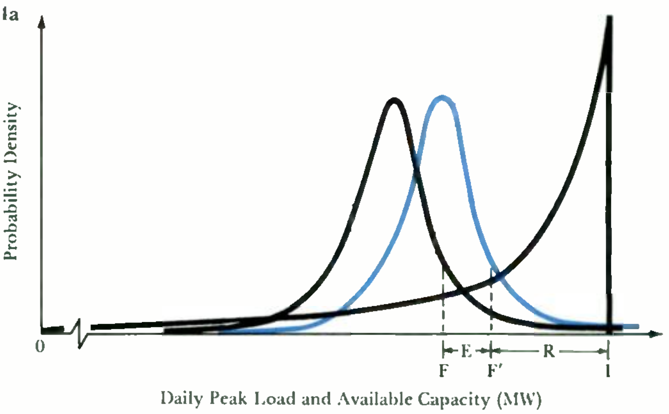

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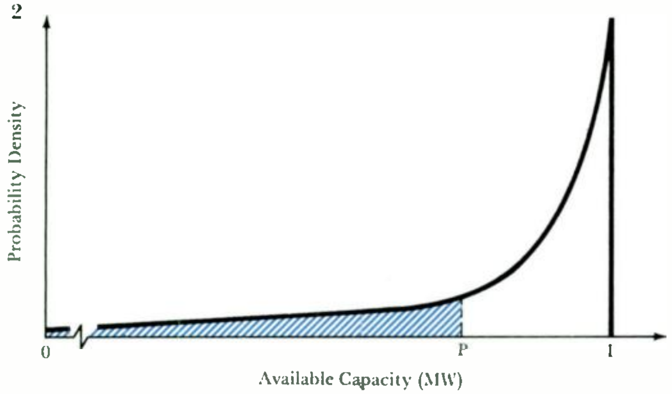

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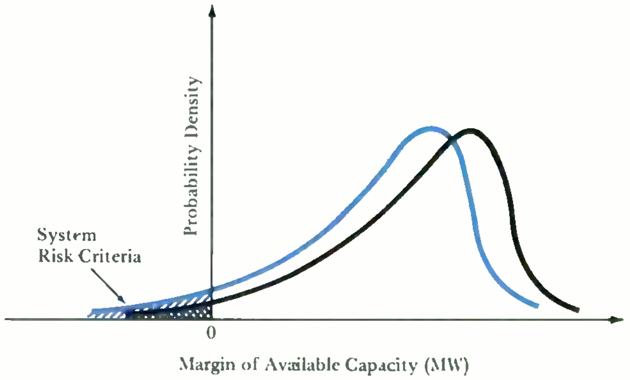

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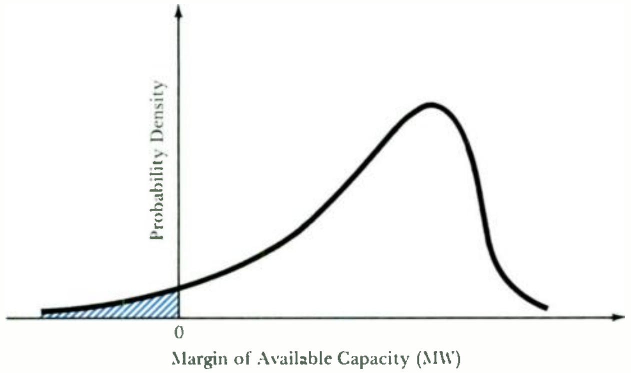

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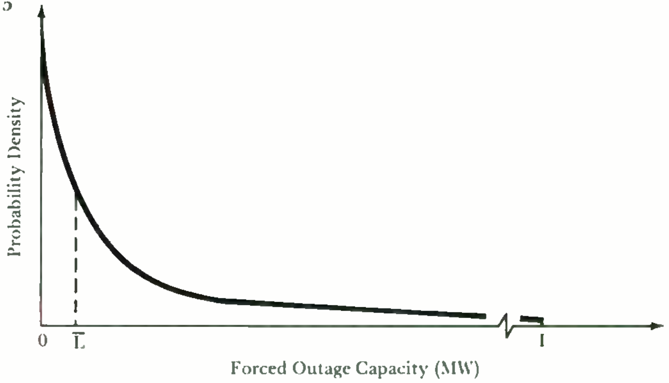


1—Daily peak loads for a given period (month) are assumed to have a normal distribution, expressed in terms of mean peak load ($\bar{P}$) and standard deviation (σ). The shaded area is the probability that peak load will exceed load *F*.

2—On the available capacity density function curve, the shaded area to the left of *P* is the probability that available system capacity will be equal to or less than load *P*.

3—Margin of available capacity is obtained by convolving peak load and available capacity density functions. Shaded area represents the probability of available capacity deficiency to meet peak loads.

4—Graphical representation of the determination of excess capacity (*E*) and required reserve (*R*). Expected peak load is increased (a) until period risk equals the period risk criterion (b).

5—Forced outage density function is developed within the capacity model program; the mean of this distribution represents the expected amount of unavailable capacity for the period.

Technology in Progress

Plant Expansion Enlarges Generator Production Capacity

A modernization and expansion program costing some $22 million has greatly increased the physical capacity of the Westinghouse East Pittsburgh plant. It enhances the capability of the Large Rotating Apparatus Division to build the large generating equipment that utilities need to meet growing electrical demands.

The largest part of the project was construction of a new fabrication aisle to allow construction of generator stators even larger than the present maximum size of 1200 MW. In electrical capacity, those generators are 3½ times as large as the largest generators manufactured a decade ago; in physical size, they are twice as large and sometimes weigh as much as 600 tons.

The new aisle replaces a group of buildings built by George Westinghouse in the 1890's. It is 864 feet long and has a clear span that is 61 feet from the floor to the top position of the 300-ton crane hook. The facility doubles the workable height available for in-plant movement of large components and triples the lifting capacity for fabrication operations.

The aisle illustrates the "checkerboard" improvement planning being applied at the plant. Buildings or manufacturing centers are replaced in such a way that the final result will be an efficient plant utilizing many of the old but sound buildings.

Generator frames the height of a six-story building, when stood on end for completion, are being assembled in the new fabrication aisle.

The project is part of a longer-range improvement program projected at least through the mid-1970's. The phase now being completed also includes substantial rearrangement of machinery and acquisition of new machine tools capable of producing large generator components. The expansion has added almost 130,000 square feet of manufacturing space to the plant, and the modernization program has involved 320,000 square feet of existing space.

Significant improvement in manufacturing efficiency is expected through the use of an automated warehouse system that stores and distributes thousands of parts and materials needed for generator construction. It is 500 feet long and 36 feet high, and it consists of 2400 storage locations. Three stacker cranes, operating automatically on instructions from punched cards at a central location, store or withdraw parts weighing up to 4000 pounds. The system was supplied by the Westinghouse Industrial Systems Division.

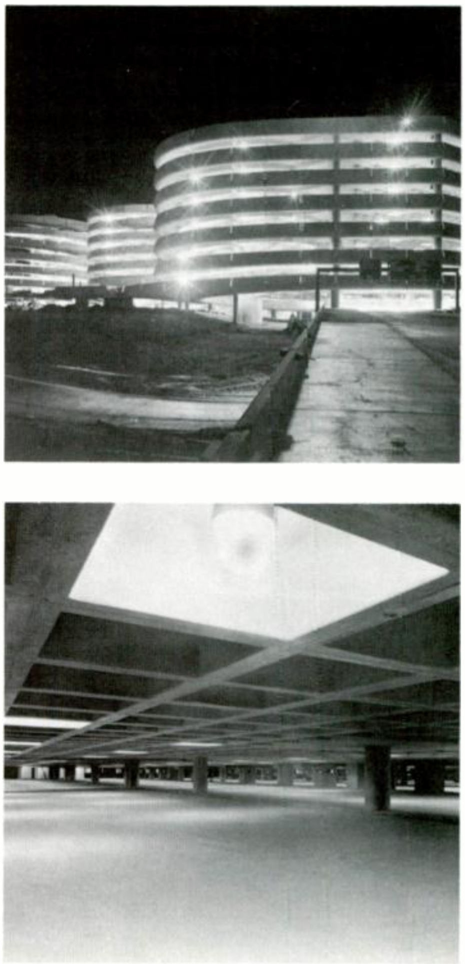
Mercury-Vapor Lighting Illuminates Parking Garage

The traditional method of lighting multi-story parking garages is with interior fluorescent fixtures. However, structural characteristics of the new eight-story parking terminal at the Seattle-Tacoma International Airport made that approach impossible. The building has symmetrically spaced wells in each ceiling, with access to the 277-volt electrical wiring for lighting provided inside some of the wells. Fluorescent luminaires, because of their inherent size and light distribution, would have had to be mounted on the edges of the wells, a location that would subject them to breakage from being whipped by the antennas of passing cars.

Moreover, a fixture was specified that would give either two- or four-way light distribution—two-way to throw light along the traffic lanes and four-way to spread it evenly over parking areas. Fluorescent fixtures are not ordinarily that versatile.

Both problems were solved by installing Westinghouse VB-15 outdoor luminaires, a type more commonly used to illuminate streets, parks, and industrial properties. Each of the 2114 luminaires houses a 250-watt color-corrected mercury-vapor lamp. The luminaires are mounted inside the ceiling wells to guard against damage by antennas, and simple adjustment of the socket position

Day-like brightness is provided in the parking terminal at the Seattle-Tacoma Airport. Mercury-vapor luminaires mounted in ceiling wells provide either two- or four-way light distribution.



provides either two- or four-way light distribution. They have integral ballasts capable of operating down to minus 20 degrees F, a necessary feature because the garage is open ended. The units are gasketed for weather protection, with controlled filter breathing preventing the entry of insects, dirt, and dust to minimize maintenance requirements.

Since mercury lamps have higher efficiency than fluorescent lamps, fewer luminaires were required to give the specified average illumination level of 7 footcandles (10 footcandles in the traffic lanes and 5 in the parking areas). Installation cost of the mercury lighting was about 13 percent less than that of the fluorescent system studied. In addition, the mercury lamp has a 24,000-hour life expectancy as compared with 9000 hours for an equivalent fluorescent lamp.

Thermoelectric Air Conditioning Unit Being Tested by Navy

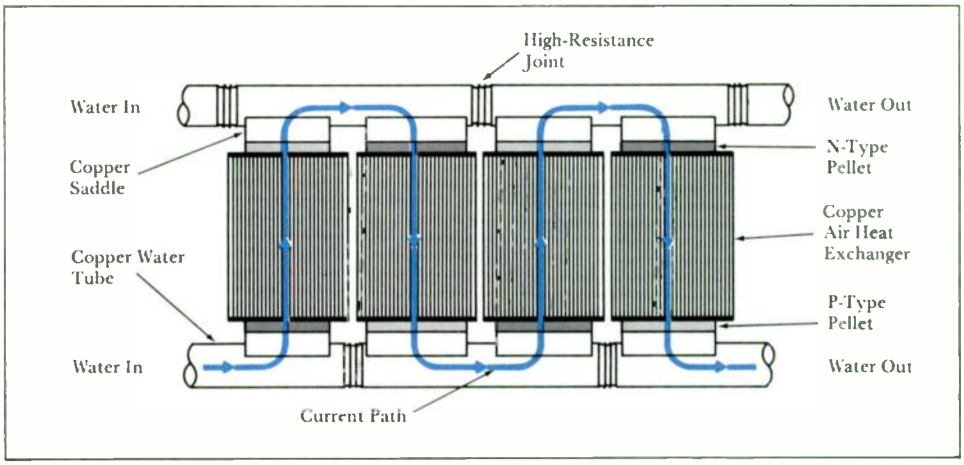
Thermoelectric air conditioning, until recently little more than a curiosity, is proving practical for some uses. One of the newest such units is intended for installation aboard a submarine. Now being tested by the Naval Ship Research and Development Laboratory of the Naval Ship Systems Command, the unit was designed and built under a Navy contract by the Westinghouse Astronuclear Laboratory. The main purpose of the program was to develop and evaluate a "building-block" module to be used for air conditioning systems of various sizes.

Ten identical modules make up the unit, which is rated at 5 tons or 60,000 Btuh of cooling capacity. Air passing through the modules is cooled by the heat-pumping action of thermoelectric elements (the Peltier effect). Waste heat is carried away to seawater by auxiliary heat-exchange systems.

The conventional approach in such cooling systems has required a layer of electrical insulation between the thermoelectric circuit and the heat exchangers. That layer creates a thermal resistance, so it causes relatively low efficiency. In the new unit, however, the thermoelectric pellets are in contact with the heat exchangers and the heat exchangers are part of the electrical circuit; there is no insulation to restrict heat flow. Data from tests show that life cycle and maintenance costs of this thermoelectric air conditioning unit are low compared with those of conventional compressor systems. Operating costs are comparable.

The thermoelectric modules are approximately 24 by 24 by 4 inches in size and weigh 100 pounds each. They can be removed and installed by hand and repaired, if necessary, while the ship or submarine is under way. Few spare parts are needed. Because of the building-block concept, a module can be bypassed in the unlikely event of failure, allowing the unit to continue to operate with little loss in performance.

Other Westinghouse-developed thermoelectric cooling units are in use in Navy surface ships and a submersible. In their total operating time of over 80,000 hours, not a single thermoelectric circuit has failed nor has there been any degradation of performance.



Thermoelectric cooling module for air conditioning is illustrated schematically. The new design is more efficient than others because it requires no electrical insulation, which is also a thermal barrier, between thermoelectric circuit and heat exchangers.

Saxton Core III Examined, Found in Good Condition

Mid-life shutdown and examination of the Saxton Core III has demonstrated additional progress in the performance capability of fuel for pressurized water reactors. The core was installed in the Saxton Experimental Power Reactor in 1969 and, since then, its nuclear fuel has been operated at unit power levels analogous to the duty required in today's large reactors. It has achieved more than 40,000 MWD/MT burnup and, at the end of its life, will reach peak burnup of about 50,000 MWD/MT.

Approximately 100 fuel rods were removed and examined nondestructively. The fuel was in excellent condition, and nothing unexpected was observed. Examinations consisted of visual inspection, profilometry, gamma scanning, and tests for fission-product leakage. They were performed under water by use of a mobile system that provides all equipment and technology necessary for complete on-site evaluation of fuel.

Core III consists of nine central assemblies of Zircaloy-clad mixed plutonium-uranium dioxide surrounded by 12 uranium-dioxide assemblies clad with stainless steel. The central assemblies contain fuel rods from Core II, which were reconstituted into a more open lattice to increase reactivity and allow for greater burnup than originally anticipated.

The Saxton Experimental Power Reactor, located about 100 miles east of Pittsburgh, has been a proving ground since 1962 for many of the concepts used in today's pressurized water reactors. It is owned and operated by the Saxton Nuclear Experimental Corporation, a subsidiary of General Public Utilities, and the experimental program there is the responsibility of the Westinghouse Nuclear Fuel Division.

Screen Amplifies X-Ray Images and Converts Them to Visible Patterns

A new solid-state radiographic amplifier screen converts X-ray images into visible images, with energy gains and without significant time delay, for industrial nondestructive testing and for medical applications. It is made in both storage and nonstorage types.

The storage type displays its visible image for several hours or until it is electrically erased, permitting detailed study without continuous exposure to the radiation. Because the screen is reusable, it provides a cost-saving alternative to X-ray photographic equipment. Moreover, there is no delay for photographic processing. The speed (absolute sensitivity) of the screen is equivalent to that of high-contrast high-resolution photographic films. Its resolution is 6 to 8 line pairs per millimeter, and its contrast sensitivity meets the requirements for industrial nondestructive testing applications (quality level 2-2T; i.e., two holes on the 2-percent penetrameter can be detected as specified in MIL-STD-453).

A storage type of radiographic screen shows the contents of a lady's purse in this demonstration. The image persists for several hours after the initial X-ray exposure.

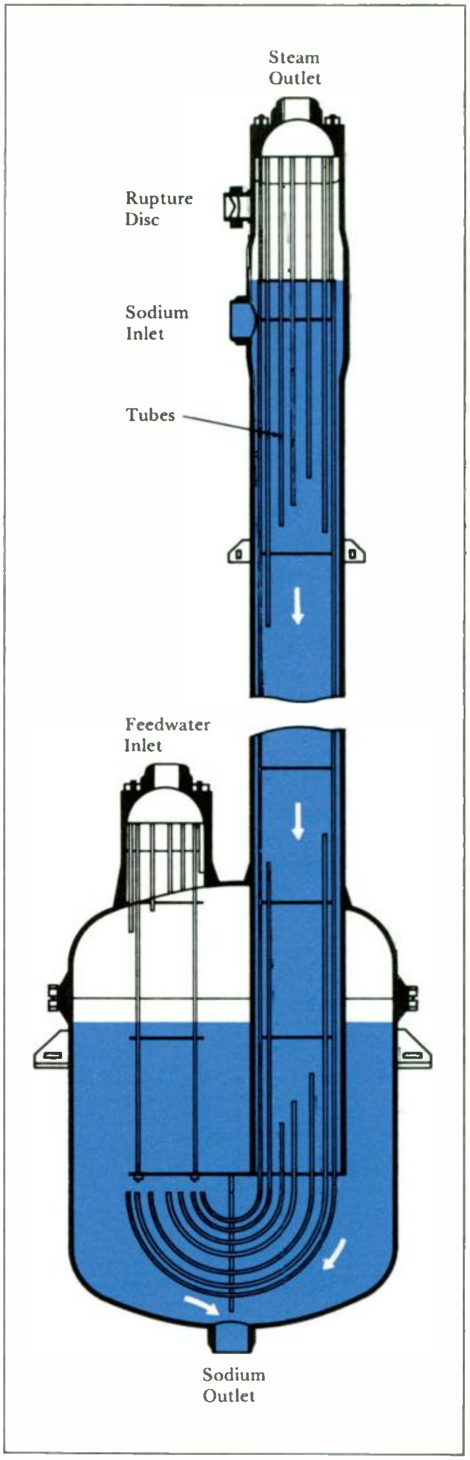
The nonstorage type is a direct replacement for existing fluoroscopic screens. It provides higher brightness (10 times or more), higher contrast (3 times), and better resolution (3 times) than standard fluoroscopic screens. The screen has a reasonably fast response, so it can view dynamic as well as static X-ray images. Applications include production-line inspection and nondestructive testing. Either type of screen can be photographed if a permanent record is desired.

The radiographic amplifier screens are solid-state panels of the photoconductor-electroluminescent type. They consist of a photoconductive layer and an electroluminescent layer. A voltage is applied across the two layers. When the photoconductive layer is exposed to X rays, its electrical resistance decreases, causing more of the applied voltage to be dropped across the electroluminescent layer. With this higher voltage applied, the electroluminescent layer emits more light in a pattern that corresponds to the pattern of incident X rays.

The screens are thin, light in weight, and shock resistant. They were developed by the Westinghouse Electronic Tube Division, with the development supported in part by the National Aeronautics and Space Administration's George C. Marshall Space Flight Center, Huntsville, Alabama.

Steam Generator Designed for LMFBR Demonstration Plant

A modular steam generator that has a J-shaped heat exchanger is being developed for the Westinghouse design of the liquid-metal fast breeder reactor (LMFBR) demonstration plant.* The heat exchanger is designed to serve both



Steam generator for the proposed LMFBR demonstration plant has a bundle of heat-exchanger tubes that can be removed as a unit when necessary. The bend in the tube bundle allows for thermal expansion.

as an evaporator and as a superheater. Its tubes are straight for most of their length, with sodium on the shell side and steam on the tube side. At its lower end, a bend is provided in the tube bundle to allow for tube expansion. (See illustration.)

An advantage of the modular design is its contribution to high plant availability. The heat-exchanger tubes, being removable as a unit, could be replaced when necessary much faster than could the tubes in more conventional designs.

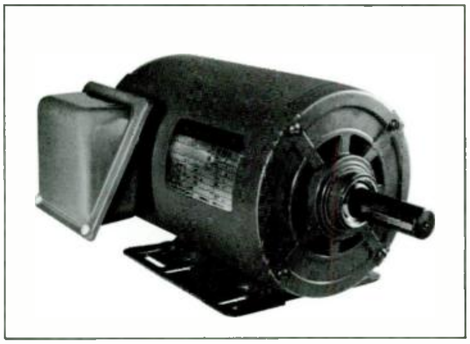
•W. M. Jacobi, "A Demonstration Power Plant Design for the Liquid-Metal Fast Breeder Reactor," *Westinghouse ENGINEER*, Nov. 1971, pp. 180-7.

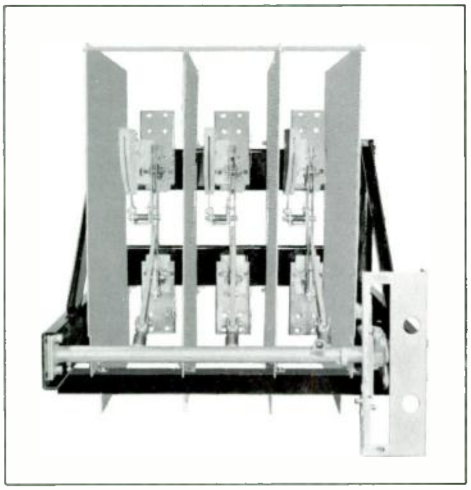
Products for Industry

Packaged water chillers in PF Whis-Pac centrifugal line have been extended in cooling capacity from 116 to 240 tons. Operation is quiet and stable down to 5 to 10 percent of the chiller's full-load capacity. Use of R-12 refrigerant, which is always above atmospheric pressure, eliminates the need for a purge unit and thus saves maintenance and refrigerant loss. The previous single-compressor models (83 to 116 tons) measure 112 by 22¼ by 57 inches high, while the new dual-compressor models (135 to 240 tons) measure 166 by 28¾ by 65½ inches high. Control components are of dependable solid state construction. *Westinghouse Commercial-Industrial Air Conditioning Division, Staunton, Virginia 24401.*

Integral-horsepower motors in new 56/140 frame size are designed to meet application needs for which a 56-frame motor might be too small while 140 might be overbuilt. They are available in single-phase designs rated at 1, 1½, and 2 hp and in three-phase rated at ¾, 1, 1½, 2, 3, and 5 hp. The motors have Class B insulation and permanently lubricated double-shielded ball bearings. Automatic-reset thermal protection is available. *Westinghouse Small Motor Division, 2025 East Fourth Street, Lima, Ohio 45804.*

Load interrupter switch provides quick-make quick-break action with spring-stored energy for safe, fast, and reliable protection for high-voltage circuits (2.4 through 13.8 kV). The type AWP switch is available in continuous and interrupting ratings of 600 and 1200 amperes. It has unitized three-pole frame-mounted construction for mounting in enclosures or in assemblies. It is available with momentary ratings of 40, 61, and 80 kA and fault-closing ratings of 20, 40, and 61 kA. The switch can be applied separately or with fuses for sectionalizing primary feeders and for isolating transformer banks, voltage regulators, and similar applications. Parts can be easily added or removed for changing applications. *Westinghouse Switchgear Division, East Pittsburgh, Pennsylvania 15112.*

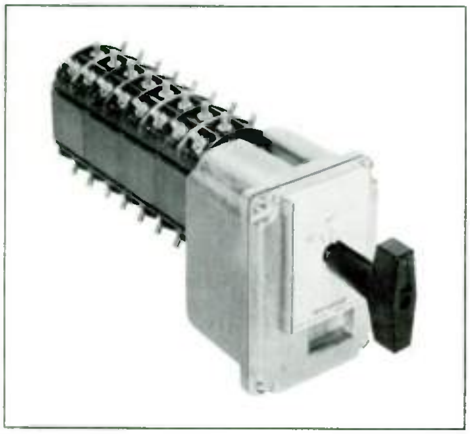

Integral-Horsepower Motors


Load Interrupter Switch

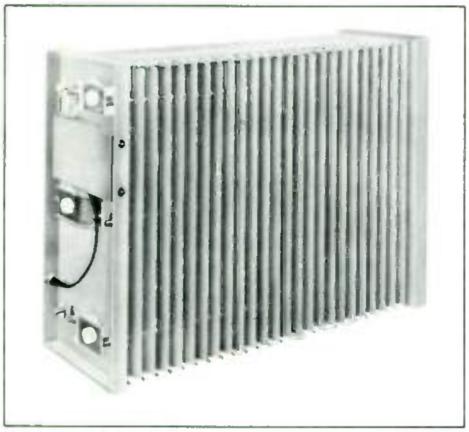

Programmed Welding System

Programmed welding system automatically controls most of the variables involved in the metal inert-gas process. Ten or more welding settings can be programmed and selected by pushbutton. The operator does not have to interrupt production to readjust the machine when changing from one welding operation to another; instead, he just selects the proper schedule and controls the travel. Variables such as input line voltage and wire feeding are automatically controlled. The solid-state RCS 500 power supply is rated 500 amperes at 100-percent duty cycle and will produce 650 amperes at 60-percent duty cycle. *Westinghouse Industrial Equipment Division, Sykesville, Maryland 21784.*

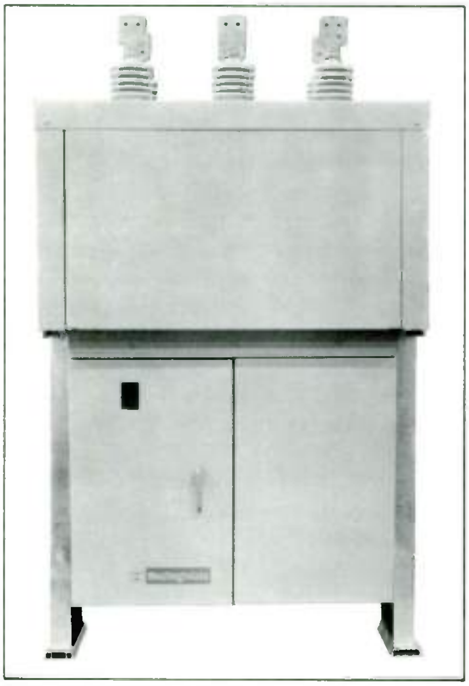
Lockout switch has up to 38 contacts closed in the trip position to enable simultaneous multicircuit transfer, as in differential protection, or to trip the system main breaker in conjunction with auxiliary breakers. Advantages of the new Type WL-2 switch over previous designs include more contacts per shaft and per unit volume, 25-percent less panel area, fewer moving and wearing parts, and hermetically sealed encapsulated coil. The switch is rated 600 volts 20 amperes continuous. It trips by electromagnetic induction, which opens a permanent-magnet latch and permits the rotor to be rotated by spring-stored energy. Magnet coil assemblies are



Lockout Switch



Electronic Air Cleaner



Type R Vacuum Circuit Breaker

available from 24 to 250 volts dc and 120 to 480 volts ac. Average operating times are 1.54 cycles for ac, 1.05 cycles for ac rectified, and 1.0 cycle for dc voltages. *Westinghouse Switchgear Division, East Pittsburgh, Pennsylvania 15112.*

Electronic air cleaner in modular form, known as the Power Cell, enables the user to design and assemble his own air cleaner in any required size and configuration by combining units. It is available in two sizes—four- and six-square-foot face area. Each Power Cell includes a solid-state constant-current power pack, an ionizing section, and dust collecting plates. It operates on 115-volt 60-Hz supply, and it is capable of removing up to 95 percent of all atmospheric dirt, dust, pollen, and smoke passing through it. Since each cell is complete, one or more can be removed from an assembly without affecting the operation of the remaining cells. *Westinghouse Sturtevant Division, Hyde Park, Massachusetts 02136.*

Type R vacuum circuit breaker is a 15.5-kV three-pole device with vacuum interrupters. Since vacuum interrupters purge themselves after each operation and are insensitive to voltage, derating for reclosing duty and aging is not necessary and the voltage range factor is unity. If an overload condition continues after reclosing, the breaker automatically cycles as many as four times before locking open. Its stored-energy mechanism is motor operated but can also be manually charged. *Westinghouse Distribution Apparatus Division, Bloomington, Indiana 47402.*

Services for Industry

Statistics for Problem Solving and Decision Making is an instruction program that provides a comprehensive introduction to practical statistical concepts and techniques for managers and professionals. The course consists of ten half-hour films and ten volumes of structured texts in an individualized instruction format. No instructor is needed, but the course is so designed that an instructor can mold it to meet specific organizational needs.

The course features Dr. J. Stuart Hunter of Princeton University, a teacher, writer, and industrial consultant. It has been tested and revised on the basis of trial programs given within Westinghouse. Rental fees vary according to the number of course participants. The texts are retained by each participant, forming a useful set of reference volumes.

For more information, write to the Westinghouse Learning Corporation, 1426 Westinghouse Building, Pittsburgh, Pennsylvania 15222.

Bryant Spec-eeze is a condensed guide to NEMA requirements for straight-blade and locking electrical wiring devices. Both sides of the 8- by 11-inch chart have information in an easy-to-read format. References are arranged so that the corresponding current and voltage ratings, number of conductor and ground wires, approved NEMA receptacle configuration, NEMA line number, and correct wiring diagram are listed together in rows.

A pull-out slide provides quick reference to Bryant catalog numbers for the wiring devices. Since the Spec-eeze lists only NEMA-approved configurations, it can aid in designing for electrical safety. It is offered without charge to users of electrical wiring devices by the Wiring Devices Department, Westinghouse Bryant Division, 141 State Street, Bridgeport, Connecticut 06602.

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Bound Volumes Available

The 1971 issues of the *Westinghouse ENGINEER* have been assembled in an attractive casebound volume having a durable cover of black buckram stamped with silver. The price is $4.00 in the United States and possessions, $4.50 in other countries. Order from *Westinghouse ENGINEER*, Westinghouse Building, Gateway Center, Pittsburgh, Pennsylvania 15222.

About the Authors

Stephen A. Lane is Senior Engineering Physicist at the Westinghouse Nuclear Instrumentation and Control Department. He arrived there by a rather unusual route, beginning with a BA in Psychology from the University of Virginia. While in school, he worked summers as a health physics technician for Union Carbide Nuclear Company, and, upon graduation, worked at the Oak Ridge National Laboratory in the Stable Isotopes Division. His transition from psychology to physics was completed in 1971 when he received his PhD in Physics from the University of Pittsburgh.

Dr. Lane also began his Westinghouse career at that time, doing technical liaison between the Nuclear Instrumentation and Control Department (near Baltimore) and the Research and Development Center in Pittsburgh. He has been primarily concerned with developing customer information on the radiation aspects of radiation monitoring systems and with the calibration of new and modified radiation monitoring channels.

Charles Griesacker graduated from Loyola College (Baltimore) with a BS in Physics in 1956 and from the University of Virginia with a BSEE in 1958. After work with Martin Company and Bendix Radio, he joined the Westinghouse Defense and Space Center in late 1963 as a design engineer, working on traveling-wave-tube low-noise receivers. His next assignment was design engineering of advanced torpedo fire control systems. Griesacker moved to the Nuclear Instrumentation and Control Department in 1969. He is project engineer for radiation monitoring systems and the boron measurement system.

Ted Hamburger graduated from CCNY in 1952 with a BEE degree and received his MEE degree a year later from Polytechnic Institute of Brooklyn. Prior to coming with Westinghouse, he spent two years each with the Microwave Research Institute, the United States Army Chemical Center, and Sperry Gyroscope.

Hamburger joined the Westinghouse Defense and Space Center in 1958. His first assignment was advanced development work on solid-state display systems. Following assignments were Project Engineer for solid-state high-power switching; Supervisor of advanced digital techniques; and Supervisor of solid-state technology, which included microelectronic techniques. He moved to the Nuclear Instrumentation and Control Department in 1968 to become Manager of Commercial Nuclear Programs.

Robert Hooke attended the University of North Carolina, where he earned a BA degree in Mathematics in 1938. He received his MA there the following year and his PhD from Princeton University in 1942. He spent ten years teaching mathematics at North Carolina State University and University of the South and then, in 1951, joined an operations research group in the Department of the Navy. In 1952, he joined Princeton University's Analytical Research Group.

Dr. Hooke came to Westinghouse in 1954 as a Senior Mathematician at the Research Laboratories, and he was Manager of the Statistics Section from 1956 until 1963. He is currently Manager of the Mathematics Department, which lends broad mathematical support to Westinghouse divisions.

Heinz G. Sell is Manager of the Advanced Development Section at the Incandescent Lamp Division and coordinator of the Division's research and development projects at the Corporate Research Laboratories. He earned his BS in physics at the University of Munich in 1949 and his master's degree there in 1951. He joined the Westinghouse Lamp Division in 1954 and served first in the equipment design section. In 1956 he transferred to the lamp research department in metals research.

Sell has developed methods of producing ultrapure metals and alloys and supervised Government sponsored investigations on tungsten-base alloys for high-temperature structural applications. Beginning in 1966, he supervised the development of advanced manufacturing techniques for tungsten filament wires and investigations directed toward an understanding of why filaments fail.

Roland Stickler received the Diplom Ingenieur and PhD degrees in physical metallurgy in 1956 and 1958, respectively, from the Technical University of Vienna, Austria. After teaching there from 1956 to 1958, he joined the Westinghouse Research Laboratories, where he is presently Manager of Physical Metallurgy. He is responsible for research on microcharacterization of solids, deformation studies, and alloy development.

Dr. Stickler's major field of professional interest is the relationship between microstructure and properties of metals, alloys, and semiconductors. Among his scientific contributions are improved understandings of the significance of hot-ductility testing for welding research and of the relationship between microstructure and properties of stainless steel and tungsten alloys. He is adjunct professor of solid-state chemistry at the University of Vienna and United States editor of *Praktische Metallographie*, an English-German journal published in Germany.

John G. Trasky joined Westinghouse in 1951 in the electrical testing program at the Large Rotating Apparatus Division, and in 1957 he moved on to the Division's large-motor design section. He also attended the University of Pittsburgh, earning his BSEE in 1963. That same year, he transferred to the Industrial Systems Division to work on shovel and dragline equipment. In 1965 he joined Industrial Projects Marketing as an application engineer in the mining, cement, and chemical industries.

Trasky returned to the Large Rotating Apparatus Division in 1971 as an application engineer in the Large Motor Department, where he works mainly with fixed- and adjustable-speed drives and ac motor applications. He has contributed to development of gearless grinding-mill drives, a load-sharing arrangement for dual synchronous motors, and shunt-capacitor motor starting.

Arthur H. Hoffmann graduated from New York University in 1942 with a BSEE degree, and he earned his MSEE degree at the University of Pittsburgh in 1947. He joined Westinghouse in 1942 on the graduate student training program and went to work in the Large Rotating Apparatus Division. He served first in insulation design and then, in 1947, switched over to large ac motor design. He contributed to the design of the m-g-set power supply for the particle accelerator at the Brookhaven Laboratories, and he invented the Westinghouse solid-state controls for synchronous brushless motors. Hoffmann's present responsibility is design of gas-turbine peaking generators.

Paul B. Shortley graduated from the University of Minnesota in 1966 with a BEE degree. He joined Westinghouse to work in the Computer Application Group on the development of computer programs for electric utility systems analysis. He has worked in the fields of generation planning, system operation analysis, probability application to transformer loading, and distribution system planning. He is presently in the System Analysis Section of Advanced Systems Technology, responsible for development work on the Westinghouse reserve planning and production cost programs.

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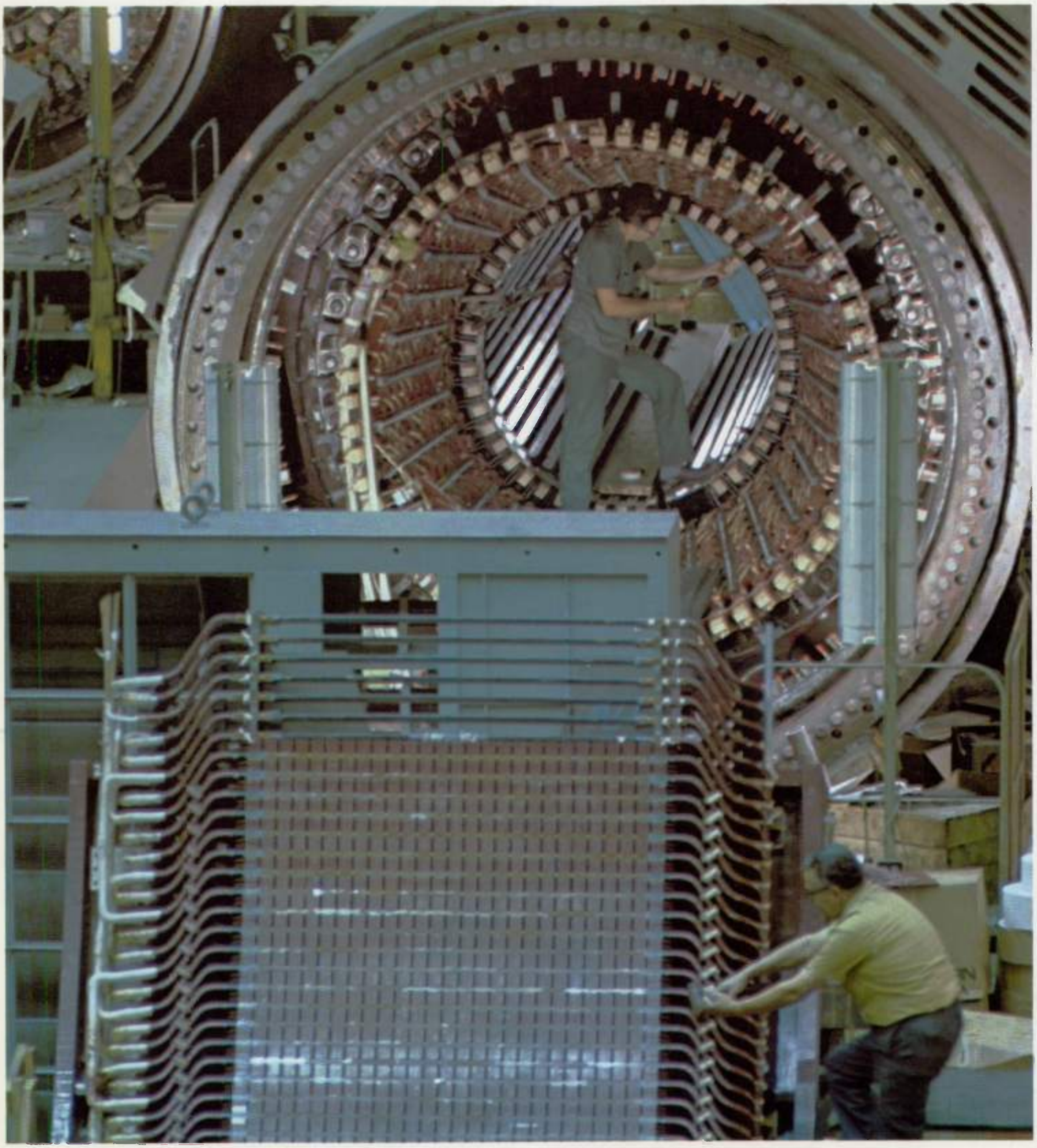

Hydroelectric and steam generators in construction.
(Information on contents page.)