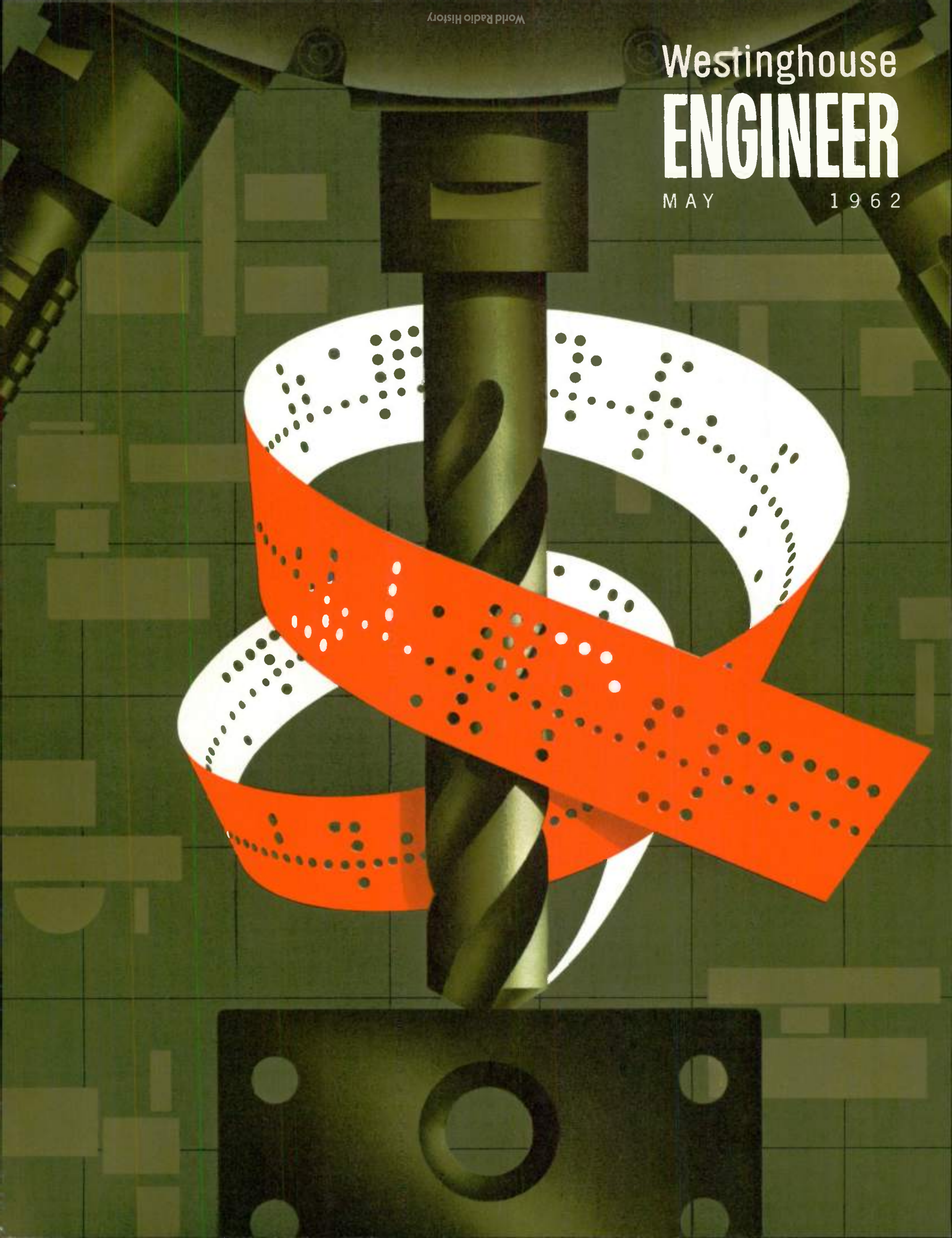
World Radio History

Westinghouse ENGINEER

MAY 1962



IN THIS ISSUE

With this issue, the Westinghouse ENGINEER starts its 22nd year of publication. During the more than two decades of the magazine's existence, this country has witnessed startling changes in technology, and sweeping revisions in the traditional concepts of industrial life. As a large, diversified company, Westinghouse has initiated, participated in, or felt the effects of most of these changes.

In the pages of the ENGINEER, we have tried to provide specific information about some of the technical changes, and occasionally some of the related management aspects. Our objective is, and always has been, to provide useful and informative material to our readers.

During these 21 years, the ENGINEER itself has changed in many ways. We've introduced new subject matter, and new features—and dropped others. We've changed many graphics aspects—paper, type faces, illustration techniques, and even the dimensions of the magazine. The changes have been gradual—and unannounced. They've been unannounced primarily because we believe that our readers are more interested in the overall result, rather than the change itself.

In this issue, however, we've made several changes or refinements that we think should be called to your attention. One is the introduction of manufacturing engineering as a subject in the ENGINEER. We've made this change simply because some of the most vital—and the most ingenious—engineering is now taking place in manufacturing. We believe that much of this technical effort in manufacturing will be of interest and potential usefulness to our readers.

A second change is the introduction of a new feature called "Research and Development." These will be short articles about topics of current interest in the research or advanced development area; for the most part such articles will tell what the new development is, explain its underlying principles, and tell where it stands today.

A third change is an increase in emphasis on short articles about new systems, products, or techniques. This is typified by the section starting on page 93, but future issues will carry this trend further.

Other changes are in the planning stage, because we believe that we must try to constantly improve the magazine if it is to merit a reader's attention and a valuable bit of his time.

RICHARD W. DODGE
Editor

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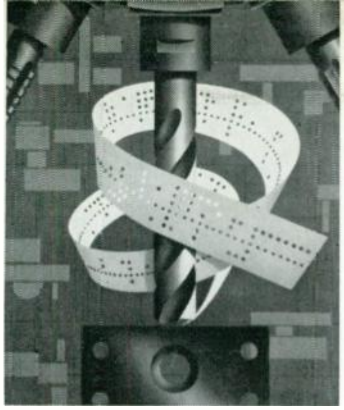

VOLUME 22 • NUMBER 3

Cover Design: Manufacturing is a new subject to the Westinghouse ENGINEER. Since our first article in this issue deals with manufacturing planning, we thought it appropriate to feature the subject on this month's cover. The drills, punched tape, and the plant layout model were used by designer Dick Marsh to portray the manufacturing planning function; artist John Churilla produced the finished artwork.

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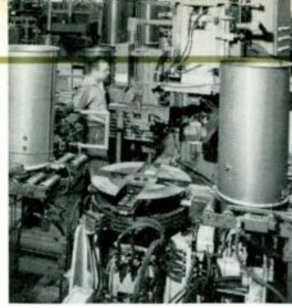

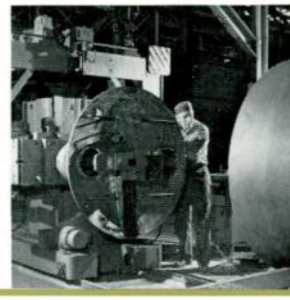

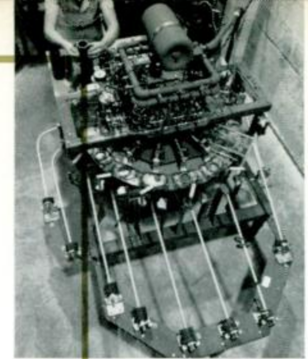

A NEW ERA IN MANUFACTURING

We are in the midst of a revolution in manufacturing. Radically new and different techniques and methods are evolving because yesterday's practices—geared as they were to simpler products and a slower-paced technology—are not adequate for the more complicated products of today, born of the rapid technological advances of our times. The traditional concept of three separate and individual functions—engineering to design the product, manufacturing to build it, and marketing to sell it—each operating separately and individually, is behind us. Today these functions must work closely together, bringing their efforts to bear jointly on the problems of designing, producing, and selling products. It is this thinking that has been largely responsible for the revolution in manufacturing. The application of an engineering approach to all functions of manufacturing has brought about a much closer tie to design engineering and has fostered a better recognition of the sales and customer relationship.

Two pressures are primarily responsible for the changes in the manufacturing approach and the closer coordination with design engineering and sales. One of these is the now famous "cost-price" squeeze, with its consequential effect on return on investment. The other is the rapid advances being made in the technologies of manufacturing in the fields of equipment and methods, and the rapidly developing science and technology that creates new and more sophisticated products to be manufactured.

The "cost-price" squeeze poses a problem of manufacturing a product at a cost that will insure an adequate profit at a competitive price. This dictates the necessity of engineering modern, efficient plants; procuring the most modern and most efficient machine tools and manufacturing equipment, and engineering the most economical tooling and production methods. The challenge to manufacturing is to be a step ahead of competition at all times in all areas of the manufacturing activity.

The second pressure—the stepped-up pace of manufacturing technology—further emphasizes the necessity for manufacturing engineering. New scientific knowledge is being brought forth at the fastest rate in history. This new knowledge is being applied to new products and new systems in an ever shorter span of time. To take full advantage of this, manufacturing engineering must match this application with new manufacturing techniques.

The challenge is of considerable magnitude. Products of all kinds—whether for the home or for industry—are becoming more complex. For example, the home washing machine not many years ago consisted of a tub, an impeller to agitate the water, a motor to drive the impeller, an on-off switch to start the motor, and a pump to remove the water. Today's washer has all these things, but in addition has a level control, a timer, a transmission, a weighing device, a mixing valve, temperature control, and a myriad of other complex components. Such sophisticated products multiply the complexity of the manufacturing function. Moreover, the complex parts frequently cannot be manufactured economically on conventional drill presses and milling machines, but require automatically controlled machines. These factors further increase the difficulties posed by the "cost-price" squeeze.

The net effect of these and other pressures on manufacturing is to create an environment in which continual change must be a way of life. A continuous program of plant modernization and manufacturing methods improvement must be carried on to achieve greater productivity and continuing reductions in costs.

To meet this situation, manufacturing at Westinghouse has evolved into three parts. The first is the *planning* function, which encompasses the development of the lowest cost production methods, obtaining the best available machinery and equipment for processing, and determining the best possible facility and plant layout. This function is described in the accompanying article.

Second is the *operations* function, whose prime responsibility has to do with the general tone of the manufacturing activity. This function covers the actual building of the product by production workers. Such things as the adequacy and training of personnel, and the application of proper operating procedures and processes in manufacturing are covered in this function.

The third is the *control* function, covering the steps necessary to deliver a product at a predetermined time; of the quality that will meet the customers' requirements with respect to reliability and service; and at a cost that will permit a competitive selling price and return an adequate profit. This function controls the amount of labor and materials that go into the product and includes such things as production planning and control, inventory control, quality control, cost and expense control, and industrial engineering.

The revolution in manufacturing has already brought about radical changes in traditional concepts, but the end is nowhere in sight. Continuing technological advances and continuing profit pressure will continue to pose problems, so that manufacturing planning will be challenged to the utmost to provide the product needs of the customer and meet the needs of the Corporation for costs that will allow an adequate return on investment.

R. V. GAVERT, *Vice President, Manufacturing*

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MANUFACTURING PLANNING A separate planning group can provide effective solutions to many manufacturing problems.

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Against a background of increasing competition, more sophisticated products, and more complex production processes, more effective planning has become essential in manufacturing. Basically, manufacturing planning must provide future capacity at low investment while maintaining minimum manufacturing cost for the product quality required.

Planning how to carry out tomorrow's manufacturing involves methods, tooling, plant layout, material handling, facilities, special equipment, and many specialized skills, such as in metals joining and packaging. The task is sufficiently complex—and sufficiently rewarding—to warrant a separate planning organization.

With such a planning organization, higher productivity can be built into new plants, and comprehensive replanning jobs can be undertaken to improve the productivity of existing plants. The planning organization can tackle any manufacturing task, and can have specialists in such fields as numerical control, manufacturing systems, metals joining systems, computer application, and so on.

Manufacturing planning is an effective concept regardless of the size of the company. However, in a large decentralized company, a headquarters planning organization adds many benefits. The work of this group can be focused on effective projects because it can readily be coordinated with the parallel group in the product division. Specialists in areas such as material handling, packaging, plant layout, and computer applications can be justified because the results of their efforts are useful to more than one product division.

At Westinghouse, the headquarters engineering and the manufacturing engineering organizations are now located at the same site. This was done to induce research and development engineers and manufacturing engineers to work together from the time an idea is born until it is a fully developed product, ready for assignment to a product division. The objective is to reduce the cycle time from inception of the idea to the production stage. Also, since manufacturing engineers will be aware of each new project from its beginning, minimum-material design principles can be applied earlier in the life of the product involved.

In a headquarters planning group such as this, one of the most important ways to investigate new methods that involve equipment is to actually build working units. Hence a manufacturing laboratory is an essential part of the planning department.

One of the first problems encountered in a manufacturing laboratory is the kind of projects to initiate. At Westinghouse, a set of policies was formulated to guide development efforts; these policies worked so well that they were also applied to the overall planning organization. There are four policies. Their objective is to insure maximum benefit to product divisions for the investment at headquarters. Their aim is to get work in production in the shortest possible time by utilizing all the services available, such as the divisions themselves, suppliers, and other outside groups, as well as the headquarters staff functions.

The first policy is: "*Interest product divisions in establishing and maintaining their own manufacturing development programs.*"

To obtain the shortest cycle time from conception to production, the development work should be done in the product division, because the division knows its products and its facilities better than anyone else. Where the return can be justified, permanent manufacturing development groups are set up in product divisions. Some have manufacturing laboratories and equipment development departments. These facilities are backed up by the headquarters laboratories. However, the headquarters objective is to get the job done in the division even if it means loaning personnel to the division.

The next policy is: "*Employ the services of suppliers as much as feasible.*"

One way to get an idea through development and into production more quickly is to put more people on the job. Supplier companies frequently have excellent development organizations and can increase the scope of our accomplishments greatly. If they can put the proper talent on the job, their development work can expedite a project and headquarters and divisional manufacturing's efforts can be conserved for jobs that must be done by Westinghouse people.

Our next policy is: "*Disseminate information to the divisions, using such tools as seminars, reports, internal publications, and committee organizations.*"

If every manufacturing operation in Westinghouse matched the most efficient operation of its kind anywhere in the corporation, the result would be the greatest cost improvement in our history. A step in this direction is to find out where the best methods are in use and communicate them to all the divisions. This also helps isolate problems that haven't been solved before, so that where possible, solutions can be undertaken by the headquarters laboratory.

With these three policies in effect, more time can be spent on the principal operating policy: "*Establish forward looking manufacturing method and equipment development programs.*"

The direction obtained from these four policies has led to work that supplements the product division effort, and also creates new information for divisions to build on.

new methods—new techniques from manufacturing planning

As the organization of the manufacturing function has changed, a parallel change has occurred in manufacturing research for new methods and techniques. Several exam-

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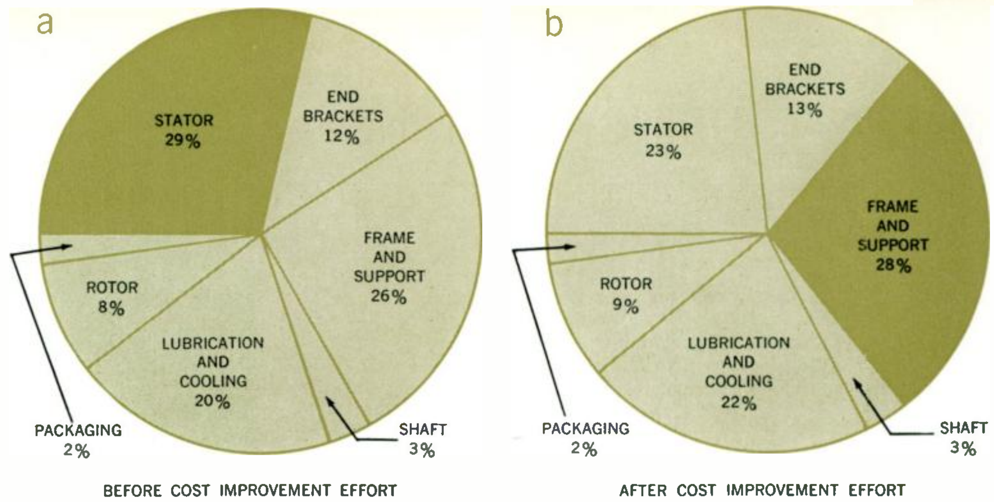

Fig. 1 The pie chart is one approach to better use of materials. This involves working on the largest cost component, in this case the stator; after cost improvement in the stator, the frame and support become the largest element, and thus the new area of potential improvement.

ples indicate the approach used and some of the results.

To insure the highest return for the manhours invested in manufacturing development programs, all the areas where Westinghouse spends its dollars were investigated. This study showed that several times as many dollars were spent on materials as on direct labor. This, in turn, indicated that more time should be spent on improving the effectiveness of our material utilization.

In the search for ways to improve material utilization, one of the first techniques uncovered was the use of the pie chart (see Fig. 1). The material cost distribution of all the components of a product are shown in Fig. 1a. Since the stator in this fictitious example is the largest increment, for the same effort, supposedly a larger cost improvement could be obtained by working on the stator rather than on the frame and support or the end brackets. With a cost reduction of the stator, the motor material cost might be as shown in Fig. 1b, with the frame and support as the high cost components, and, therefore, the next most likely increment for cost improvement.

While this technique points out the areas of greatest potential cost improvement, it obviously does little to help the design engineer uncover actual cost reductions through improved design. This broad reasoning is similar to that applied to the study that indicated that materials were a fertile field to save dollars. However, since the pie chart technique did not help the engineer in doing his design work, this procedure was abandoned, and the search continued for a better technique.

Many of the directions taken in the investigation ended up with a series of questions—Can cheaper material be used? Can operations be eliminated? Can two parts be combined into one? Can the unit be made smaller? Can the cost be reduced and still meet the function? When all the questions were listed, there were 90 that an engineer could use as a check on his efforts to reduce the cost of his design. However, this general questioning procedure proved ineffective because it was illogical to ask this many questions each time a part was designed; few of the questions actually applied to the specific design problem. This general questioning technique has its counterpart in Value Analysis. And, while this technique is helpful, experience has proved that the engineer needs to be guided more specifically in the effective use of materials than is possible through a general questioning procedure.

At this point, work done in an entirely different field was of considerable help. Many years ago, Taylor and Gilbreath developed specific techniques that became the foundation of industrial engineering as it exists today. They reduced the number of questions that could be asked to eliminate unnecessary motions in manual operations, and came up with three basic questions:

Can the motion be eliminated?

If not, can the motion be combined with another motion?

If not, can the motion be reduced?

These three questions are so logical and fundamental that they can be applied to many other fields, and have become one of the cornerstones to the logical questioning of material.

Can the part be eliminated?

Can the part be combined with another part?

Can the material in the part be reduced?

However, questions alone were not enough. To develop a technique that would apply equally well to a transistor or a steam turbine, the common factor in every manufactured product had to be found.

The answer was to separate the components of all manufactured products into two different subdivisions, and then develop a technique for each subdivision. The separations chosen were: (1) the assembled parts, and (2) single parts. Assemblies and subassemblies perform *functions* and should be considered from this standpoint; this led to a technique called Functional Analysis. Specific parts are considered from the standpoint of every *individual particle in that part*. This is called Particle Analysis.

The complete procedure is called Material Analysis TechniqueS (MATS), and is essentially a logical two-step procedure:

Functional analysis applied to assemblies and subassemblies.

Particle analysis applied to parts and waste material.

As a byproduct of the investigation, a material distribution chart was developed (see Fig. 2). Note that unnecessary material is found in the product itself, as well as in material discarded after manufacturing operations.

The following examples show how the MATS procedure can contribute to product design through more efficient use of materials.

Power Transformer—A MATS analysis was made of a terminal stud assembly used on power transformers, shown

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Fig. 2 A typical breakdown of raw material distribution. Note that some unnecessary material is found in the product itself, as well as in the discarded material. The term "off-all" refers to that part of the material received in a plant that is either taken off or not used as a part of the product shipped.

in Fig. 3. The assembly is produced in various sizes for different transformer ratings, but always with the same general configuration. Electrical leads from the transformer coils are brazed to the flat surface on one end of the terminal stud while cross connections between coils are bolted to the flat nut threaded on the stud. The stud assembly is mounted in the wooden structure of the transformer. Functional analysis of this ten-part assembly resulted in a number of part eliminations and combinations.

The group analyzing the assembly developed a seven-part assembly, which meets the primary function of conducting electricity and supporting coil leads. During the analysis, they questioned the reason for the circular cross section of the stud when both leads attached to the stud have a rectangular cross section. Changing the stud assembly from a round bar to a flat bar greatly reduced manufacturing cost.

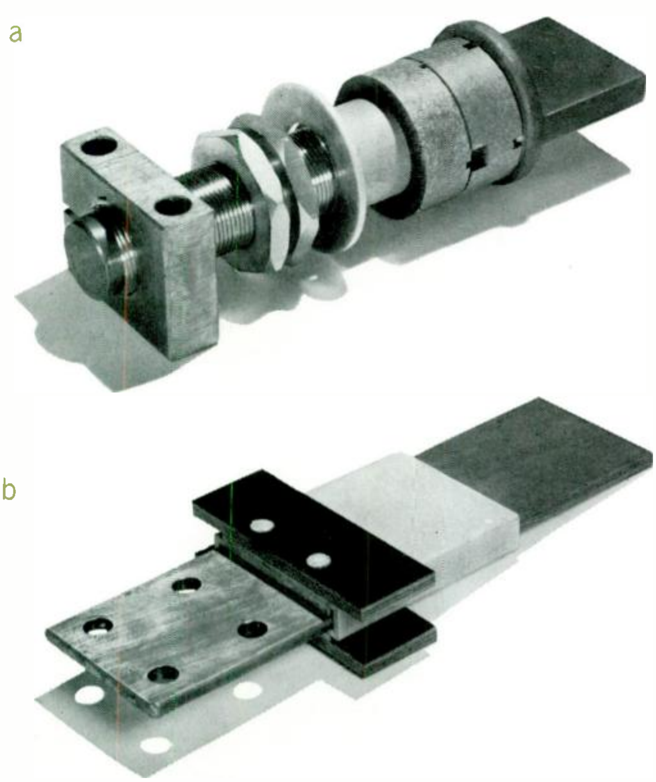

Fig. 3 A MATS analysis of the terminal stud assembly at top, used on power transformers, resulted in the development of the assembly below. The new assembly has fewer parts, costs less, and has more current-carrying capacity.

Following the anlysis, a MATS model was quickly built and tested. The tests showed that for the same cross-sectional area the rectangular bar could carry more current than the round bar because of improved heat transfer.

The design resulting from the MATS analysis (Fig. 3) costs less than the original design with the additional feature of approximately 30 percent more current-carrying capacity.

Motor Mount—One of the effective material utilization practices in MATS is the use of wire. During a particle analysis of this motor mount, the use of wire was considered during the rebuilding of functional material particles into a new part. The use of wire resulted in a new motor mount design (Fig. 4) that reduced material cost for this part by 65 percent and also produced an appreciable saving in labor cost. An additional benefit is a less bulky appearance.

Trinistor Controlled Rectifier—A MATS analysis was made of the internal lead assembly of a 50-ampere Trinistor controlled rectifier (Fig. 5). The analysis resulted in an immediate reduction from 16 to 6 parts in the assembly with a reduction in manufacturing cost. Additional material reduction possibilities requiring development and test can increase the savings almost two-fold.

The revised internal lead assembly is not only less costly, but more reliable. The new assembly is less vulnerable to shock and vibration, and a higher yield is obtained in production.

Ultrasonic Generator—After a conventional cost reduction procedure had been applied to a 500-watt ultrasonic generator, MATS procedures were used on the same product. The MATS procedure doubled the potential cost reduction made by conventional methods, and other ideas requiring some development should increase the figure still further.

Functional analysis resulted in a total reduction of parts from 243 to 68—72 percent (Fig. 6). Particle analysis of critical parts pointed out numerous areas where unnecessary material was being used. The final result of this addi-

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tional effort was a product that cost less than the former design, and weighed half as much—20 pounds instead of 40 pounds. At the same time, both performance and reliability were improved because the MATS technique stressed providing material where it would do the most good—in primary functioning parts. Secondary functioning parts and unnecessary materials were eliminated where possible.

MATS represents a new kind of research work for Westinghouse. It is not the development of a new product, a new process, or even a piece of manufacturing equipment. The research work culminated in a technique which can be used by many of our engineers. Over 5000 engineers all over Westinghouse have been formally trained. Licensees are now being given similar training.

automation techniques

Division and headquarters manufacturing planning organizations are also working on automation. Many divisions are actually building an appreciable quantity of their own automation equipment. The leader in this respect is the lamp division, which designs nearly all new equipment and builds over a third of all equipment for their various departments.

Calibration of Circuit Breakers—An example of an advanced system is the project to calibrate small circuit breakers. To expedite calibration of Quicklag circuit breakers, the Manufacturing Laboratory has developed a machine to calibrate, test, and classify breakers automatically. The breakers may have either prong or screw contacts; current ratings range from 10 to 70 amperes. On a bench setup, calibrating equipment can accommodate 100 breakers per hour—the automatic machine calibrates 400 per hour.

The core of the machine is a 9-foot-diameter circular table that rotates continuously (see Fig. 7). Around its circumference are 120 fixtures that hold the breakers. Jaws inside each fixture can be quickly repositioned so that the machine can be adapted for a different type of breaker in only 15 minutes. An operator loads breakers into the fixtures as they pass the loading station.

Once loaded, the breakers are carried through a five-minute preheating period. Heated until they are just ready to trip, they pass an automatic screwdriver. Some breakers may trip before they reach this point. If they do, relays take over the job of carrying the current and energize a time-delay that keeps the screwdriver stationary. As the breakers move past the screwdriver a rapid-fire sequence takes place. The screwdriver comes in and engages the breaker's adjusting screw, and, while moving along with breaker, turns the screw until the breaker trips. This calibrates the breaker. The tripping also fires relays and solenoids that retract the screwdriver and thus allow a counterweight to pull it back to position in time to meet the next breaker.

The table carries the breakers through a cooling period, between two rollers that reset them, and then into the checking period. Breakers that are too sensitive for practical use ("low" breakers) will trip early in this period. But all breakers that trip after they have traveled through this zone for a minute and 15 seconds are "good" breakers, which will perform acceptably in actual use. Recalcitrant breakers ("high" breakers), which won't trip at all, must be

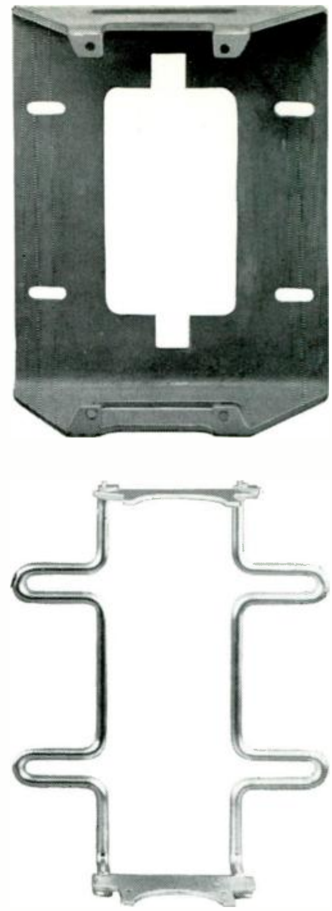


Fig. 4 The motor mount at bottom has considerably less material than its predecessor, at top, and demonstrates an effective use of wire.

Fig. 5 A MATS analysis of this Trinistor controlled rectifier made the internal lead assembly less vulnerable to shock and vibration and reduced the number of parts from 16 to 6. Original version is at top, newer version below.

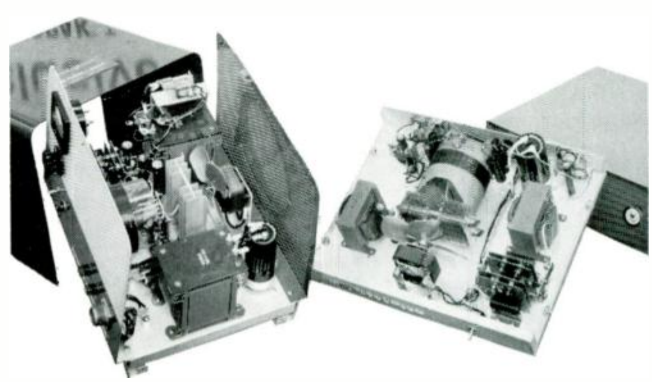
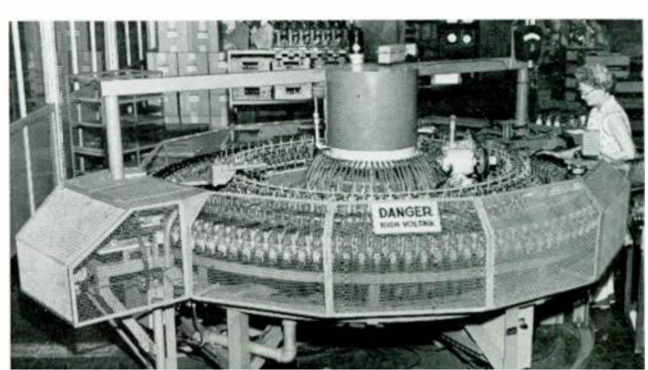


Fig. 6 (Above) Functional analysis of the ultrasonic generator at left reduced the number of parts from 243 to 68, cut the weight from 40 to 20 pounds, and improved both performance and reliability.

Fig. 7 (Below) This machine calibrates, tests, and classifies small circuit breakers automatically at a rate of 400 per hour.



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reconditioned before they can be used. At the unloading station, breakers are unloaded in chutes according to their tested characteristics.

For accurate calibration, the temperature of the breakers, the length of time they are in a zone, and the current applied to them must be kept constant. In this machine, a heat exchanging solution is pumped through all the fixtures to keep them at 90–95 degrees F, and a synchronous motor transmitting power through a geared drive turns the table at a fixed speed.

Since the resistance changes every time a breaker trips, the current continually tends to fluctuate. (Resistance also changes rapidly as breakers enter zones during loading and as they leave when the machine is being shut down.) To stabilize the current, a new feedback control was developed. It employs a current transformer that monitors load current and feeds this information to a voltage regulator. Input current is sent through this regulator and through other transformers to a constant-current bridge, whose output is applied through brushes to the breakers.

Since these conditions are kept constant, the machine calibrates breakers more uniformly and then checks, or tests, this calibration with greater accuracy than could be achieved on a bench setup. Because it eliminates so much rechecking, it has quadrupled daily capacity.

Motor Testing—Major changes are occurring in the testing of products. Induction motors up to 25 horsepower are now tested in 90 seconds. With all the handling, making test setups, reading meters, and recording results that is involved—not to mention the "skew" sometimes introduced into results by an imaginative operator—manual testing has inherent drawbacks. If a product is made in different models or with different ratings, these drawbacks multiply.

One way to prevent this is to automate the testing. A new motor tester tests three-phase single-speed induction motors up to 25 horsepower automatically under a program controlled by punched cards and tape (see Fig. 8). It eliminates human error, makes test conditions uniform and exactly repeatable, and guarantees a product of consistently high quality.

The only time the operator handles a motor is when he loads it on the 10-station indexing table and connects it to the tester with a single plug-in connector. From then on all handling is done by the machine under the control of the permanent timing program contained on a loop of punched tape. The rotary table carries the motors through a preheating period and delivers them to the test stand. A pneumatic ram transfers them to the stand and, after testing, to powered rollers for delivery to the next operation, disconnecting them from the tester at the same time.

The motor runs continuously while it is in the machine. The indexing table has been designed to provide a 10-minute interval between loading and testing so the motors will reach stable operating temperature before being inspected. Punched cards, one for each different type of motor, supply the test specifications and are inserted into the card reader. The machine translates this information into resistance settings that represent the limits for each of the various tests.

With the programmed tape dictating the sequence of operations, the machine rates each motor on five counts: power, speed, current, vibration, and dielectric strength. It measures motor performance and compares it with the test limits that have been set up. The entire procedure takes only 90 seconds.

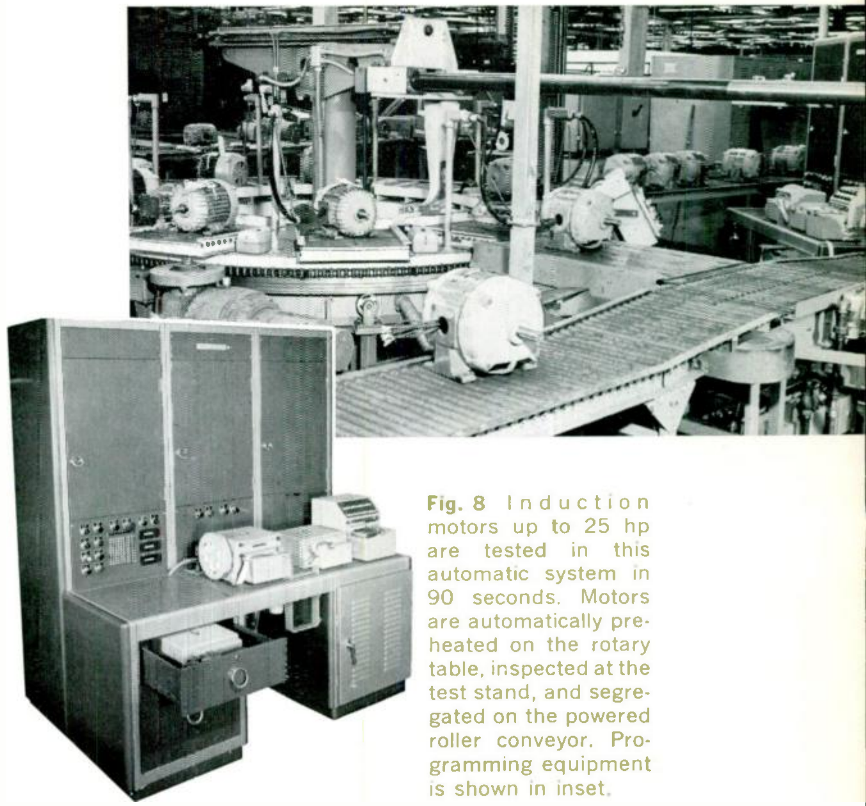

Fig. 8 Induction motors up to 25 hp are tested in this automatic system in 90 seconds. Motors are automatically preheated on the rotary table, inspected at the test stand, and segregated on the powered roller conveyor. Programming equipment is shown in inset.

The machine remembers the results of the tests and, when necessary, also turns on lights in the operator's console to indicate on what counts a motor has failed. The operator labels a faulty motor with strips of colored tape, the colors coded so the repairman will know why the motor was rejected. Memory devices actuate the powered rollers that send satisfactory motors on to be painted and return unsatisfactory ones to be repaired.

The machine is not limited to a fixed number of motor styles, but can handle any standard type of induction motor up to 25 horsepower. If, as with special motors, no cards are available, input test data can still be programmed into the machine by manually operated dials. Again, the timing program, as is presently contained on the tape, is used for every motor, regardless of type. But it is possible to change this program simply by preparing a new tape instead of rewiring the control system or resetting a large number of timing cams.

Since the motor tester is integrated into the assembly line, it preserves continuity of production flow; since it eliminates storage of motors before they are tested, it conserves valuable floor space; and it provides the inherent reliability of testing possible only with automatic methods.

probing—new platforms for cost improvement

Not all the development projects in the Headquarters Manufacturing Planning Department result in a specific technique like MATS or others now in use. Neither do they

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always result in a piece of equipment, such as the breaker calibrator or the motor tester described earlier. As indicated previously, manufacturing must assume the responsibility of continuous improvement in methods. In some areas this means probing and exposing entirely new approaches to make major cost improvements. In other words, manufacturing researchers must look for new platforms, which lead to a new start on the product cost improvement curve.

An example of one such probing operation is the application of the electron beam to manufacturing. The research program began when engineers asked themselves several questions: Would it be possible to part metal without using a heavy machine that employs chip-forming tools? Is it possible to separate the metal crystals, or even possibly the molecules, without such "brute force" methods, by focusing or concentrating the energy into small areas? Perhaps large amounts of metal could be removed without actually working all the metal removed (such as chips). While making a general investigation in this area, engineers discovered a patent by a German inventor; this described the use of an electron beam to cut metal. The inventor, Carl Steigerwald, worked for the Zeiss Foundation in Germany; he was invited to come to this country and discuss the process with a group of Westinghouse people to determine their potential interest. One division immediately foresaw possibilities and with the inventor developed an entirely new application—that of using the beam to weld instead of cut. Electron beam machines are now in use in several locations, including the Headquarters Manufacturing Laboratory. At the Manufacturing Laboratory problems of extremely fine machining are being probed. Several examples are shown in Fig. 9.

Along the same lines of concentrating energy into a small area, the plasma jet process has some interesting possibilities. The application of this equipment for a number of different manufacturing processes is now being investigated. Its first obvious use is the acceleration of the existing and commonplace process of torch burning. Another possible application is the deposition of metals from powder form that could not be melted and sprayed in a conventional torch. The temperature inside a plasma jet gun can vary between 25 000 and 50 000 degrees F (Fig. 10). The first Westinghouse commercial application of the plasma jet gun to deposit metals will be made this year.

Such probing work does not always head in the direction of a machine or process directly applicable to products. Sometimes the tools used to develop processes also have to be probed. An example of this is the work now being conducted with closed circuit TV. This involves exploring the use of TV to examine cutting operations on machines where it is not possible to observe these operations directly.

communication

A necessary step in manufacturing is to make sure that the best methods of each division are *known* in the others. This is a communication problem, and to solve it a separate Manufacturing Communications group was organized.

The principal method of communication in this group is the use of specialized single-page newsletters. Each of the various areas of manufacturing methods have been assigned to a specialist covering the area and he is responsible for getting out one issue every month in his field. He not only seeks ideas from divisions but also looks outside the company to our suppliers, technical journals, and our competitors. A series of newsletters are being issued on different subjects. This method of communication is surprisingly effective, but other means are also used, such as exhibits, display boards, committee reports, etc.

what does it all add up to?

The Manufacturing Planning organization is oriented to tackle the overall job and to integrate the results with engineering and marketing. At the new Headquarters Manufacturing Planning Laboratory projects are undertaken only when they can add to the knowledge available. Policies have been established to avoid overlapping the work of division, suppliers, competitors, or anyone else. Projects include developing new techniques, such as Material Analysis TechniqueS; new processes, such as plasma jet cutting and spraying; and new equipment such as the automatic calibration of circuit breakers and the tape controlled testing of ac induction motors.

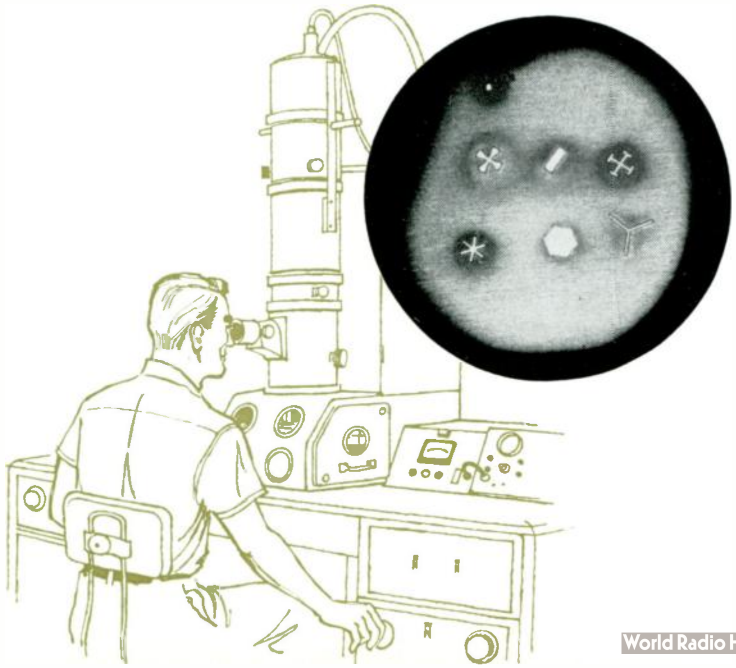
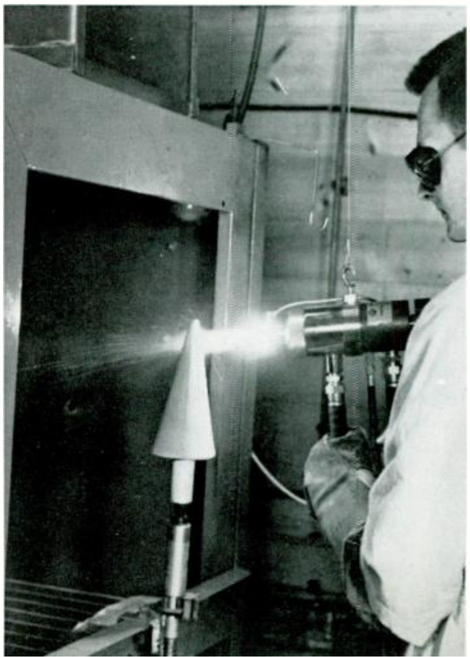


Fig. 9 (Left) This electron milling machine is being used in the Manufacturing Laboratory. Inset shows shapes cut in 0.005 inch thick stainless steel by an electron beam under automatically programmed control. Each figure is about 0.02 inch across.

Fig. 10 (Right) A plasma-jet gun in operation. One possible application for such devices is the deposition of metals from powder form.



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AEROSPACE DIGITAL COMPUTERS Today's most versatile and powerful method for the automation of aerospace systems.

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Perhaps no development in recent years has captured the public and scientific imagination more than the electronic digital computer. Digital computers have been widely utilized and are well known in a wide range of applications including huge and powerful scientific data processing systems, the accounting processes of business, and the control of industrial tools and processes. A less publicized and less well known facet of computer application, which is of importance to us all, is in military control systems for national defense. In these military systems digital computers are applied to control functions that are too remote, too dangerous, too time consuming, too precise, or too exhausting to be done by other means. Nowhere is the need for computers more demanding or the problems of developing them more challenging than in advanced aerospace weapon systems.

the need for computers

The progress in man's abilities to use the vast areas above the earth's surface for military purposes has been largely accomplished at the cost of increased complexity and sophistication of the hardware in the weapons system. The number of subsystems to be controlled and (more or less) routine actions to be monitored have increased; and simultaneously, the precision and speed of control activities have become more complex and more exacting. The pilot has more to do and must do it faster. Without some form of automatic control his multitude of tasks and responsibilities would soon limit the weapons system's effectiveness. Toward this end, the modern manned aerospace weapons system concept is built around a large number of automatic and semiautomatic control systems which aid, augment, or altogether relieve the man in the performance of routine and quick-reaction, high-precision tasks. A brief description of these systems in a typical application (a one-man attack aircraft) is pertinent to an understanding of the role and importance of automatic control devices in modern aerospace weapons systems.

An electronic navigation system using doppler radar provides the pilot or autopilot with continual present-position coordinates, ground speed, track, heading and distance to target, and wind direction and velocity. This information as well as alternate destination selection is supplied automatically and independently of ground installations through a self-contained computer.

Additional radar provides forward ground track display for direct sight navigation and fire control purposes. This radar allows the pilot to keep track of his route visually on a realistic synthetic display—regardless of outside visibility. This all-purpose radar is adapted for both low-level and high-level missions and its display aids the pilot

DEFINITIONS OF MILITARY WEAPONS SYSTEMS FUNCTIONS

Some functions that are automated in modern military weapons systems include the following (the definitions are typical but not necessarily restrictive):

Navigation—inertial (usually doppler aided) calculations providing present position and course and time to destination with a high degree of accuracy.

Stabilization—momentum dumping or impulse corrections to orient a space vehicle and maintain correct orientation with the earth, a star, etc.

Time Sequencing—switching signals generated by a programmer purely as a function of accurately measured elapsed time.

Track-While-Scan Radar Data Processing—correlative processing based on time-position data collected from multiple targets. Involves matching new target return data with accumulated track data without ambiguity.

Electronic Countermeasures Control—collection and sorting of large quantities of data to measure and define radar signals. Examination of received data to determine selection and switching of countermeasure devices with little or no time delay.

Antijamming Radar Data Processing—collection and processing of data from one or more radar sources to determine target range when true target range is normally denied by jamming.

Communications Data Processing—nonnumerical processing involving encoding, format changing and buffering at high rates.

Reconnaissance Data Reduction and Processing—similar to electronic countermeasures processing in some respects. Involves encoding, sorting, storage and recognition of redundant data.

Flight Control—real time calculations to control attitude and aspect of aerospace vehicle; includes stabilization, fuel monitoring, cruise control, etc.

Synthetic Display Generation—logical and numerical processing to display collected or calculated data in symbolic form.

Fire Control—general category of weapon control processing including:
(1) threat evaluation and target selection
(2) bombing computations (free-fall, glide, or powered, nonballistic bomb or missile)
(3) ballistic computations
(4) remote (mid course) guidance computations

Self and Systems Testing and Check Out—logical and numerical processing to exercise and monitor responses of the system as well as the functioning of the computer itself.

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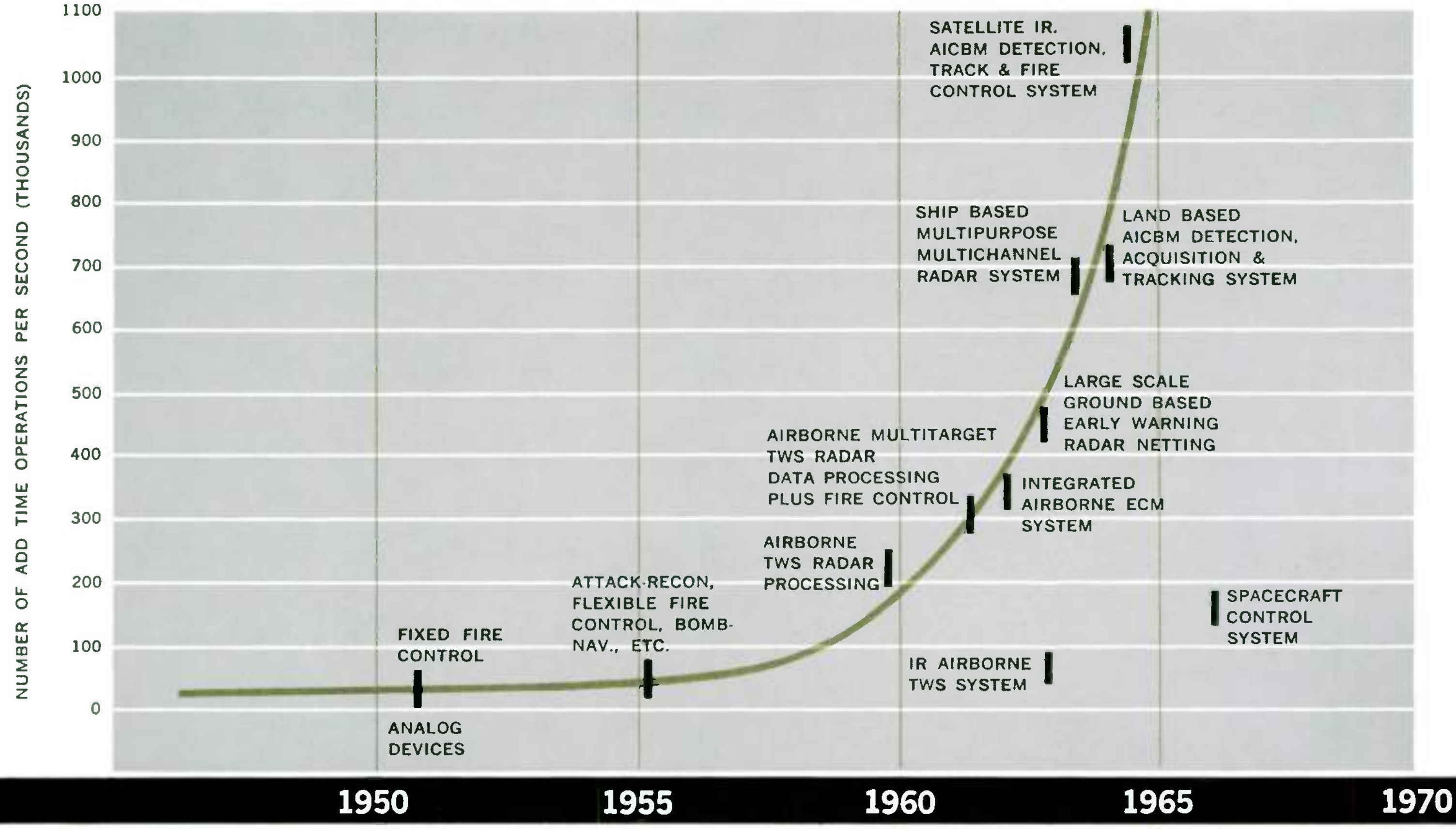
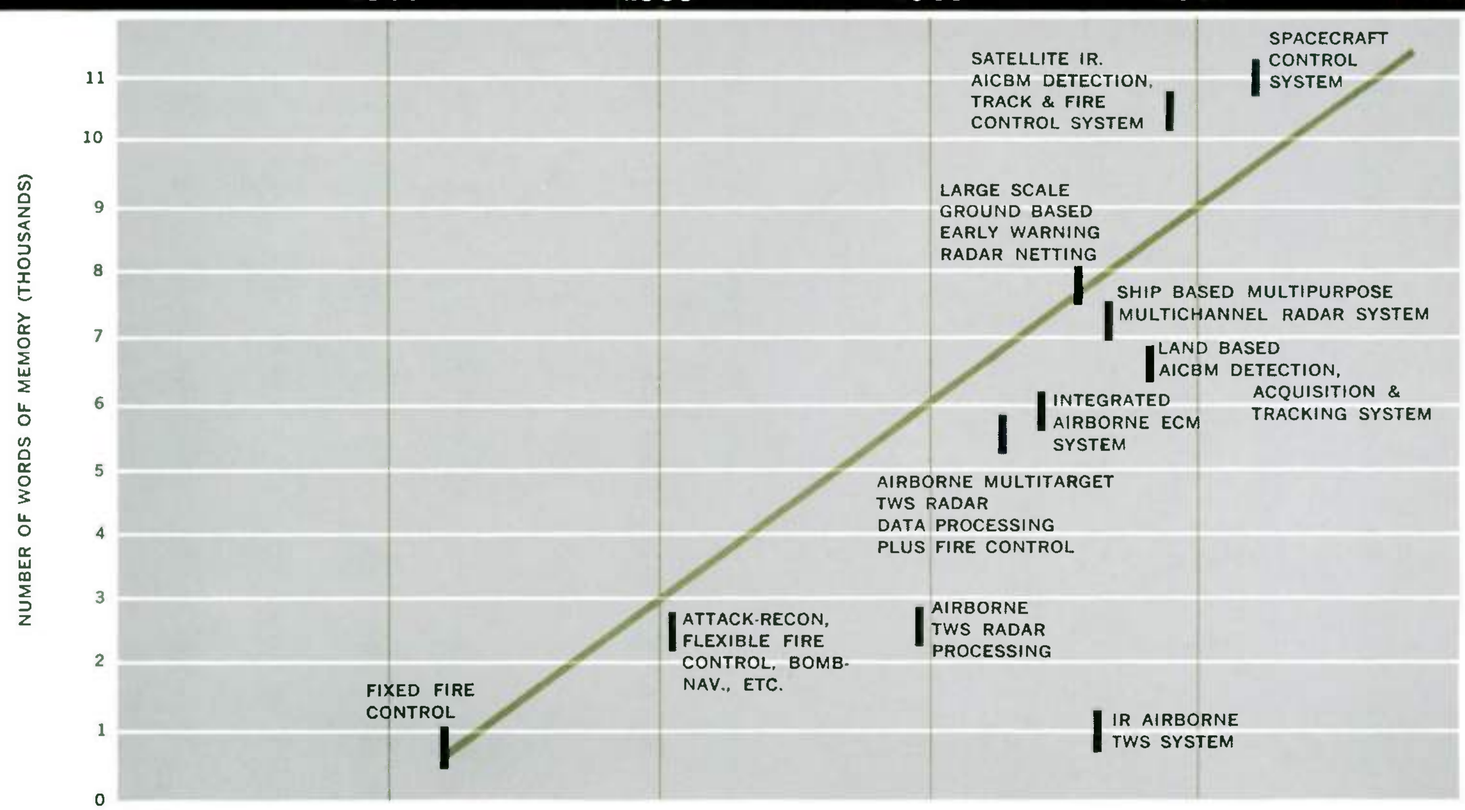
Fig. 1 Computing speeds for typical large-scale military systems.





*AICBM = ANTIBALLISTIC MISSILE
*IR = INFRARED SENSING SYSTEM
*ECM = ELECTRONIC COUNTERMEASURES
*TWS = TRACK-WHILE-SCAN

Fig. 2 Memory capacity for typical large-scale military systems.

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in such functions as air search, automatic tracking, ground and contour mapping, and terrain avoidance.

An automatic flight control system, tied to the doppler radar for navigation data, acts as an electronic co-pilot. It can be called upon to aid the pilot or to take over control of the aircraft completely.

The overall fire-control system combines the navigation, flight control, and bombing subsystems into a coordinated automatic, or semiautomatic, attack system. This system, through a bombing computer, arms and controls the actual release of the bomb while solving such problems as release altitude, flight time to target, angle of attack, and cross-wind effects. In certain modes of delivery the system also initiates an escape maneuver following bomb release. The automatic aids incorporated into the fire-control system also include a correction to level wings at bomb release, a toss-bombing computer, and a nontumbling reference system for control in vertical bombing.

From the preceding brief description of the automatic control devices built into one existing type of aircraft, the increase in sophistication of airborne weapons systems necessary to make an effective, useful weapon out of a high performance aerospace vehicle is evident. Virtually all modern large-scale military ballistic missiles, satellites, and aircraft include digital programmers or compilers for automatic control functions. An advanced strategic bomber now in development as a weapons system will contain as many as three separate and complete general purpose digital computers in addition to a number of small special-purpose analog and digital computer-type units utilized in the flight control, air data, and communications subsystems. The primary Air Force continental air defense interceptor can perform its entire mission including takeoff, interception of target, attack, return to base, and landing without the pilot touching his controls. In this weapons system the entire mission is normally flown under automatic (computer) control with the pilot as a backup to take over in an emergency or as an alternate mode to cope with unpredictable situations. The high speed of aerospace vehicles demands control decisions and actions faster than human reactions can provide.

It should be emphasized that not all aerospace digital computer applications are in military systems. Notable examples include the NASA (National Aeronautics and Space Agency) space vehicles and boosters, such as the Orbiting Astronomical Observatory, Surveyor, Apollo, and Saturn, which are now being developed with digital computers or programmers for automatic control. The next generation of commercial airliners now on the drawing boards will undoubtedly specify the use of airborne digital computers for supplementary or automatic control of such functions as navigation, cruise control, fuel management, monitoring of critical stresses and emergency conditions, and other routine tasks that are manual in present-day airliners.

analog vs digital

Before the era of the airborne digital computer began some five years ago analog computational techniques had been developed and utilized with excellent results as automatic control devices in aircraft systems. As early as 1946, airborne fixed-fire-control systems were built around analog computers. The analog computer has much in its favor in systems where dynamic aiming or positioning is involved and the routine is highly specialized. Analog machines are, however, less well suited for decision making and, in general are limited in precision and initial response speed. Also, being basically single purpose (specifically designed to a particular application or function), these airborne analog computing devices are not readily adaptable to changes in equipment or tactics. The number of analog devices required (and correspondingly their aggregate size, weight, and power consumption) tends to increase markedly as the complexity and number of their assigned tasks increase. On the other hand, the technology of these devices is well developed, they are reliable, and they are rather insensitive to small random disturbances (noise) in their inputs.

The general purpose digital computer utilizing arithmetic techniques is the most flexible and adaptable type of airborne control device known, and the most capable of high-precision operation. Accuracies of one part in many millions can be computed and maintained with ease. Its "settling rate" can be one or a few computation periods, as desired. The general purpose digital computer has the capability of performing many tasks of varying nature and complexity with one set of hardware. However, the digital computer does have a computational delay; even though its individual operation time may be only a few millionths of a second, many individual operations are required to provide a problem solution. Therefore, considerable developmental effort has been spent in obtaining higher operating speeds, more efficient hardware or logic organization, and better programming and data processing techniques. The intrinsic limits of general purpose digital computers involve information theory considerations that are, as yet, not fully developed.

The breakthrough that has gotten digital computers "off the ground" has been the development of new technology that permits the application of digital techniques in the restrictive physical and environmental conditions imposed on an aerospace system. Silicon semiconductors provided the key and an intensive adaptive engineering campaign has turned the lock.

getting "off the ground"

Although such factors as size, weight, reliability, power requirements, temperature range, and speed are important to any computing system, nowhere are these factors so vital as in the aerospace computer.

In an unmanned satellite application, the need for the utmost in reliability is apparent. A digital computer exercising control in such a vehicle must operate reliably, unattended (without maintenance) for the entire period of time that the satellite is to be effective.

The power consumption of the computer is also of great importance in space vehicle applications since all present satellite electrical systems rely on solar energy sources to power storage batteries. Atomic power supplies now in development will eventually provide more power for space vehicles but the increasing electrical sophistication of space systems will continue to require that computer demands be kept low.

The sizes and weights of all on-board hardware are an important consideration for high-speed aerospace vehicles. The availability of space often dictates that electronic

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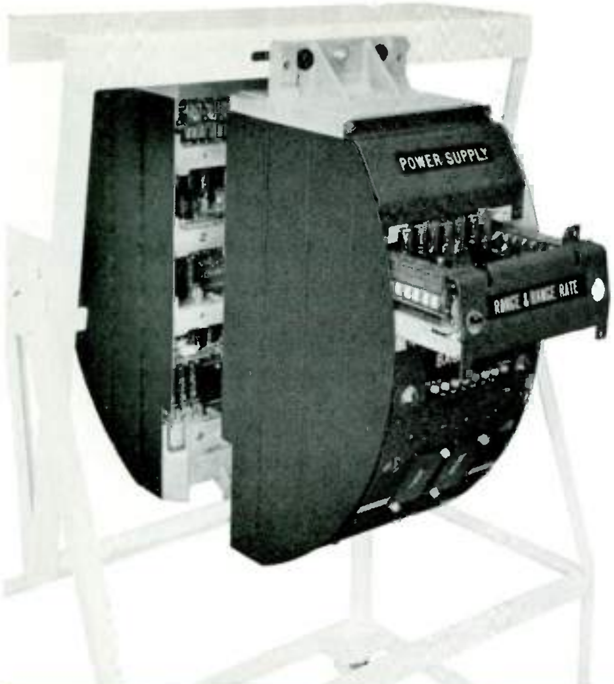


Fig. 4 (Left) The WETAC (*WE*stinghouse *T*ubeless *A*nalog *C*omputer) is an advanced analog system, which can supply all the fire control functions for an interceptor system.

Fig. 5 (Below) A typical plug-in printed circuit board is shown for the arithmetic and control unit of a Westinghouse airborne digital computer.

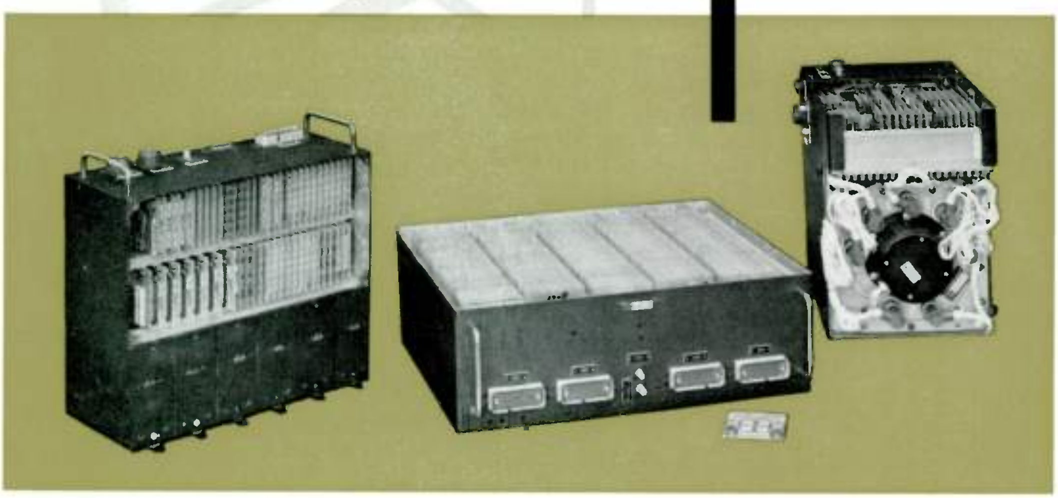
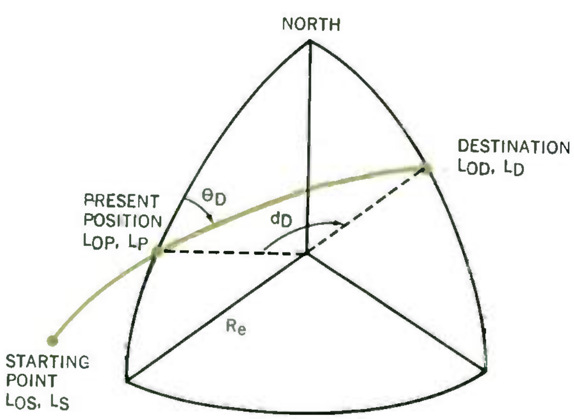


Fig. 3 The WEDAC general-purpose airborne computer is a relative-access unit that can perform 4000 modified three-address add-time instructions per second.

GREAT-CIRCLE NAVIGATION COMPUTATIONS OF THE FOLLOWING TYPE ARE COMMON IN AEROSPACE COMPUTER APPLICATIONS



Determination of present position:

$$L_{OP} = L_{OS} + \frac{1}{R_e}\sum_{0}^{p}\Delta d\,\frac{\sin(\theta_{HP}+\partial_p)}{\cos L_p}$$

$$L_P = L_S + \frac{1}{R_e}\sum_{0}^{p}\Delta d\,\cos(\theta_{HP}+\partial_p)$$

Distance-to-destination and course-to-destination:

$$d_D = \cos^{-1}[\sin L_P \sin L_D + \cos L_P \cos L_D \cos(L_{OP}-L_{OD})]$$

$$\theta_D = \tan^{-1}\left[\frac{\cos L_D \sin(L_{OP}-L_{OD})}{\cos L_P \sin L_D - \sin L_P \cos L_D \cos(L_{OD}-L_{OP})}\right]$$

Where:

L_{OS} = Longitude of starting point, etc.
L_S = Latitude of starting point, etc.
d_D = Distance-to-destination.
θ_D = Course-to-destination.
R_e = Radius of the earth.
Δd = Distance traveled during sampling interval.
θ_{HP} = Present aircraft heading.
∂_p = Present drift angle.

packages be arranged in cylinders, cones, or other shapes of minimum rigid dimensions to be fitted compactly into the pointed nose, along aircraft structural members, in underslung pods, etc.

The operational temperature range through which aerospace computers can operate reliably is of great importance, particularly for high-speed or high-altitude vehicles. Unlike ground-based installations where air conditioning can easily maintain selected room temperature to within ±5 degrees F, the aerospace system is subject to temperature extremes. A computer that can operate over wide temperature ranges without supplementary cooling or heating is most applicable to advanced aerospace systems.

In addition to temperature, aerospace computers are subjected to great diversities of pressure, radiation, shock and vibration, and other environmental parameters. Humidity can vary from zero in space to 100 percent near the ground. Wide variations in barometric pressure from sea level to outside the atmosphere are to be expected. The high-vacuum effect in space imposes packaging restrictions due to the probable disintegration of some popular types of potting materials. The computer should be able to operate normally and perform its control function during the high-G loadings of lift-off in a missile, the shocks of carrier landings or "soft landings" on the moon (either of which is more aptly described as a controlled crash), and during the normal pitch, roll, and vibration expected of low-altitude, high-speed flight.

The operational computing speed required of the military aerospace computers is, of course, a function of the specific system in which it is applied. The task of performing fire control for multiple supersonic targets is a case where high speed is mandatory if missiles or aircraft are to be fired on and intercepted before they are within destructive range. The trend of computing speed requirements for a number of large-scale sophisticated military systems—air, space, sea, and ground based—is shown in Fig. 1. High speeds are required now, and the need for even higher computing speeds is anticipated. The alternative to developing high-speed aerospace computers is to find a breakthrough in computer organization to allow paralleling of computing functions to a greater extent in one machine, or to use multiple slower speed computers. Since technology generally lags present-day needs, both alternative approaches have been frequently considered, and multiple computer configurations have been used. The parallel network devices proposed to date appear to be relatively costly to build and none of them have been actually developed into an operating system. Multiple computer configurations also leave much to be desired—they increase the number of components with a resulting decrease in reliability for the overall computing system, present communication problems that prevent utilizing all computers at their maximum rate, and generally cost more than a single higher-speed computer.

The memory capacity requirements of aerospace computers are also largely dependent on the computer application. In general, memory capacities are much less than those provided in large-scale, scientific computers. Most general-purpose aerospace computers have memory capacities of 10 000 words or less with the great majority being in the vicinity of 2000 to 4000 words. The memory capacities required for the same large-scale military weapons systems surveyed for speed requirements (Fig. 1) are shown in Fig. 2.

computer status today

The first airborne digital computers were built around the miniature magnetic drum. This storage medium offered economy of storage and well-known technology from on-the-ground scientific computer developments. The magnetic drum was used in conjunction with control circuitry made up of subminiature tubes mounted on plug-in printed circuit boards. The Westinghouse WEDAC general-purpose airborne computer, which was operating in 1957, was built up entirely of silicon transistors and semiconducting diodes (with the exception of the clock generating circuitry in the prototype) in conjunction with a four-inch magnetic drum. The prototype WEDAC computer is shown in Fig. 3. This computer, which is still representative of operational relative-access airborne digital computers can perform 4000 modified three-address add-time instructions[1] per second. As in other computers using serial memories, which include not only drums but magnetic discs and delay lines, the arithmetic and control logic is serial in nature.

While rotating relative-access memories (access time to a specific memory word is dependent on the physical location of that word in relation to the reading circuitry at the time it is called for) offer economy in costs, size, weight, and power consumption along with nonvolatile, nondestructively read storage, they are limited in speed. The access process, which includes the revolution of the rotating device to a fixed read head and the subsequent serial pick-off of binary digits is time consuming. Typical access times may be from 100 microseconds to several milliseconds, depending on how well the actual sequence of arithmetic processing can be synchronized with the rotating storage device. For high-speed applications, the penalty of relative access and serial readout is prohibitive and faster access memory devices must be used.

Hybrid memory systems combining rotating relative-access memories for bulk storage plus solid-state random access memory (equal access time to all memory words, regardless of physical location in the memory) for temporary storage have been built and tested. These devices, when operated with parallel arithmetic and control circuitry, offer a relatively high-speed system that is limited only in high volume correlative type processing where transfers of large amounts of data and control are both frequent and diverse.

The rotating memory itself is somewhat speculative for aerospace application. The problem of gyroscopic reactions created by the pitch and roll of the vehicle, lubrication and bearing problems in space, precise head alignment and replacement difficulties, and the need to counterbalance the angular moments of the rotating device in a satellite or spacecraft are largely unanswered. The air-bearing flexible

[1] "Modified three address" is defined as a computer organization wherein a single instruction specifies the address of three memory locations. Thus A+B→C (add A to B and store the sum in location C) is an example of a three-address instruction. The modified three-address structure of WEDAC provides the capability of performing a three-address instruction of the type indicated above and a simultaneous two-address transfer (A+B→C and D→E) within one instruction time.

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disc tends to minimize some of these problems and is a reasonable memory device on which to base a slow-speed, low-cost, aerospace control computer, particularly for low-rate aircraft control tasks.

For the high computer operating speeds necessary in the more demanding systems, random access solid-state memories have been successfully used. A major difficulty is that such memories are normally destructively read, i.e., the numerical content of the word location is destroyed in reading and must be read back into the word location at some later time. The risk exists in this procedure for a random error to regenerate itself, thus becoming a repetitive error. Furthermore, conventional solid-state memories are volatile—if power is lost momentarily the memory contents are lost. Wired or mechanically alterable arrays of ferrite cores have been the most practical means of providing fast, yet reliable storage for high-speed airborne computers to date. A current Westinghouse airborne data processor, which is the highest speed airborne digital computer now flying, utilizes a wired-core instruction memory of 2048 words plus a separate, conventional, word-organized core memory for operand storage. This parallel high-speed computer, operable over a wide range of environmental conditions including temperature ranges of −55 to +100 degrees C, can perform 200 000 separate single-address add-time operations per second. The entire prototype computer is packaged in 6.5 cubic feet, weighs 285 pounds, and requires 800 watts of power. A typical plug-in printed circuit card containing three complete flip-flops and six encapsulated AND or OR gates from the prototype computer's arithmetic and control unit is shown in Fig. 5; it is typical of the packaging techniques of present-day aerospace computers. As in most presently operational airborne digital computers, exclusive use of silicon semiconductors is necessary because of the wide range of environmental conditions under which the computer must operate.

Unfortunately, wired or mechanically alterable memories commonly used to gain nondestructive readout are not flexible enough to allow easy reprogramming. The basic philosophy behind this type of memory is that, once programmed for a specific application, the need for changing or altering the program will be minimum or (hopefully) nonexistent. Experience has shown that this hope frequently cannot be realized; hence, much developmental effort is being expended throughout industry to produce a solid-state memory that has high speed, is reliable, can be nondestructively read, and that can be electrically reprogrammed. The multiaperture core is such a device, and many varieties of it are being developed. Multiaperture cores offer faster readout speeds (less than 0.5 microsecond) than single-aperture cores, provide nonvolatile and nondestructively read storage, can be altered electrically by card or tape readers, and have an inherently wider temperature range than conventional single-aperture cores. The multiaperture core is currently being used in developmental aerospace computers, which offer single-address add-time speeds up to 400 000 operations per second.

A nondestructively read multiaperture core laboratory model memory and control box is shown in Fig. 6. This memory has been run continuously for 1900 hours and has demonstrated that access times of about 0.25 microseconds with high reliability can be obtained in production hardware.

The logical organization of high-speed, random-access aerospace computers has been centered about straightforward parallel binary arithmetic logic. Techniques for fast multiplication (several bits at a time) and cutting down long logical propagation paths, such as in an accumulator carry chain, have been successfully implemented. Direct-coupled transistor logic and diode-transistor logic are both frequently used in high-clock-rate aerospace computing systems. The more economical diode logic utilized in early serial computers, such as WEDAC, has not been applied extensively to higher speed designs due to gating limitations. The clock rates of parallel computing systems have ranged upward to about 2.0 megacycles per second, with a number of existing high-speed computers at 1.0 to 1.3 megacycle clock rates.

It is important to note that the aerospace digital computer can be no more accurate (and no faster iteratively) than the encoding and decoding devices that enable it to communicate with the outside analog world. Analog-to-digital and digital-to-analog converters have been brought along as needed for individual aerospace computer systems but, in general, have not been subject to the same intensive advanced development programs as memory and logic systems. Shaft positions can be encoded up to 19 binary digits, but the equipment is comparatively large and heavy. Very-high-speed voltage-to-digital conversion devices of a significant number of bits of accuracy are somewhat behind the needs of present-day high-speed computing systems. Increased emphasis will undoubtedly be focused in these areas to keep aerospace computing systems from becoming input-output limited.

computers for the future

Due to the size, weight, power, and reliability restrictions placed on digital computers for future aerospace weapons and scientific systems, these computers are the prime candidates for new computer techniques. Two of the most promising developments, directly applicable to the present problem areas, are magnetic thin film memory devices and monolithic functional molecular electronic blocks.

Thin films offer extremely high memory access speeds in comparison with core memories. Access times of a few nanoseconds are realizable and packaging densities and operable temperature ranges are far in excess of what can be expected of ferrite cores.

The monolithic molecular block offers the possibility of building a complete encapsulated circuit or logic complex on a single miniature block. A large portion of the intracircuit wiring is eliminated because the block performs a complete electronic function, whereas in the conventional circuit the function is performed by a number of components which must be connected together. Thus the total number of interconnections in a computer (which has been shown by actual error tabulation to be the greatest single source of failure in aerospace computers) may be greatly reduced. The monolithic molecular block should have a low production unit cost and yield comparable to present-day transistors when processes are well developed.

Other developmental areas that hold promise for improving aerospace computers include advanced logical organizations utilizing redundant networks or self-healing, adaptive logical paths (which can detect and correct failures

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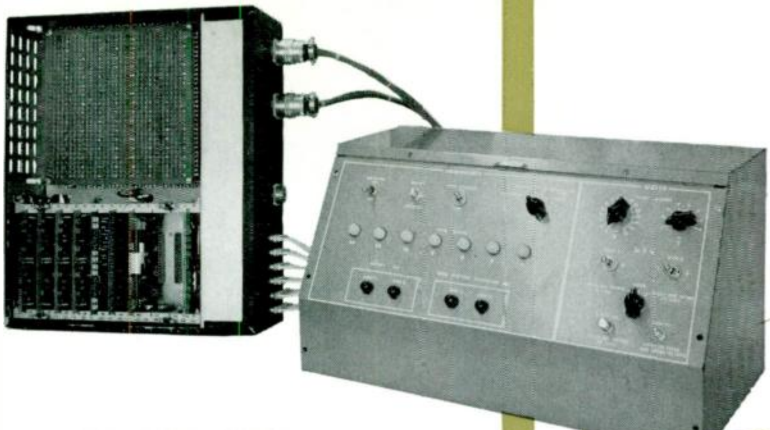

Fig. 6 Nondestructively read multiaperture core model memory test setup.

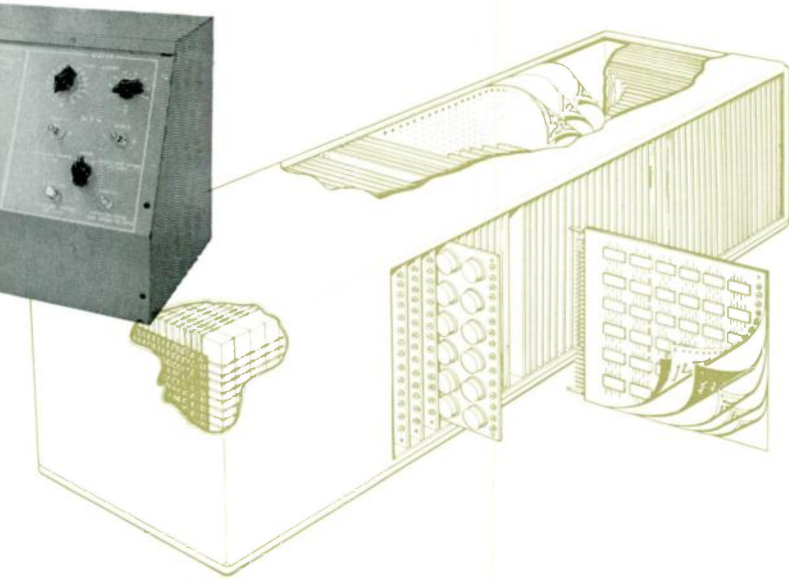

Fig. 7 Engineering sketch of prototype MOL-E-COM aerospace digital computer, which will employ multiaperture core memory, functional molecular electronic blocks, and multilayer printed circuitry.

by switching to alternate networks), and threshold logic systems utilizing majority/minority logic gating techniques.

Catalog or associative memory techniques are being investigated to make possible the correlation of data without the time-consuming procedure of making sequential arithmetic comparisons. In this concept, memory recall is controlled by the content of a storage location rather than by a specific address. By this means a sample of data may be compared simultaneously with an entire memory file. This technique, if successful in very-high-speed operations, could find extensive usage in multiple-channel, track-while-scan data gathering systems.

In the area of components, tunnel diodes, magnetic logic elements, and cryogenic devices, such as the thin film cryotron, are being investigated for use in aerospace data processing systems. Tunnel diodes offer the advantage of extremely high switching speeds (operation at clock rates of hundreds of megacycles does not appear unreasonable) in both the memory and logical areas. Magnetic logic offers greater resistance to radiation than transistor logical elements have, but it appears to be most feasible for low-speed applications. Cryotrons are still "farther-out" than the other devices being evaluated; but even though this equipment must be kept at extremely low temperatures, the small size and fast switching offer attractive benefits to the aerospace computer field.

In the effort to achieve increased reliability, military computer designers have for some time derated circuits and components below their designed capacity. This technique pays off not only in reliability but also in maintenance, since precision checking and balancing of replacement components is not necessary. Welded connections are rapidly replacing conventional soldered methods for making aerospace computer interconnections. Welding improves computer reliability, saves space, and lowers manufacturing costs. Circuit encapsulation has provided greater protection from environmental disturbances and increased overall reliability, except perhaps in space systems where the high vacuum effect on certain plastics cannot be neglected. Molecular devices, now available in limited numbers, promise a large reduction in the overall number of interconnections due to the elimination of intracircuit wiring. Redundant networks and majority logic are being combined to provide redundancy in unattended satellite systems. At least one such redundant data processing system for a satellite is in active development. The nondestructively read multiaperture cores for aerospace memory systems have provided computers with a versatile, reprogrammable, high-speed memory in which random errors cannot be propagated into repetitive errors by virtue of being rewritten during memory access. The Westinghouse MOL-E-COM aerospace computer, now in the early stages of development, will take advantage of each of the above reliability improvements by incorporating each to a large degree in its design. This computer is expected to be approximately 0.3 cubic feet in volume and will weigh about 15 pounds while offering computing speeds of 50 000 single-address add-time operations per second.

An engineering sketch of the prototype MOL-E-COM aerospace general purpose digital computer is shown in Fig. 7. In this sketch the multiaperture core read-write memory, the universal "stroke gate" functional molecular electronic blocks, and the use of multilayer printed circuitry are evident and significant.

Since the general-purpose digital computer presently offers the most versatile and powerful method for automating aerospace systems, the next decade should continue to see increasing emphasis on development of more and better aerospace digital computer equipment and techniques.

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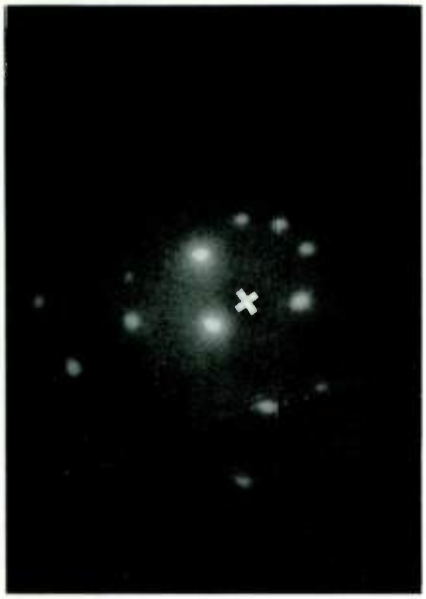
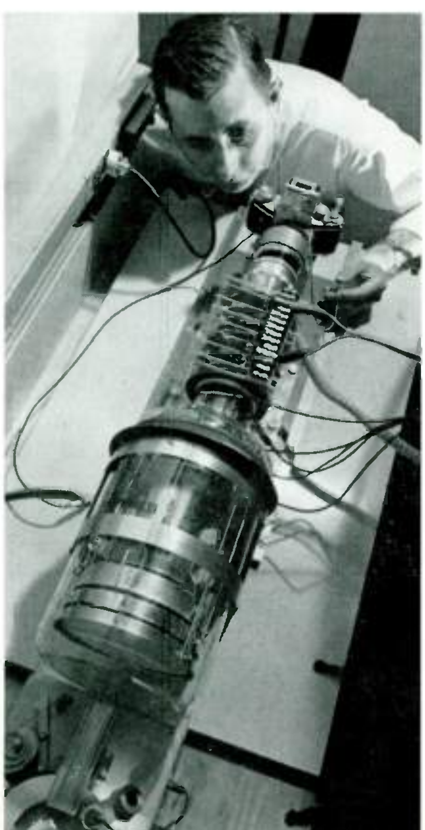
RESEARCH AND DEVELOPMENT



Above Photograph of Laue pattern of lithium-floride taken with new experimental x-ray intensifier tube. (The "X" marks the location of the main beam, which is usually blocked off to prevent fogging the film.)

Below New experimental electronic system for brightening x-ray images, developed at the Westinghouse Research Laboratories.



LOOKING "INSIDE" MATTER

Man's progress in the new "solid-state sciences" depends upon his ability to "see" what he is doing when he studies and controls the atomic structure of materials. Until now, the viewing process—primarily with x-ray diffraction—has been extremely tedious.

The German scientist, Von Laue, first suggested and then developed the x-ray diffraction technique almost 50 years ago. He calculated the atomic spacing of rock salt, and found it to be within the x-ray wave length region of the electromagnetic spectrum (he assumed at this time that x-rays were similar in nature to visible light). This led him to hypothesize that x-rays would be diffracted by the crystal structure (somewhat analogous to the diffraction of light by a diffraction grating). However, the exposure periods required for recording the x-ray diffraction patterns on film ranged from 1 to 20 hours, which is not too different from the time required with modern x-ray equipment employing conventional x-ray tubes. Only recently have experimental techniques been developed that permit direct observation and high-speed photography of x-ray diffraction patterns.

x-ray diffraction

The mechanics of x-ray diffraction can be described in principle by considering a hypothetical atomic crystal structure model, consisting of eight atoms at the corners of a cube. If a lattice of such crystals were viewed "endwise," the two dimensional array shown in Fig. 1 would be seen. Because of the regular and repeatable arrangements of atoms, many parallel "rows" of atoms exist; in three dimensions, each row lies in a plane.

If an x-ray beam is directed at an atomic plane (Fig. 2) most of the energy will continue through the plane. But each atom (similar to a slot in the diffraction grating) becomes an individual radiator of a small amount of diffracted x-ray energy. A diffracted ray is formed where the individual diffracted rays from all the atoms in the plane reinforce each other. This is frequently termed a "reflection" by analogy with the reflection of light.

Since a crystal lattice consists of many parallel planes, reflection in the crystal can only occur if the reflection

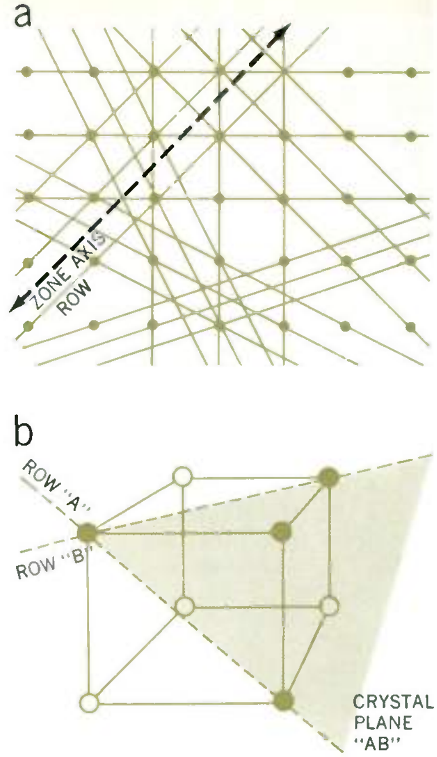


Fig. 1 (a) Two-dimensional view of hypothetical crystal lattice illustrates the various rows of atoms; (b) in three dimensions, these rows lie in planes.

from each plane reinforces that from adjacent parallel planes. The conditions necessary for reflection are stated in the Bragg equation,

$$n\lambda = 2\,d \sin\theta,$$

which is derived in Fig. 3. For any particular lattice plane spacing (d), reflections can only exist for certain combinations of incidence angle (θ) and wavelength (λ).

Laue patterns

X-ray "pictures," called Laue patterns, are obtained by radiating the crystal under observation with a beam of "white" x-rays, i.e., a beam that contains all wave lengths within a certain range. Thus, the conditions necessary for x-ray reflection will always be satisfied for a few wave lengths.

The technique for taking Laue patterns is shown diagrammatically in Fig. 4. A beam of heterogeneous x-rays, limited to about 0.5 millimeter diameter by means of pinholes in two lead diaphragms, is focused on the crystal. It can be shown that the reflections of this beam from all possible planes in the lattice fall in a pattern of multiple ellipses (Fig. 4). To scientists trained in crystallography, these

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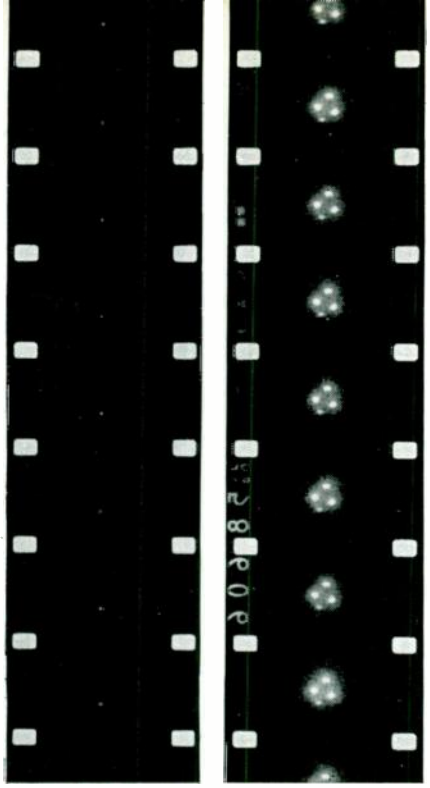

A section of 16 mm movie film of Laue spots (left) taken with an Astracon tube, and (right) taken with the combined Fluorex and Astracon tube.

patterns yield much information, such as the type of lattice structure, kind of material, and plane orientation.

Unfortunately, the x-ray diffraction technique since its inception has suffered from a lack of sensitivity in available x-ray detection devices—and this is the only area where noticeable gains can be made. The use of "white" radiation for taking Laue patterns imposes serious limits on the maximum strength of the x-ray beam. Furthermore, x-ray reflections from the crystal planes are extremely weak since most of the energy remains in the central axis of the beam. As a result, the radiation pattern is so weak that direct viewing with a fluorescent screen is impossible, and long exposures on film are necessary.

improvements in x-ray detection

Crystallographers have long realized that any major breakthrough in the x-ray diffraction technique depended upon improving detection sensitivity. The ultimate sensitivity would be realized if each x-ray photon diffracted by the crystal could be detected. Two scientists at the Westinghouse Research Laboratories, Dr. G. W. Goetze and Dr. Abraham Taylor, have recently announced a new technique that takes a big step in this direction. The experimental system combines into a single device the functions performed by two earlier intensifier tubes developed at the Westinghouse Research Laboratories—Fluorex, an x-ray image amplifier, and the Astracon, a light amplifier so sensitive that it makes visible every photon of light that triggers its input.

The diffraction pattern is beamed directly on the face of the Fluorex-Astracon tube, where it hits a fluorescent screen (Fig. 5). A sensitive photosurface adjacent to the phosphor converts the fluorescent image into a pattern of electrons, which are electronically focused upon a thin film in the rear of the tube. This film consists of two layers, a film of metal and another of an insulating material. The film ejects from its rear surface up to 100 electrons for each electron that hits its front surface. The strengthened pattern is then accelerated and focused onto an output surface, similar to the face of a television picture tube. Here the pattern of electrons becomes a visible light image, which can be viewed directly or photographed.

new uses for x-ray diffraction

This new x-ray amplification system opens up whole new areas of investigation for x-ray diffraction. Now that Laue images can be viewed directly, the crystal structure can be "watched" as it changes with temperature or other outside influence. This immediately suggests a possible future application of the device as a means for control of crystallization of man-made materials during the "setting" period. Any of these observations can be permanently recorded on movie film.

The new system also provides a means for quickly selecting precisely aligned crystals required by modern solid-state devices.

Many other applications are under study. For example, Laue patterns of samples of electrical steel up to 12 mils thick have been viewed directly; this is a common thickness used in transformers and other electrical apparatus.

Further experiments under way for exploiting the new technique include powder diffraction studies (which use reflected x-rays rather than transmitted rays), and studies of continuous phase transformations in metals and semi-conductor materials. ■ ■ ■

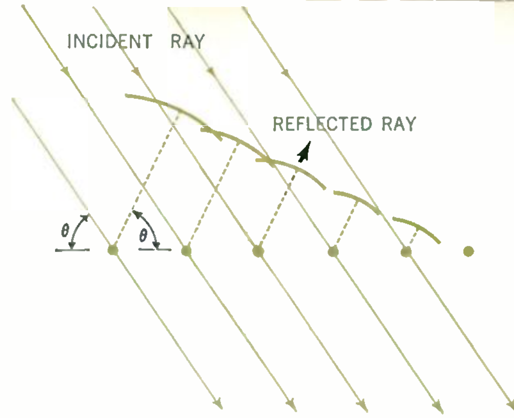

Fig. 2 Reflection from a crystal plane.

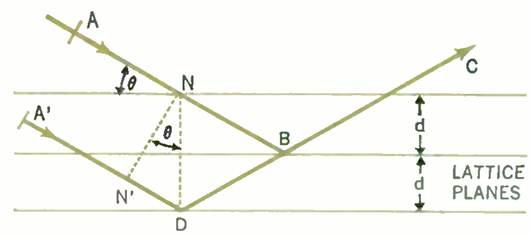

Fig. 3 The conditions necessary for reflection from lattice planes can be derived from this diagram:

The difference between the optical paths ABC and A'DC is N'D [NB=DB because NBD is an isosceles triangle]. Therefore, N'D must equal some integral number of x-ray wavelengths ($n\lambda$). In terms of the lattice spacing, N'D equals $2d \sin\theta$. The condition for reflection is therefore $n\lambda = 2d \sin\theta$, n being a whole number.

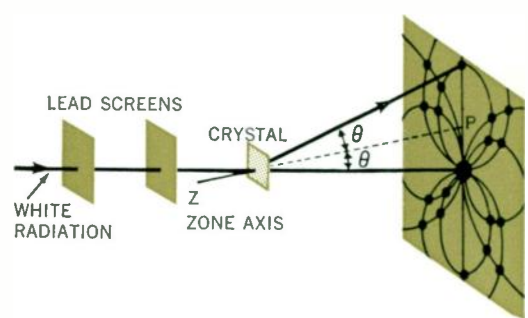

Fig. 4 Production of a Laue photograph.

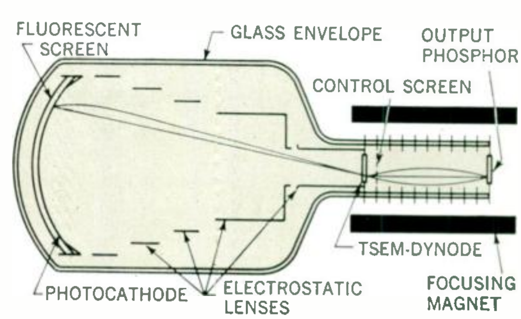

Fig. 5 Cross section of the experimental electronic tube for brightening x-ray images.

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AUTOMATIC CONTROL OF CONTINUOUS DIGESTERS A computer control system can provide optimum process operation.

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Optimum process operation, to produce more salable product at lower cost, is the goal of management in the paper industry. This goal can only be obtained by combined control of all important process variables, a level of control not heretofore available. Reliable process computers now provide the tool for effecting such control.

With few exceptions, only *individual* process variables are being controlled today; e.g., speed, temperature, pressure, flow, and consistency. *Multivariable* control of the major processes has been investigated by Westinghouse, with detailed analysis of papermaking, pulping, bleaching, and black-liquor recovery. Pulping with a continuous digester was found to be one of the most promising areas for multivariable process control, so a systems study was conducted with Gulf States Paper Corporation. The study, described in this article, shows that optimum operation of continuous digesters with computer control is feasible. A Prodac 580 control system will be installed at the Gulf States pulp and paper mill in Demopolis, Alabama, to operate a Kamyr continuous digester capable of producing 350 tons a day.

A number of factors pointed to the continuous digester. First, pulping is the initial major process in making paper, so it strongly influences the processes that follow—screening, bleaching, refining, and papermaking. Better understanding of the first process leads to better control concepts for the entire operation. Moreover, the pulping process is better understood than most other processes, so the digester can be controlled to show immediate gain.

Continuous digestion is a dynamic process with several important variables, and this makes it difficult for an operator to obtain optimum process operation when not operating in a steady state. True steady-state operation seldom exists anyway because of uncontrollable changes in some variables and required changes in production rate and pulp grade. The problem is to run the system with minimum deviation from production and quality requirements.

Multivariable control of the continuous digester would yield high economic gain. The study produced the estimate, based on production facilities of 350 tons a day, that a direct saving of $250 000 a year could be expected. This saving comes from increase of salable product because of closer quality control, product upgrading from better identification of pulp quality, better use of chemicals through lowered residual losses and makeup, an increase of up to one percent in wood fiber yield, and decreased warehousing costs.

Indirect savings would be of a long-term nature and, therefore, have not been included in the estimate. They are important, however, and should be considered. By continually determining unit efficiency, for example, the computer could project a performance trend and thus determine the optimum time for such maintenance operations as periodic removal of scale from heat exchangers.

accumulation and analysis of data

With the continuous digester selected as the most promising area for control development, the study progressed to the detailed phase. Information on plant layout and instrumentation was collected to determine process time

THE CONTINUOUS DIGESTION PROCESS

Digestion is the treatment of wood chips in a pressure vessel under controlled temperature, pressure, time, and liquor composition. Its purpose is to dissolve lignin from the wood, thereby separating the wood's cellulose fibers from each other.

Digestion was a batch process for years, but continuous digesters have gained favor recently. Their advantages include reduced liquor-to-wood ratio, lower steam consumption, uniform steam demand, reduced vessel corrosion, and more uniform pulp quality. Several types of continuous digesters are used; the system study performed by Westinghouse was based on a vertical Kamyr digester like the one shown in the photograph.

The process is diagrammed in the illustration. Chips are metered into a steaming vessel by a star feeder and a low-pressure feeder. The steaming vessel contains steam at 13 to 25 pounds per square inch (psi), and the chips are moved through it by a screw conveyor in about five minutes. The steaming vessel preheats the chips and removes air and gases, which are vented to a turpentine condenser. The chips are discharged through a high-pressure rotary feeder into a pipeline. Liquor drawn from the digester is pumped through this line to move the chips in a slurry to the top of the digester.

A mixture of white liquor and black liquor enters near the top of the digester through a pump that maintains digester pressure at 165 psi. Vaporization within the system is prevented at this pressure. In the soaking zone, liquor penetrates the chips before its temperature is raised to the point where chemical reaction begins. This aids uniformity of digestion.

As chips and liquor move downward to the cooking zone, the liquor is removed through screens and circulated through indirect steam heaters. This brings chips and liquor to cooking temperature, and digestion proceeds until the mass reaches the bottom part of the vessel. Here, cool black liquor is introduced and hot black liquor is extracted through a valve to a flash tank. The resulting reduction in pulp temperature stops chemical reaction and also reduces the possibility of mechanical damage to the fibers when they are blown through a valve into the blow tank.

As the pulp is discharged from the digester, some of the black liquor removed through a strainer is recirculated to the bottom of the digester to control discharge consistency.

Retention time in the digester is approximately 2½ hours but varies with production rate. To change production rate, chip and liquor input rates and pulp discharge rate are changed together to maintain a constant chip level in the digester.

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delays and to evaluate data obtained from the instrumentation. This information was drawn from existing logs and recorders as much as possible.

A statistical analysis was then made to determine if there were correlations between certain process variables and, if so, whether the correlations were linear or nonlinear. When correlations were established, further analysis determined the coefficients of the equations (called transfer functions) relating independent input variables to dependent output variables. The initial correlations produced rough approximations of the transfer functions, and these were then verified and improved by use of actual operating data from the digester.

Output variables include solid content in the extraction liquor, amount of lignin residues in the pulp, pulp temperature, and quantity of pulp produced. All of them affect the quality of the paper made from the pulp, but the most important is the amount of lignin residues (expressed as permanganate number). The input variables that affect the output variables are quality and quantity of chips fed in, quality and quantity of active chemicals in the white liquor, amount of dilution by black liquor, time of retention in soaking and cooking zones, and temperatures in these zones.

The final transfer functions describe the hydraulic, thermodynamic, and chemical characteristics of the process. Many of them are time dependent because of such delays as chip travel time and heat transfer time, making them non-linear differential equations. The purpose of the system analysis was to explore these transfer functions.

development of system model

The next step was to develop a mathematical model of the digester system. A model, in this sense, is a set of transfer functions that mathematically relate process output variables to input variables. By simultaneously solving the transfer functions, the effect of changes of input variables on output variables can be calculated.

DIGESTION PROCESS TERMS

Lignin The interfiber bonding material in wood.

Pulp Fiber produced from wood by grinding or chemical digestion. The product of grinding is called mechanical pulp; that of digestion, chemical pulp.

Continuous digester A process vessel for producing chemical pulp continuously.

White liquor A solution containing active chemicals, used for digesting wood.

Black liquor An inert solution resulting from the chemical reaction between white liquor and lignin.

Sulfidity The amount of sodium sulfide in the liquor that enters the process at the top of the digester. A small amount of sodium sulfide improves pulp bleachability, strength, and yield.

Yield The ratio of dry output pulp to dry input wood, expressed in percent.

Permanganate number (*K number*) A measure of the amount of lignin left in chemical pulp after digestion, determined by laboratory tests on a sample. The more lignin there is in the pulp, the larger the K number.

Ratio of active alkali to wood (*AAW*) The ratio of active chemical in the liquor to dry wood charged into the digester. In the sulfate process, the chemical is sodium hydroxide and sodium sulfide.

Temperature out of heat exchanger (*TOS*) Temperature of the liquor after it has been heated to cooking temperature in external steam heaters. Expressed in degrees F.

Temperature of cooking zone (*TCZ*) Temperature of chips and liquor in the cooking zone. It is a function of TOS and chip feed rate and is expressed in degrees F.

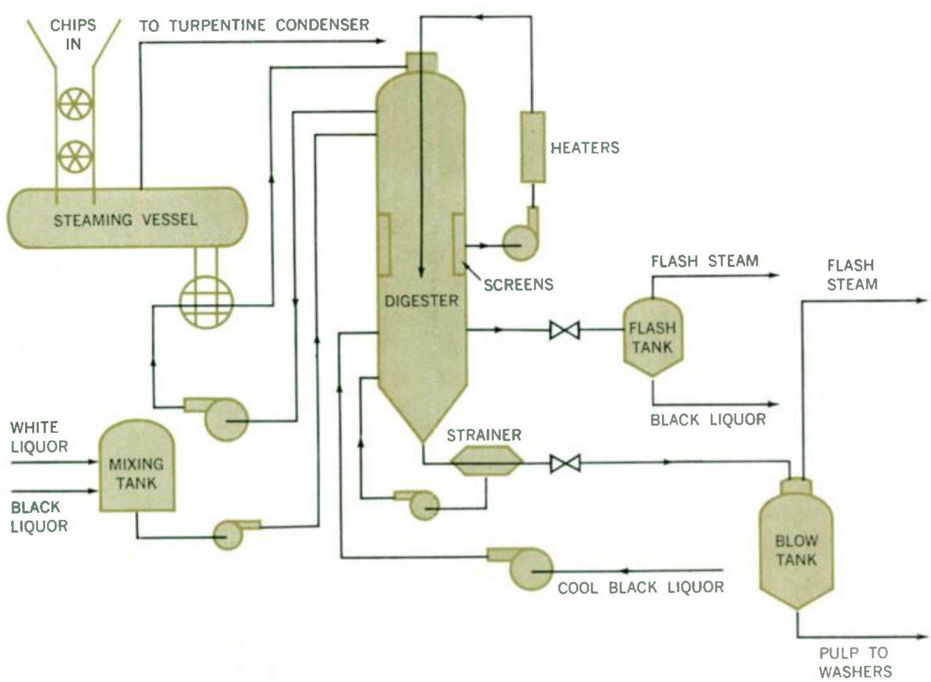
Soaking zone (*SZ*) Upper part of the digester.

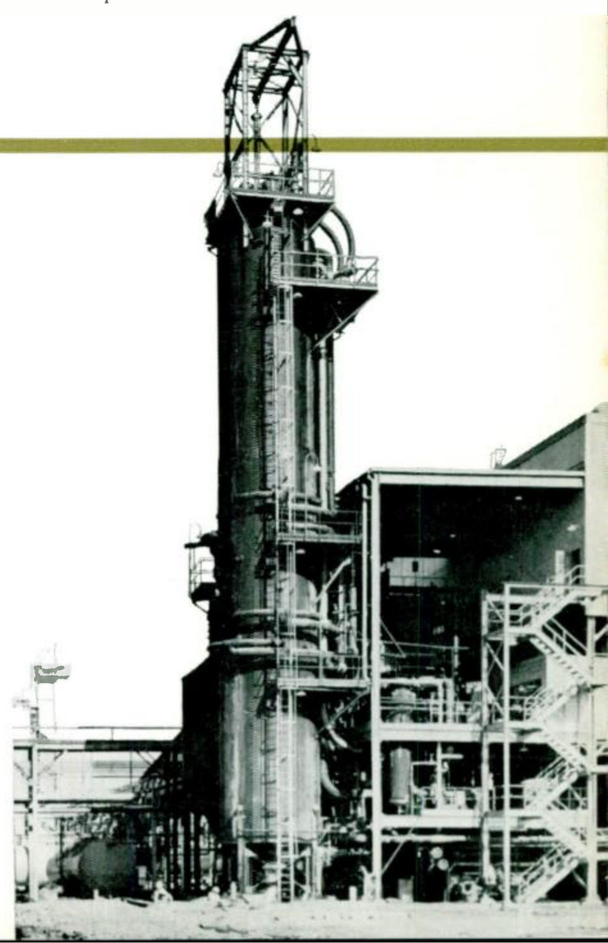
Cooking zone (*CZ*) The middle and lower parts of the digester, in which the chips and liquor are at cooking temperature.

Blow zone The part of the digester below the point where hot liquor is extracted and replaced by cool liquor.

Blow tank A tank into which pulp from the digester is blown.

Retention time in soaking zone (*RSZ*), *cooking zone* (*RCZ*), *blow zone* (*RBZ*), *and blow tank* (*RBT*) The time the liquor and chips (or the pulp) remain in the respective zones. All are functions of chip feed rate and are expressed in minutes.





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To save time and effort, the complexity of the model was restricted as much as possible without losing the important characteristics of the process. Separate models were developed for the chemical, hydraulic, and thermodynamic transfer functions. The model simulating the chemical transfer functions was found to include the variables that have the greatest effects on quality (K number) of the output pulp, so it was used for the studies.

Research findings made in batch digesting were evaluated and translated for the continuous digester chemical model. The most important relationships were the effects on K number of active alkali-to-wood ratio, sulfidity, cooking temperature, and retention time.

These relationships are illustrated in Fig. 1. The ratio of active alkali to wood (*AAW*) is set at the top of the digester by controlling the proportion of chips to active alkali. While liquor and wood pass through the soaking zone, the effect of *AAW* on digestion is negligible. Thus, the effect of *AAW* is delayed for a time equal to the soaking-zone period and becomes effective only in the cooking zone. These zones are shown as transport delays whose magnitudes are proportional to chip rate (production rate). Temperature in the cooking zone (*TCZ*) is set by heating liquor and chips just as they enter the zone, so it is effective throughout the cooking-zone transport delay. The simulated soaking-zone and cooking-zone delays associate the proper values of *AAW* and *TCZ* with each layer of chips progressing down the digester.

K number of the output pulp is calculated as a function of *AAW*, *TCZ*, and retention time in cooking zone (*RCZ*). The calculated K number is then delayed for a time equivalent to retention time of the pulp in the blow zone and blow tank (*RBZ* and *RBT*) and to a fixed delay. (The fixed delay represents time required for the pulp to pass through the washers and for the K-number test.)

Pulp rate is a function of chip rate and K number. (This transfer function is based on an assumption that pulp yield is directly proportional to K number.)

The effect of a change in retention time when there is no compensating control is illustrated in Fig. 2. When chip rate is suddenly changed from 100 percent to 80 percent, retention time in the cooking zone (*RCZ*) increases as a ramp until a new *RCZ* is established. The time required for *RCZ* to reach its final value is equal to the final value. After the change in chip rate, pulp coming out of the cooking zone has been in this zone longer and longer. When chips that were at the top of the zone when the change was made emerge, the new retention time has been reached.

As *RCZ* increases, output K number decreases. To bring K number back to its original value, the ratio of active alkali to wood (*AAW*) or the temperature in the cooking zone (*TCZ*) or both have to be changed to compensate for the change in *RCZ*. However, changes made now in *AAW* and *TCZ* cannot compensate for the new retention time of chips already in the cooking zone, so pulp produced from these chips will fail to meet the K-number specification. The anticipatory control described later considers these system dynamics and controls the process for constant K number.

Because of the complexity and nonlinearity of the many transfer functions in the model, solutions were obtained by programming a combination of digital and analog computers. This simulated the process, and the simulation was then studied and used for experiments to find the best way of controlling the process. Using the actual process to make these studies would have taken longer and interfered with production.

study of model

The computer program was written in such a way that the simulated process could be operated in four distinct modes—open-loop operation, operator control without anticipation of production rate changes, operator control with anticipation of production rate changes, and operation under the Westinghouse anticipatory control that uses new concepts developed in this study. These modes are diagrammed in Fig. 3.

Variable transport lags in the model necessitated use of the digital computer both for simulating the plant (open-loop program) and controlling the plant. The analog computer was used only for input-output operations.

Open-Loop Operation—This consisted of operating the model to check its operation with the actual system. Inputs were set from data obtained in actual digester operation, and the model came reasonably close to simulating steady-state and dynamic characteristics of the real process. The data simulated was taken from 24-hour periods of normal operation, sampling every hour. To decrease the time required to conduct studies, 40 seconds in the computer simulation was approximately one hour in the actual process.

Operator Control Without Anticipation of Production Rate Changes—This simulated a typical operator closed-loop control. The computer corrected temperature out of heat exchanger and ratio of active alkali to wood once an hour if the K-number analysis warranted it.

For small changes in chip rate, K number gradually deviates from the desired value. Off-quality pulp may be produced for a short time, but the hourly corrections restore equilibrium at the new production rate. A large change in chip rate causes considerable variation in K number and up to four hours of rejected production.

Operator Control With Anticipation of Production Rate Changes—Whenever possible, an operator makes an anticipatory step change in temperature out of heat exchanger about 30 minutes before a change in production is made. This can prevent rejected pulp for reasonably small changes in chip rate, but K number may change considerably and have to be corrected by operator action. Inferior pulp will be produced whenever changes in system variables such as production rate are of such a magnitude that anticipatory changes in temperature out of heat exchanger are not sufficient to provide the required effect on K number.

Test runs showed that the rate of sampling and the magnitude of the correction steps in temperature out of heat exchanger and ratio of active alkali to wood can greatly affect operation. If the sampling period is too small or the corrective steps are too large, instability results.

Operation Under Anticipatory Control—If an intended change in chip rate is known in advance, proper time-varying adjustments can be made in ratio of active alkali to wood and temperature out of heat exchanger to almost eliminate transients in K number. As Fig. 2 shows, the transient in K number that occurs with a change in chip rate is due to the ramp change in retention time in cooking

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zone (*RCZ*). The effect of this ramp change could be counteracted if a ramp change in temperature out of heat exchanger were initiated, a time interval in advance equal to the cooking-zone retention time. Alternatively, the ratio of active alkali to wood could be varied in a ramp starting at a time equal to the sum of the soaking-zone and cooking-zone retention times before the actual change in chip rate. Either variation would have to be of a duration equal to the old cooking-zone retention time; when the change in chip rate was made at the proper time, the effects of the transient and the new steady-state value of retention time in cooking zone would be counteracted.

The following paragraphs tell how the anticipatory control applies these principles to keep K number constant.

The magnitude of the required ramp change is determined by calculating the new desired steady-state values of temperature out of heat exchanger and ratio of active alkali to wood for the new production rate. The control change is carried out entirely on temperature out of heat exchanger if this can be achieved within allowable limits. If the intended change in chip rate is too large for this, temperature out of heat exchanger is varied in a ramp up to its limit and a ramp change in ratio of active alkali to wood also is made at the right time.

In the steady state, this mode is the same as operator control. The anticipatory control determines once a minute whether the program is in the steady or transient state. If it is in the steady state, the computer determines whether a change in scheduled chip rate has been requested. If so, it transfers control to a program that calculates slope and duration of the required ramp changes. During succeeding cycles, the computer executes the transient program (the part of the program that makes the ramp changes).

Behavior of the simulated digester when a change in chip rate is scheduled is shown in Fig. 4. A command to change chip rate causes ramp changes in ratio of active alkali to wood (*AAW*) and temperature out of heat exchanger (*TOS*), but K number remains constant. Chip rate is changed after these preliminary controlling actions. The digester then goes back under operator control, and small corrections in cooking temperature and alkalinity may be made.

These evaluations provided the basis for the estimate of economic gain cited in the introduction to this article.

The anticipatory control actually used in the study was more complex than is indicated in this brief description. For example, the relationship between temperature out of heat exchanger and cooking-zone temperature is a function of chip rate, not a direct proportional relationship. This had to be considered in the model study.

The control and process simulation revealed that the continuous digester, like most continuous processes, requires an anticipatory type control. The more standard technique of feedback control cannot be used. Feedback control is based on the ability to detect the value of an output variable and then to control one or more input variables to maintain the desired output. The long and complicated time functions between digester input and output variables make it impossible to stabilize a feedback control system.

Anticipatory (feed-forward) control predicts effects of input variables on output variables by solving transfer

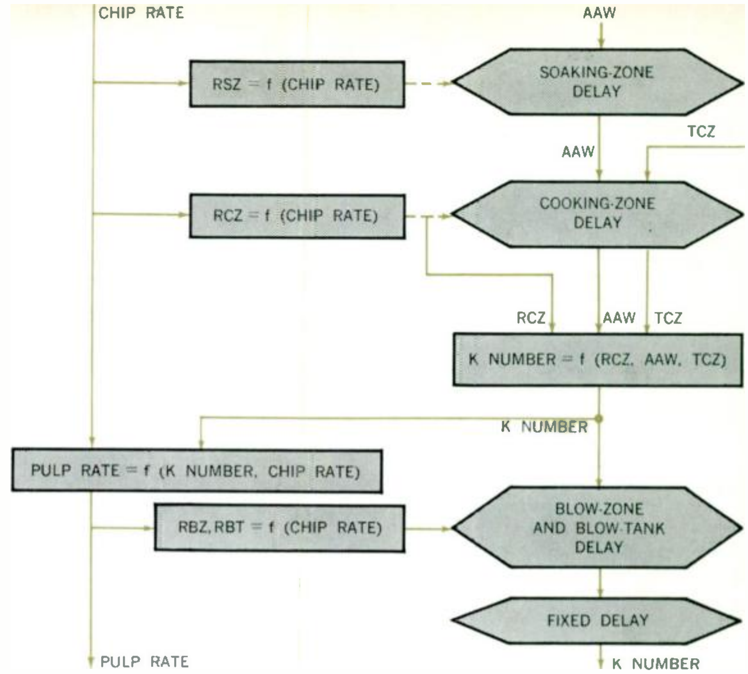

Fig. 1 Simplified mathematical model of the continuous digestion process. The model was used to study the relationships between input and output variables and to evaluate operator and computer control.

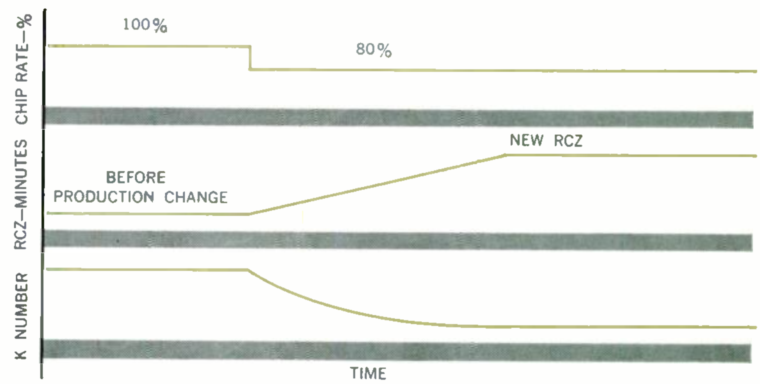

Fig. 2 When no compensating control is applied to the continuous digestion process, a step change in chip feed rate causes a ramp change in the retention time in the cooking zone (*RCZ*). This in turn causes the K number of the output pulp to diminish.

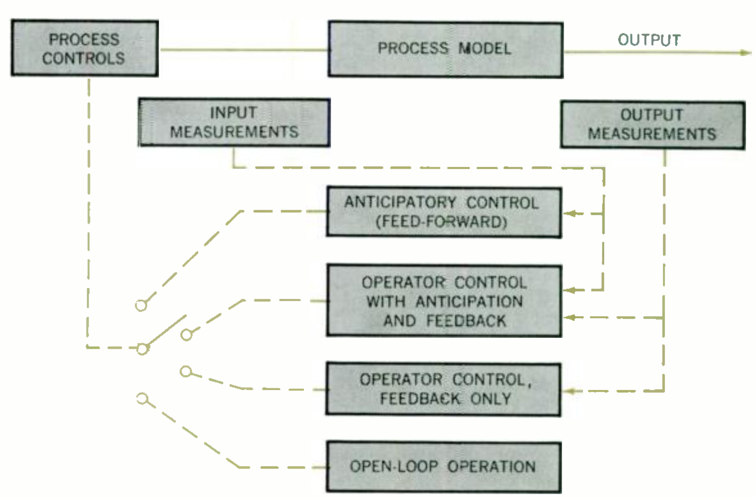

Fig. 3 The digestion process model was studied with a computer programmed to operate the model in four modes. Anticipatory control predicts the effect of input variables on output variables and regulates inputs as required to keep pulp quality constant.

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functions. Thus, an output change can be predicted as soon as a change is made in an input variable instead of having to wait until the output variable can be measured.

the process controller

Anticipatory control for a continuous digester requires the use of a process computer. The computer would have a stored program with instructions needed to perform the anticipatory control and other operations. The advantage in using a stored-program computer is that the program can be changed easily to improve the anticipatory control.

K-number tests would be made approximately every hour and the results fed into the computer. If there were any difference between actual K number and desired K number, the computer would calculate and perform the necessary operation changes. This feedback would compensate for any long-term system drifts and would be used to update and refine the system equations. Other variables that cannot be measured directly but whose magnitudes are determined by laboratory tests would be fed into the computer manually.

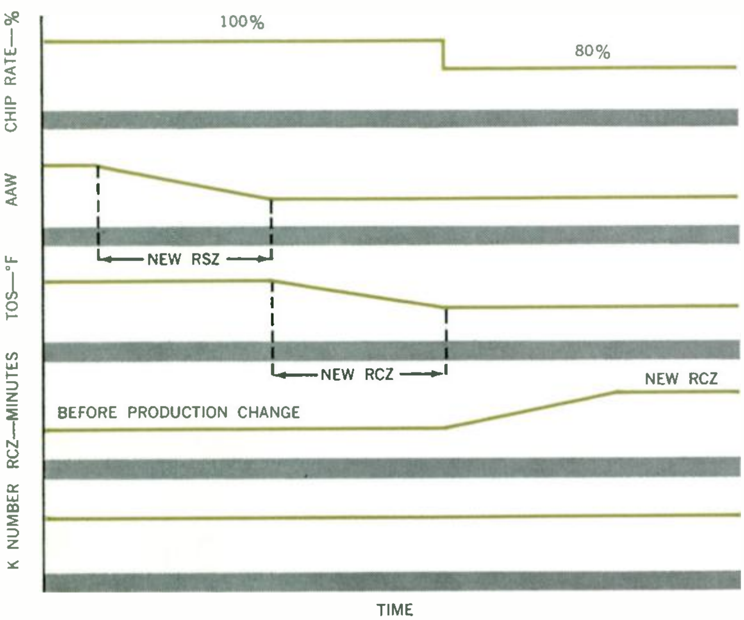

Fig. 4 With the simulated process under anticipatory control, the effects of the new retention time in the cooking zone (*RCZ*) caused by a step change in chip feed rate are counteracted by anticipatory changes in ratio of active alkali to wood (*AAW*) and temperature out of heat exchanger (*TOS*). These changes keep pulp quality (K number) constant.

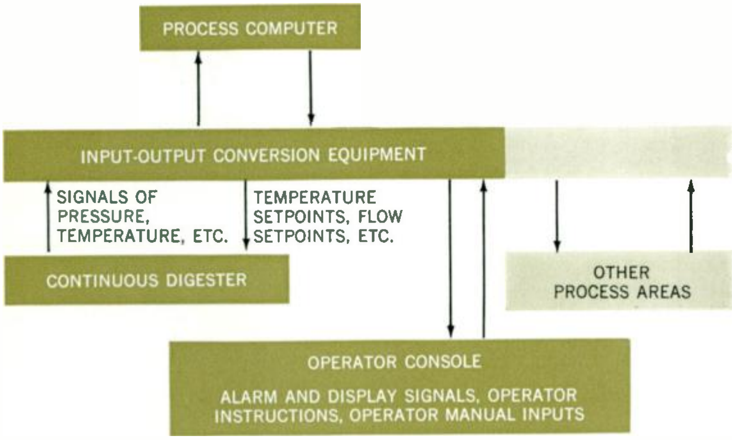

Fig. 5 Simplified diagram of a process controller for the continuous digester. The light block indicates how other process areas could be served by the same computer.

A simplified diagram of the controller is shown in Fig. 5. Inputs from the process (such as temperatures, speeds, flow rates, and pressures) can be obtained primarily from existing instrumentation. When pneumatic controllers and instruments are used, a pneumatic-to-electric converter would have to be installed.

Electrical signals proportional to process variables are converted by the input-output equipment to digital information for computation. The results of the computations are converted into signals that are printed out on an electric typewriter and/or used for automatically adjusting the setpoints of the various controllers.

The computer also could check process variables for off-normal conditions and notify the operator if such conditions occur. It could perform calculations to check the operation of the components that make up the continuous digester and provide alarms when operation of any component is not correct. Many material flows could be integrated and a running log typed out to show total amounts of material used.

total capabilities of the process computer

A process computer has more capacity than is required for only one process area. This extra capacity can be used to accumulate and process data in other areas for eventual control of these areas.

Capacity of a process computer depends on three major factors: computing speed, size of memory, and size of input-output equipment. Computing speed is basically fixed and cannot be changed. However, some mill processes are of such a duration that it may only be necessary to sample inputs at intervals of five minutes or longer. If only 30 seconds are required to perform the computations on these inputs, 4 minutes and 30 seconds of computing time would be available for control of additional areas.

The sizes of the memory and the input-output equipment are dictated by the requirements of the processes to be controlled and studied. Both can be expanded to bring additional processes under control, with computing speed determining the limit of expansion.

The main obstacle to application of anticipatory control is not lack of computers capable of performing the required control functions but rather inadequacy of process data. With present instrumentation, data with the proper time relationship cannot always be obtained. However, a process computer can operate with existing instrumentation to collect the data, time-correlate it, and reduce it to the form necessary for constructing a mathematical model.

Once the model has been determined, the same computer can be programmed to bring the process under anticipatory control. The extra computer capacity would then be used for collecting and analyzing data from other process areas such as power plant, bleaching, black-liquor recovery, refining, paper machine, and waste disposal. When sufficient information had been collected and analyzed, the same computer would be used to control these additional process areas.

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LIGHTNING ARRESTER CURRENTS How five different currents affect arrester design, rating, and effective operation.

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The valve type lightning arrester, in performing its normal function of protecting electrical insulation, is required to pass current from line to ground. Often, current in a lightning arrester is assumed to be *lightning surge current*. Actually, this is only one of five different currents that should be considered in evaluating a lightning arrester application. The additional currents to be considered are *grading current*, *switching surge current*, *power follow current*, and *safe fault current*. These different currents vary in magnitude and cause, and determine completely the operating duty on a modern valve arrester. They are a function of lightning arrester characteristics, system parameters, or a combination of both.

valve arrester operation

A modern valve-type lightning arrester consists of two main operating elements: a series gap assembly and nonlinear resistance blocks. These elements are shown in the cutaway view of a station type arrester in Fig. 1. The gap insulates the resistance blocks from the system voltage, and provides controllable sparkover levels. If a lightning surge exceeds the sparkover voltage of the gap, the gap flashes over and the surge is discharged through the nonlinear conducting valve element. After the surge has passed, the nonlinear resistance element limits follow current to a relatively small percentage of the total system fault current available so that it can be interrupted by the arrester gap at the first current zero. Generally, these arresters are of module construction, i.e., for each 3 kv of arrester rating there is one resistance block and 2.5 gaps.

arrester grading current

Grading current, sometimes called *leakage current*, is inherently present in a modern intermediate or station-type valve arrester. This small continuous current flows when the arrester is energized, and is determined by the resistors that shunt each individual series gap. A cutaway of a two-element series gap (Fig. 2) illustrates the shunting resistor location in this particular design.

The function of the series gap design is to provide uniform and consistent sparkover values for various types of system overvoltages. The gap is broken into many small units to aid in its function of interrupting current once it sparks over. However, the gap must operate as if it were one large gap during initial sparkover.

The voltage across a group of series gaps is developed from the grading current and the impedance shunting the gap. Without the grading resistor, a group of series gaps would develop voltages from internal and stray capacitances, as shown in Fig. 3a. The shunting resistor stabilizes the value of grading current (Fig. 3b), thereby minimizing the stray capacitance effect.

Modern arresters use two types of grading resistors, a substantially linear unit and a nonlinear type. The volt-ampere characteristics of these resistors are shown in Fig. 4. The curves show that at arrester rating, typical values of grading current are 0.5 and 2 milliamperes depending on the type of resistor used.

As can be seen from Fig. 4, grading current is constant for all ratings with the same percent voltage applied. This value can be used as an indication of arrester condition while in service. If voltage on the arrester is less than rating, as is usual, the curves can be used to determine the normal grading current. A periodic comparative reading should be used as a field test since some variation often exists between arrester units.

Contamination—In the past few years contamination has often been advanced as the cause of lightning arrester failure in lieu of unknown cause. Practically, most applications are free from the problem. However, manufacturers must investigate the causes and effects of contamination

Fig. 1 Cutaway view shows construction of a typical station-type valve arrester.

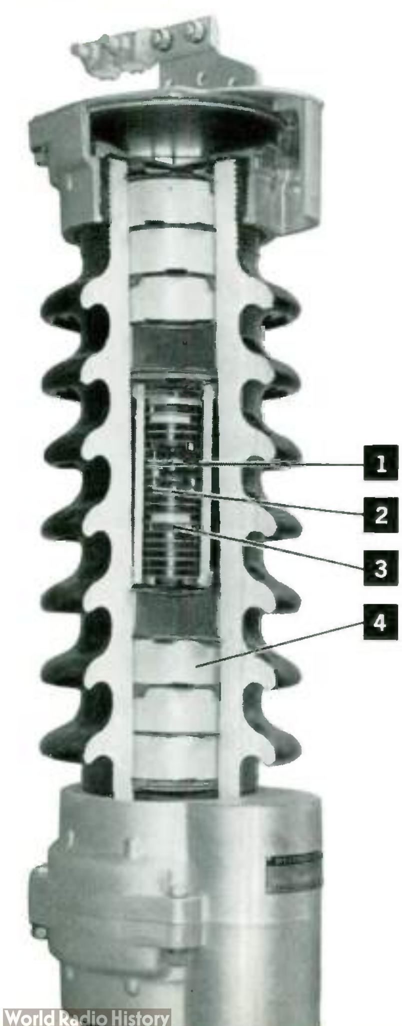
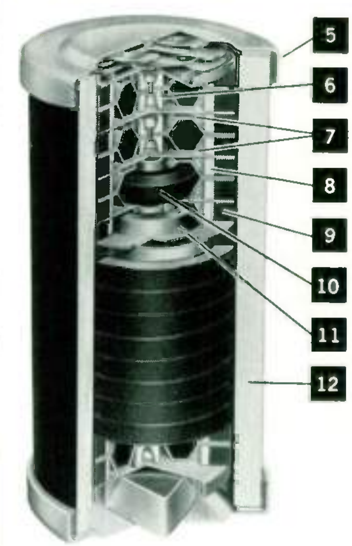


Fig. 2 This cut-away series gap assembly shows the location of the grading resistor.



1 Grading Resistor
2 Gap Terminal
3 Sealed Gap Element
4 Valve Block
5 Solder-Sealed End Cover
6 Pre-ionizing Button
7 Mobilarc Gap
8 Ceramic Guard Ring
9 Resistance Spacer
10 Permanent Ring Magnet
11 Formed Brass Electrode
12 Porcelain Casing

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Fig. 3a The voltage across a group of series gaps without shunting impedance is developed from internal and stray capacitances. Inherent capacitances between each gap electrode (C_1, C_2, C_3) are equal; distributed stray capacitances (C_{S1}, C_{S2}, C_{S3}) vary depending on the distance from gap elements to ground. If an instantaneous current flow is assumed, current through the top gap will be $i_{S2} + i_{S3} + i_{S4} + I_{G4}$. This current will leak off and lower gaps will have proportionately less current. Therefore, current through the top gap shunting the capacitive reactance will be greater than that through the bottom gap reactance. The voltage developed across the top gap accumulates as the voltage rises, and the top gap tends to spark over first. This raises voltage on the remaining gaps, and initiates a cascading effect, which results in erratic sparkover values.

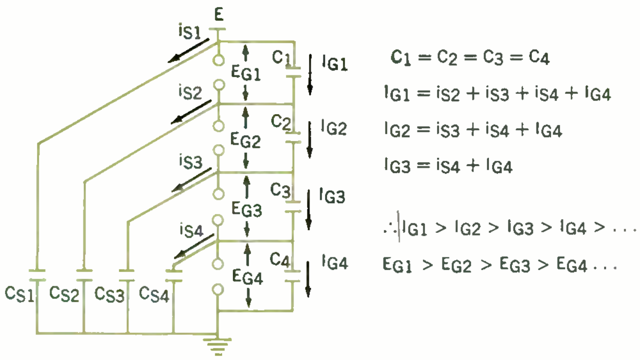
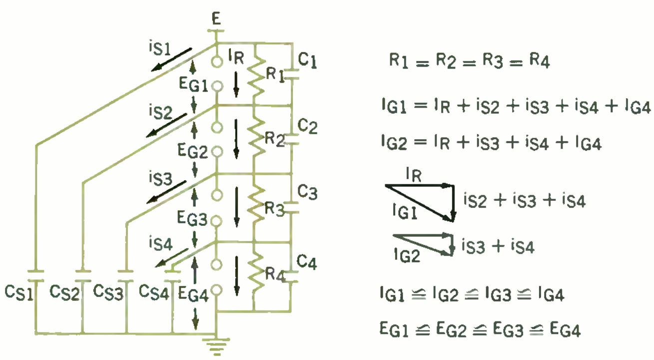


Fig. 3b The addition of shunting resistance stabilizes grading current and minimizes the stray capacitance effect. Current through the gap-shunting impedance becomes the vector sum of the resistance component and the stray capacitance component. Hence, the stray capacitance current in the top gap can be twice that in the bottom gap without appreciably affecting total current. I_{g1} approximately equals I_{g4}, and equal voltages are developed across each gap.



and provide solutions and recommendations because the arrester must be universally applicable.

Two types of contamination exist—a continuous conducting coating covering the arrester surface, or a noncontinuous conducting coating on the arrester surface.

The first type of contamination is the more likely to occur, but is also easier to avoid. The general causes are heavy deluges of water due to the arrester pole being located inside a fire protection water spray system, or from washing an energized arrester pole with a high velocity, high volume hose. The volume of water necessary to cause this condition is far greater than can occur from natural causes. Also, rain water is usually clean with high resistivity as compared to water in hosing or fire spray systems, which may have a resistivity as low as 500 to 1000 ohm/cm^3.

The mechanics of the problem are illustrated in Fig. 5, where two units of a three-unit arrester pole are shown effectively shorted. Grading current in the top unshorted unit is increased by a factor of three with a linear grading resistor, or much more when a nonlinear type is used. Since gap voltage is developed by grading current, sparkover can occur in the top unit, possibly at normal voltage. Even if the gap can clear, thermal failure may result because of repetitive operation.

The obvious solution to this shorting type of contamination is to keep the arrester out of fire spray pattern and not hose energized arresters. The least that should be done is to keep the water deluge to less than one-third of the arrester stack.

An arrester pole with only one or two units is not subject to trouble of this type. With one unit, external flashover of the whole pole occurs and no current flows inside the arrester; with two units, one unit can withstand normal system voltage without internal sparkover.

The second type of contamination results from excessive chemical effluent in the atmosphere. When wetted unevenly, it effectively energizes the porcelain surface part way down the unit. This develops corona on the internal parts of the arrester and a current flow from the outside to the inside of the arrester occurs. Since this current does not flow equally through all the gap-shunting impedances, an unbalance in grading current results, thus affecting sparkover characteristics. However, a serious situation from this type of contamination requires second and third contingencies: The right type of contaminant must be present along with the right amount of moisture, and a repetitive overvoltage (such as switching surges) must exceed the reduced sparkover of the unit. This unusual combination is most likely to be found close to seashore or industrial locations such as a cement plant or a paper mill.

The mechanics of this second type of contamination phenomenon are much the same for all arrester designs regardless of the number of units in the pole; the noncontinuous coating varies the parameters of distributed capacitance, formed by the porcelain surface as one plate or electrode of the capacitor and the gap elements as the other. It can best be described by breaking distributed capacitance into small increments as shown in Fig. 6. Voltage across the top gap is the product of normal grading current and grading resistance. As each increment of capacitance adds a component of current, total grading current increases until the voltage developed across the bottom gap exceeds the sparkover value. This triggers a cascading effect, causing the arrester to operate.

Distributed capacitance is, of course, present at all times. However, current flow is so small that there is no detrimental effect. In fact, a small amount of contamination might be considered beneficial since it actually increases the sparkover of the arrester. The stray capacitance effect that accumulates voltage on the top gap in a series string is balanced by the contamination effect, which develops voltage across the bottom gap. This effect is illustrated by comparing the sparkover of a clean-dry unit with its clean-wet value—the latter is usually higher, indicating better voltage balance between gaps.

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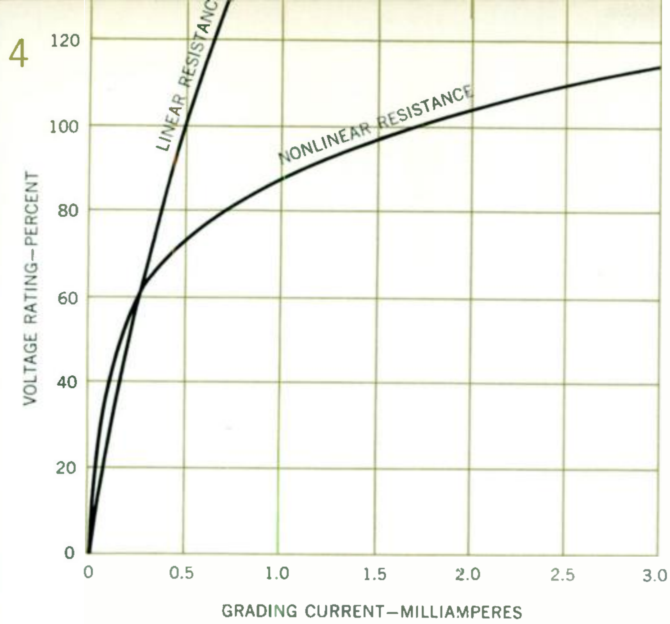
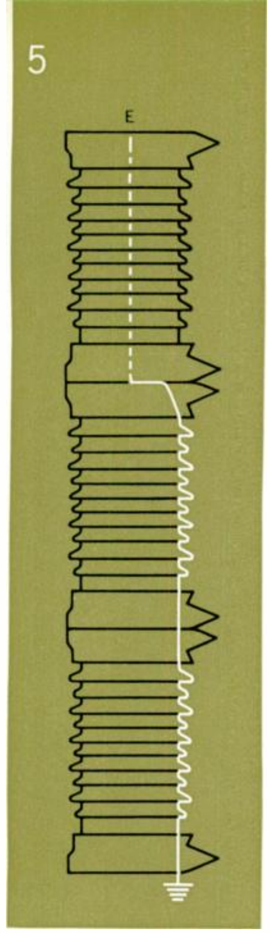




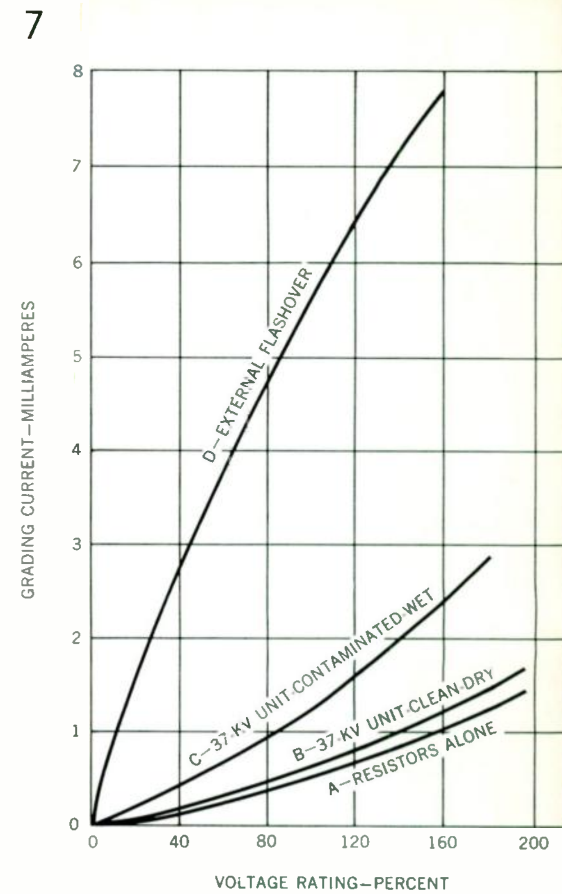
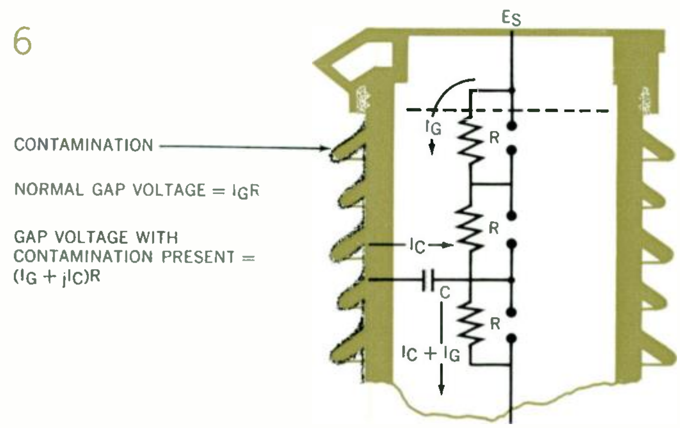


Fig. 4 Grading resistance volt-ampere characteristic curve.

Fig. 5 Normal voltage across each unit is $E/3$; with two bottom units shorted, voltage across top unit becomes E.

Fig. 6 Increased distributed capacitance due to contamination progressively increases grading current toward the bottom of the arrester.

Fig. 7 The contamination effects on grading current are shown in these voltage-current curves.



The variation in grading current under different conditions is illustrated in Fig. 7. The characteristics of the grading resistors alone are shown by curve *A*. The grading current variation on a single 37-kv arrester unit is shown by curve *B*. The change from curve *A* is due to the stray capacitance effect. When this same unit is contaminated, the total grading current increases and the characteristic is shown by curve *C*. Finally, if enough external contaminant is added, an external flashover curve can be developed, as shown by curve *D*.

The effects of noncontinuous contamination on in-line arrester designs does not appear to be as severe as observed on folded arrester units. (A folded arrester design is one whose elements are electrically in series but mechanically in parallel.) A heavily contaminated in-line arrester will drop only about 10 percent in sparkover value, which is not considered serious; folded arrester designs may, under the same relative conditions, drop about 25 percent, which can cause problems, primarily due to a greatly increased number of operations on switching surges. The difference in the contamination effect is due largely to the better voltage gradation that can be obtained with in-line units.

The need for the folded design is obvious—at the present state of the art it is the only method for keeping high voltage arrester height within practical limits. Fortunately, recent laboratory studies have uncovered a solution to the noncontinuous contamination problem, if it exists. The hermetically sealed porcelain is filled with SF_6 gas at atmospheric pressure. The high insulation strength of SF_6 suppresses internal corona, thus maintaining the effective physical size and separation of the capacitor electrodes formed by the arrester parts. (The presence of corona creates an effectively larger electrode because it is a conducting envelope surrounding the electrodes.) The suppression of corona keeps the internal conditions the same as without contamination, so that large extraneous capacitive current is prevented.

arrester lightning surge current

Lightning surge current is the high-magnitude, short-duration current that the arrester must pass to ground in dissipating lightning surge energy. It is primarily a function of arrester location and system constants.

If a direct lightning stroke terminates near an arrester, the current flow through the arrester can be very high. However, many years of collecting lightning stroke data have indicated that this current rarely exceeds 100 000 amperes. Sufficient information has been recorded to develop probability figures on the magnitude and wave

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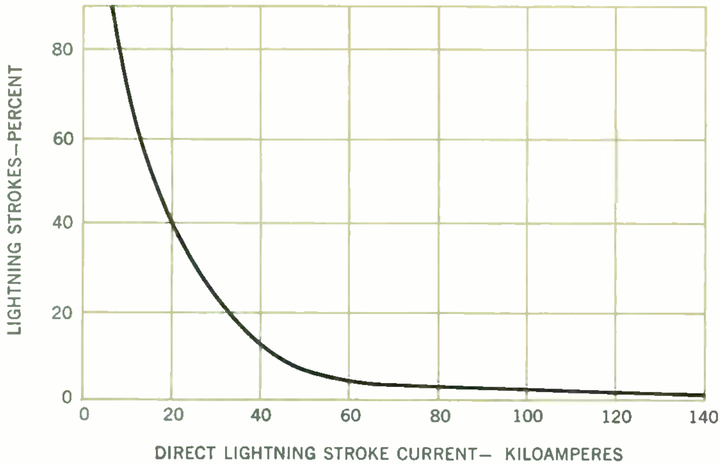


Fig. 8 This curve shows the distribution of direct lightning stroke current to electric power lines.

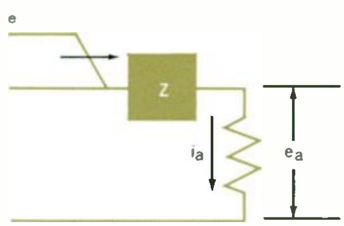
Table I LIGHTNING SURGE CURRENT

$2e = Zi_a - e_a$

$i_a = \dfrac{2e - e_a}{Z}$

where i_a is lightning arrester current, e is 1.2 × line insulation level, e_a is lightning arrester voltage, and Z is line surge impedance.

Usually, $e_a < 0.1\,(2e)$, so that e_a can be neglected, and $i_a = \dfrac{2e}{Z}$.



MAXIMUM LIGHTNING SURGE CURRENTS

System Voltage (kv, L-L)	Surge Impedance (Z)[1]	Arrester Current (i_a)
2.4	500	1 000
4.16	500	1 200
14.4	500	1 400
25.0	450	2 100
34.5	450	3 200
69.0	450	5 500
115	425	6 300
138	425	7 400
230	325	10 000
345	325	13 000
500	275	17 500

[1]These surge impedances are the lowest values recorded in service — thus, arrester currents shown are conservative.

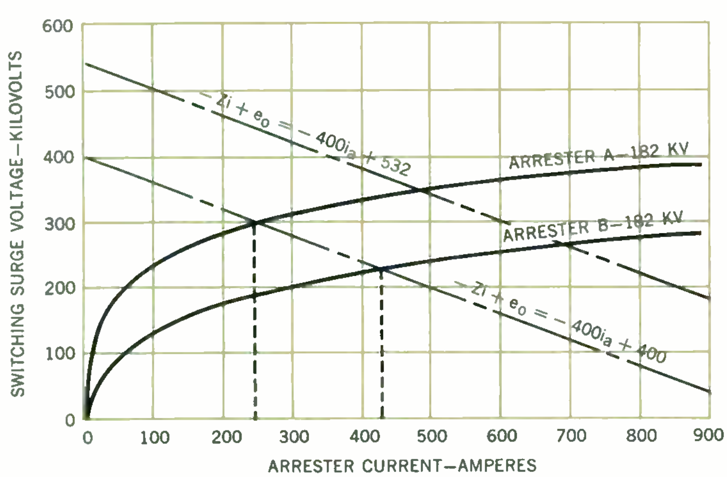


Fig. 9 Comparison of lightning arrester current under identical switching surge conditions for two different types of arresters.

shape of stroke current. The curve shown in Fig. 8 is the result of this field research with respect to magnitude of surge current for strokes to transmission towers. These probability figures can be used for all voltage classes with reasonable accuracy, and have been verified recently in field studies at distribution voltage levels.

Where shielding is adequate to practically prevent direct strokes from occurring, the surge must arrive at the arrester terminals as a traveling wave with an initial magnitude lower than the line insulation level. The current through the arrester is obtained from the following formula, derived from the equivalent circuit shown with Table I:

$$i_a = \frac{2e - e_a}{Z}$$

where i_a is lightning arrester current, e is 1.2 × line insulation level, e_a is lightning arrester voltage, and Z is line surge impedance.

The driving voltage is assumed as $2e$ (a maximum reflected wave of two times the incoming wave) to obtain the worst condition of a line and location. The volt-ampere characteristics of the arrester valve element must be used to obtain the arrester voltage, e_a. However, since it is a function of current, an approximation is often made. Actually, e_a is always less than 10 percent of the resultant surge voltage, and can be neglected without affecting the results appreciably.

The magnitude of lightning surge current is important in all insulation coordination studies. It is the arrester discharge voltage at specific currents that stresses insulation and can ultimately cause breakdown and failure. The arrester manufacturer provides a table of discharge voltages at several standard currents. The maximum current expected for a given application and the discharge voltage for that current or the next highest standard current as given by the manufacturer would be compared to the BIL of the equipment to be protected. A margin of 10 to 15 percent should exist for adequate protection.

Table II SYSTEM STORED ENERGY CAPACITY[1, 2, 5]

System Voltage Kv L-L	Energy (ω_m-watt-second/mile)
115	530
138	770
230	2 150
345	4 800
460	10 200[3]
500	12 200[3]
750	30 000[4]

NOTES

[1]Calculated from $\omega_m = \frac{1}{2}\,C\,(e_0)^2$ where C=0.015 mfd (except as noted); $e_0 = 1.05 \times 2.7 \times E_{L-N}$ crest

[2]To calculate specific line requirement per kv of arrester rating use as follows:

$$W_L = \frac{\omega_m \times D}{E_R}$$

where ω_m is value from table; D is line length in miles; E_R is arrester rating in kv.

[3]C=0.018 mfd (bundled conductor effect)

[4]C=0.02 mfd (bundled conductor effect)

[5]Surge impedances calculated from the capacitance used in this table will not be identical with those used in Table I. Values used in each case give conservative results.

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switching surge current

Switching surge current results when a transient voltage produced by a system disturbance causes a lightning arrester to spark over. Switching surges are usually caused by disconnect switches or circuit breakers energizing or de-energizing a portion of the system. They are different from lightning surges in that the surge voltage is lower and persists for a longer time; the source of energy is the system itself. Therefore, a switching surge always appears on the arrester terminals as a traveling wave. The energy the arrester must dissipate following sparkover is stored in the system capacitance—either line or cable capacitance, or in bank capacitors connected to the system.

Theoretically, the current in the lightning arrester when discharging a switching surge can be calculated in the same manner as the lightning surge current since the equivalent circuit is the same. However, since the switching surge voltage is considerably less than lightning stroke voltage, the lightning arrester voltage (e_a) must be retained in the equation. Since e_a is dependent on arrester current (i_a), the solution is somewhat complicated. The graphical method illustrated in Fig. 9 is the most direct method of determining arrester current, assuming line surge impedance and switching surge voltage are known or can be estimated. The arrester volt-ampere characteristic is plotted from test data and an equation for arrester voltage can be obtained from the equivalent circuit shown with Table I. The intersection of these two curves provides a solution for arrester current for the assumed conditions.

Actually, the current is of low magnitude, generally below 1000 amperes, so that the discharge voltage from this current never approaches the insulation level of the protected equipment.

The manufacturer, through the standards, often describes the *thermal durability* of lightning arresters in terms of switching surge current magnitude and duration. Actually, this is not a complete description, since current, discharge voltage, and duration must be known to compare two or more arrester types under equal conditions.

Thermal durability is a measure of the heat or energy absorption capability of the arrester valve block. During long duration surges the block must withstand all the energy flowing through it without failing. Energy (watt-seconds or joules) can be calculated for the arrester block from the following relationship: $W = e_a i_a t$, where e_a is lightning arrester voltage, i_a is lightning arrester current, and t is time in seconds.

If, in discharging under certain line conditions, all arresters produced the same voltage and current, energy absorption would be equal, since t is a function of line length only. However, two arrester types under equal conditions—i.e., surge voltage and surge impedance—can have as much as a 70-percent difference in current (Fig. 9). Therefore, durability cannot be expressed in terms of current alone.

A true measure of arrester thermal durability can be obtained only by determining the watt-second or joules/kv rating of the arrester. This rating can be compared to the energy stored in the line under given maximum switching surge conditions to ascertain whether the arrester is satisfactory for that particular application. This procedure is similar to that employed in checking circuit breaker interrupting rating against system short circuit capability.

The maximum energy stored in a transmission line, which an arrester must safely discharge if sparked over, can be calculated from the following equation:

$$W_L = \frac{1}{2} C (e_0)^2 D$$

where C is line-to-ground capacitance per mile, e_0 is switching surge voltage, and D is length of line in miles.

At present, the maximum switching surge voltage that has been recorded on a system is 2.7 times crest line-to-neutral voltage. Using this voltage and an average value of 0.015 microfarads per mile for C, the stored energy per mile for typical system voltages can be calculated. Typical values per mile are shown in Table II. With this table, the watt-seconds or energy requirement per kv for a particular application can be obtained from the formula:

$$W_L = \frac{\omega_m \times D}{E_R} \qquad \text{(watt-seconds/kv)}$$

where ω_m is watt-seconds/mile from Table II, D is length of line (miles), and E_R is arrester rating (kv).

This calculated value must be less than the arrester thermal capability to assure proper application margin.

power follow current

Power follow current is a relatively low power current that flows through the arrester following the dissipation of surge energy through the arrester. The arrester is a conducting path to ground at this instant, and consequently must interrupt the current that normal system voltage forces through it.

Two characteristics of power follow current make it possible for the relatively simple gap structure to clear on any system regardless of size: First, the nonlinear characteristic of the arrester valve block limits current severely at normal voltage; secondly, this limiting impedance is resistive in nature, so that follow current is essentially in phase with voltage. As a result, there is no recovery voltage other than the normal frequency component.

The magnitude of power follow current is dependent on the valve block characteristics and, other things being equal, will vary considerably between arrester designs—generally from 200 to 400 amperes. Other conditions that affect the magnitude of power follow current, even on a single-arrester design, are the rate of rise, crest current, and duration of the prior surge.

For example, two typical volt-ampere curves obtained on the same valve block are shown in Fig. 10. The characteristic does not change much on the rising part of the curve, but as the voltage drops back to normal, the curve does not retrace itself but returns to zero on a different path forming the typical volt-ampere loop. Since power follow current is determined by the impedance obtained on the falling side of the loop, current could be as low as 200 amperes following one type of surge and as high as 600 after another. Actually, current usually will not exceed 200 to 300 amperes because, as indicated in Table I, lightning surge current through station arresters rarely exceeds 20 000 amperes even at extra-high voltages.

Many times after a valve arrester conducts a surge to ground there is no power follow at all. This is due to the

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nonlinear characteristic of the block, and is a function of when the surge occurs relative to the 60-cycle voltage wave. As illustrated in Fig. 11, the current wave shape obtained by impressing a sine wave voltage on a typical arrester valve block is not sinusoidal, but has an elongated period of current zero, sometimes as much as 60 electrical degrees. If the surge occurs during this current zero period, no power follow current will flow.

Since gap interrupting duty is determined by power follow current, this quantity is of primary interest to the manufacturer. Occasionally, the magnitude and duration of power follow current will be of concern to the user if sensitive, high-speed bus differential relaying schemes have operated and tripped an important bus for no obvious reason. Although the lightning arrester is more often suspect than guilty, cases have been known where arresters with unusually high power follow currents have tripped relays.

safe fault current

Safe fault current (often called the *pressure relief rating*) is the rms symmetrical amperes a failed arrester will carry for a short time without resulting in a violent explosion of arrester porcelain. Fault current magnitude is entirely dependent on system fault capacity, and its duration is a function of system relaying.

When a valve arrester fails, because it is a sealed device, tremendous internal pressures are developed due to the gas generated by the arc sublimating the valve block material. This pressure must be relieved by venting quickly, within $\frac{1}{2}$ cycle, or the porcelain will shatter.

The only impedance to the fault created by a failed arrester is the arc drop and generally this is a negligible amount. Therefore, the fault current magnitude is virtually the same as obtained from a bolted line-to-ground fault at the same location.

A typical pressure-venting operation is illustrated in Fig. 12. This was a laboratory test involving an arrester with prefailed blocks and shorted gaps. The system short circuit capacity was 45 000 amperes, and a measured fault current through the arrester of 44 500 rms symmetrical amperes resulted. Nearly symmetrical fault current is characteristic of most arrester failures because failure usually occurs at or near voltage crest.

Most arresters will also have a *minimum venting fault current* value since the possibility also exists of a failed arrester not venting if system fault current is very low at a given location.

The user must consider the pressure relief rating similar to the interrupting rating of a circuit breaker: At the arrester location the maximum system fault current in rms symmetrical amperes should not exceed the safe fault current rating of the unit; and minimum fault current available should be greater than the minimum venting current of the unit to assure venting on any arrester failure.

Although the protective function performed by a lightning arrester can best be defined in terms of voltage, knowledge of typical values of lightning arrester currents, the parameters that control them, and their effect on lightning arrester design and application gives the user a unique insight on the capabilities that a high voltage lightning arrester must possess if it is to efficiently perform its protective function.

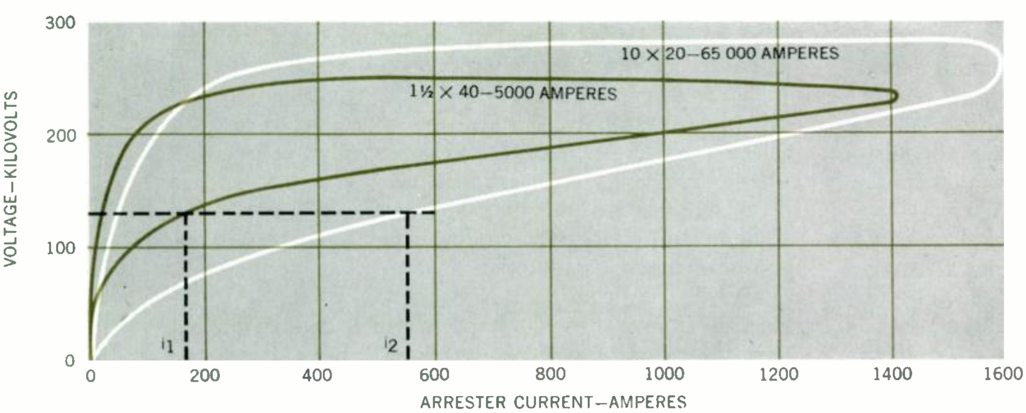

Fig. 11 Lightning arrester current has an elongated period of current zero due to the nonlinear characteristic of the valve block.

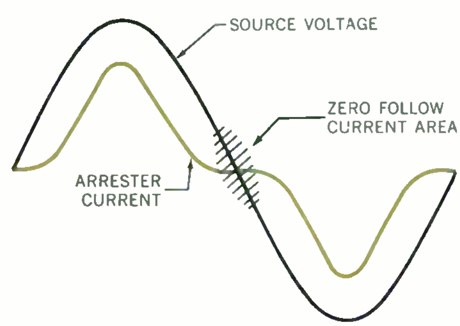

Fig. 10 (Above) Power follow arrester current will be affected by the preceding lightning surge.

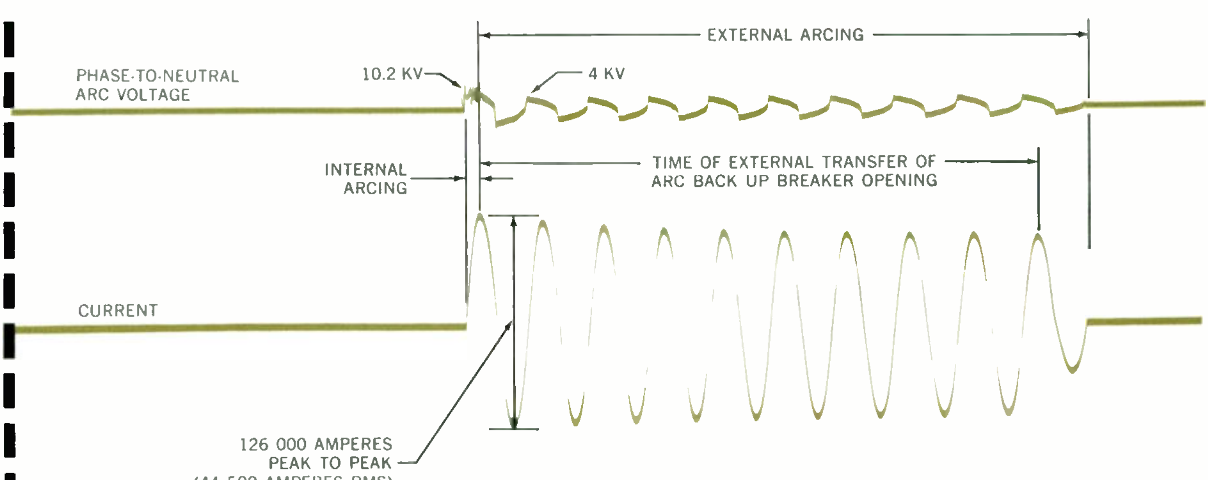

Fig. 12 (Right) Pressure relief test oscillogram demonstrates the nearly symmetrical fault current characteristic of most lightning arrester failures.

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TECHNOLOGY IN PROGRESS

Silicon Rectifier for Graphitizing Furnace

Graphite components used in industry are often made by charging carbon shapes into a furnace and passing electric current through them until heat has converted the amorphous carbon to graphite. Single-phase alternating current has been used in all large graphitizing furnaces for years. This large single-phase load unbalances the load on a plant's three-phase power system. Where a plant generates its own electric power, the single-phase currents in generators cause much more rotor heating than is caused by an equivalent amount of three-phase current. The result is an effective reduction in the capability of the plant's generators.

To eliminate these problems, a dc furnace served by the first semiconductor rectifier system designed for graphitizing has been installed at the Dow Chemical Company plant in Midland, Michigan. The rectifier system distributes the furnace load to all three phases of the power supply, and it also permits use of a bus system that is simpler and easier to maintain than an ac system. It employs low-voltage silicon cells and is rated at 76 volts, 75 000 amperes. ■ ■ ■

Molecular Electronics Applied In Military Radio Receiver

A radio receiver built with molecular-electronic functional blocks has been demonstrated to show the feasibility of combining the blocks in complex military electronic systems. It is a fixed-tuned unit patterned after the U. S. Air Force AN/ARC-63 emergency voice-communication receiver. It weighs less than half a pound and occupies about nine cubic inches (see photos). A comparable receiver built by conventional methods weighs more than five pounds and occupies 148 cubic inches.

The nine functional blocks used in the experimental receiver are silicon wafers slightly smaller than a dime and about one-fourth as thick. They are a 28-mc mixer-oscillator, two 2.93-mc tuned intermediate-frequency amplifiers, an untuned intermediate-frequency amplifier, an audio detector, an audio amplifier, an audio power amplifier, a differential automatic gain control dc amplifier, and a two-stage cascaded automatic gain control dc amplifier.

The conventional AN/ARC-63 receiver has 219 parts; the molecular-electronic version has 82. Twenty-nine parts, including the functional blocks, in the molecular-electronic version do the work of 133 of the conventional version's parts. The molecular-electronic portion of the new receiver contributes about 80 percent of the gain, or amplification, needed for operation. The receiver operates anywhere in the range of 238 to 248 megacycles.

Besides reducing size and weight, the use of functional blocks should increase a system's reliability by reducing the number of components and soldered connections. However, actual environmental and life-test data have not yet been determined.

The receiver is the result of work by Westinghouse engineers under a contract with the Electronic Technology Laboratory, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. ■ ■ ■

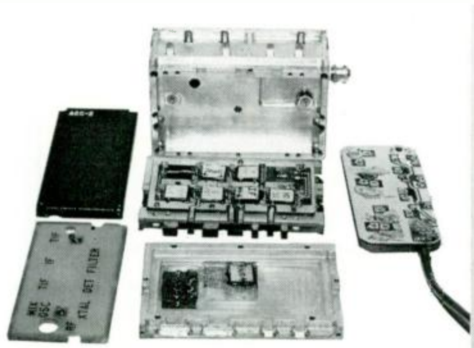
Static Frequency Converter for Aircraft Systems

Constant-frequency electric power is provided on most of today's aircraft by a generator driven at constant speed throughout the engine's speed range by a variable-ratio hydraulic transmission. In a new approach, the cycloconverter method long used for interconnecting 25- and 60-cycle systems in industry has been adapted to 400-cycle aircraft systems. Unlike the hydraulic transmission, the cycloconverter has no wear, leakage, or lubrication problems.

The principle of operation is essentially the same as in industrial cycloconverters, but high-power Trinistor controlled rectifiers have been substituted for ignitrons. The aircraft cycloconverter has one positive and one negative set of controlled rectifiers for each output phase. The inputs are connected to the variable-frequency supply, and each controlled rectifier is triggered when the input voltage and polarity are correct to synthesize the desired output wave. Turnoff occurs automatically as the current across each controlled rectifier tends to reverse. Both voltage and frequency are controlled by turnon timing, but voltage is corrected to the desired value by regulating the generator field. Frequency is controlled by an oscillator in the converter package.

The development model has a 40-kva 400-cycle output over a two-to-one generator speed range. Because of the transient response required over the operating range, the generator is larger than would be required with the constant-speed system at the same minimum speed. However, the weight increase is less than the weight of a variable-ratio transmission, so total size and weight of the package mounted on the engine are reduced.

Another advantage is that the cycloconverter could be located anywhere in an aircraft where there is suitable ventilation. The complete system in the present state of develop-



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ment is heavier than an equivalent conventional system, but this penalty may be more than offset by reduced maintenance requirements. ■ ■ ■

Controller Designed for 2300-Volt Motors

Motor users have long applied modified 5000-volt controllers for 2300-volt motors, resulting in installation of unneeded and unused capacity. Now, a controller has been developed specifically for 2300-volt motors.

The Ampgard 2500 medium-voltage motor controller is rated at 2500 volts, 180 amperes, three phase, 50–60 cycles ac. It can control squirrel-cage, synchronous, and wound-rotor motors of up to 700 horsepower for across-the-line or reduced-voltage starting. An estimated 80 percent of the 2300-volt motors used in American industry are rated at 700 horsepower or less, so the controller has many applications in industry and also in commercial and institutional fields.

High- and low-voltage compartments in the new unit are isolated from each other, and all assemblies are of the drawout type. Connections are accessible from the front, so routine inspections, parts replacement, and most maintenance can be performed without removing assemblies. Mechanical interlocks prevent opening the door when the starter is energized. The entire unit, including the control transformer, can withstand 45 000 volts impulse. The contactor with fuses has a short-circuit interrupting rating of 150 000 kva.

The contactor magnet is dc operated to eliminate the hum and chatter often experienced with ac-operated magnets. Provisions for metering and control modifications are built in. A test switch and circuit permit operational testing of the contactor with an external 110-volt line.

Component-to-component circuitry minimizes the number of current-carrying connections and eliminates internal cable and bus. It also helps make the Ampgard 2500 the most compact controller available—about one-fifth the size of previous models. It is 22 inches wide, 30 inches deep, and 33 inches high, and it can be floor, wall, or ceiling mounted. ■ ■ ■

Supervisory Control Goes Binary

The binary number system is rapidly replacing man's decimal system in the thinking and information-handling processes of digital control equipment. Since supervisory systems are generally used with digital control equipment, creating "binary harmony" between the supervisory equipment and its coworkers is advantageous. This has been accomplished in the new Redac supervisory system developed for the pipeline and electric utility industries.

Redac (*re*mote *d*ata *a*ccumulation and *c*ontrol) will gradually supersede Visicode as the Westinghouse supervisory control system. The fundamental improvements of Redac over the Visicode system result from adoption of a binary-coded decimal system for transmitting information. (The Visicode system employs a decimal count.) The principal improvements are increased security against noise, faster operation (particularly during master checks), and increased functional capacity.

The added security is obtained by employing self-checking binary-coded decimal signals in a method similar to the parity check system used in digital computers. Briefly, information is transmitted in five-bit groups, and the code is designed so that each group always contains two 1's and three 0's. If channel noise causes any deviation from this predetermined pattern, the complete group is rejected as a non-valid signal. This feature reduces the time required for master checking operations by eliminating the need for checkback during the master check.

The Redac system transmits signals that consist only of pulses, at an impulse rate up to 15 pulses per second. Since audio tones or variable frequencies are not used, Redac may be operated over any of the common telegraphic-type channels, such as a pair of wire lines, power-line or telephone-line carrier, or microwave radio.

The present trend in supervisory systems is to use digital rather than analog telemetering and to combine this with automatic programming and printing equipment. The Redac system can fit directly into digital data-logging processes. Each reading is positively identified as it is transmitted, so the receiving station does not identify readings simply by the order in which they are received. Also, the digits of a reading are not fed into the typewriter or tape punch as they are received; instead, they are temporarily stored in a register until the reading has been checked. If the reading does not meet all the checks, it is rejected. In this case, the print-out control is usually programmed to print X's and space the typewriter to the next reading, operating an alarm signal if desired.

The equipment is modular so that a system can be expanded and functions not provided in the initial installation can be added easily. It requires a 48-

The contactor assembly and all other unit assemblies of the Ampgard 2500 motor controller can be drawn out for inspection and service.

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PRODUCTS FOR INDUSTRY

DUCTILE PERMANENT MAGNET MATERIAL can be rolled to less than a thousandth of an inch. Unlike conventional magnetic materials, the new alloy, called Vicalloy, can be easily machined or worked. Alloy can be fabricated into tape, wire, bar, or sheet, and can be punched, drilled, tapped, bent, drawn, coiled, and machined without tearing or cracking. Alloy is suitable for permanent memory devices for digital computers, and for other electromechanical devices such as recorders, speedometers, and hysteresis motors.
Westinghouse Materials Manufacturing Department, P. O. Box 128, Blairsville, Pa.

MAGNETIC CLUTCH for motors protects both motor and driven machine in case of stalls, overloads, or jamming, but that's only the beginning. For high inertia loads, new clutch, called Tormag drive, permits use of smaller frame size motors; such loads can be accelerated without overheating motor. Magnetic air gap cushions load when drive is inched, stopped, or started. Tormag drive can be supplied on motors from 1 to 30 horsepower; drive can be direct-connected to load, or through belts, chains, or gearing.
Westinghouse Electric Corporation, P. O. Box 2099, Pittsburgh 30, Pa.

LONG LIFE OR MAXIMUM OUTPUT? New dual line of 40-watt fluorescent lamps offers this choice: One line has 12 000-hour-life—an increase of 60 percent over the previous 7500-hour rating. Maximum-light-output line provides 7 percent more light than standard line —3100 vs 2900 lumens—and is rated at 9000 hours.
Westinghouse Lamp Division, Bloomfield, New Jersey

500-KVA POLE-TYPE TRANSFORMER has 28 percent lower no-load losses, 19 percent lower total electrical losses, 10 percent less impedance, and 12 percent lower first cost than the comparable substation-type unit. It's also lighter (weighs 3400 pounds), has lower height by 33 percent. These 34.5-kv distribution transformers are made in a range of ratings from 25 through 500 kva.
Westinghouse Electric Corporation, P. O. Box 2099, Pittsburgh 30, Pa.

or 125-volt dc power supply at each station. The power supply need not be regulated and may be a storage battery or a rectifier.

Redac Applications—Redac provides remote automatic control and data logging for a gas compressor station of the Texas Eastern Transmission Corporation. The station, located in Longview, Texas, consists of three 2500-horsepower engine-driven reciprocating compressors. An automatic control selects the engines that are to operate, starts and stops engines, positions cylinder valves, and controls engine speeds to maintain pressure or flow at setpoint values. This gives the dispatcher control over the station without burdening him with relatively minor decisions.

The setpoints are selected by a dispatcher in Shreveport, Louisiana, and the station operates unattended. The system also transmits data in digital form to the Shreveport control center, where it is displayed and logged.

The first electric utility installation of Redac is in the Utah Power and Light Company system. It will be used initially to control three substations near Salt Lake City, which are tied together with microwave channels. Supervisory control will be used on 230-, 138-, and 46-kv circuit breakers. Digital telemetering permits continuous voltage monitoring and display at the control station. Watts and vars are telemetered on command. Telemetering system error will be less than one percent. ■ ■ ■

Versatile Plate Mill

A new plate mill in the Alan Wood Steel Company plant at Conshohocken, Pennsylvania, supplies the present plate-rolling needs of the plant and also provides for future expansion. The plate mill is in line with a blooming mill and is so constructed that a continuous hot-strip finishing mill could be added in line with the plate mill. The plate mill would then perform alternate duty as a roughing mill, enabling the plant to roll steel from slabs to coils without reheating.

The installation consists of a two-high 36- by 66-inch scalebreaker driven by a 1200-horsepower 150-rpm synchronous motor, a 36-inch and 54- by 110-inch reversing plate mill with an 8000-horsepower twin-motor drive, and a 36-inch and 54- by 110-inch

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nonreversing mill driven by a 5000-horsepower 240-rpm synchronous motor. Electrical equipment for drives, controls, and auxiliary equipment of the mills and slab reheat furnace were supplied by Westinghouse.

A high-performance 400-cycle magnetic-amplifier regulating system provides peak performance in the main and auxiliary drives. Static solid-state bistable magnetic amplifiers were used for voltage and current sensors, and provision was made for future addition of programmed or computer control. ■ ■ ■

Semiconductor Materials Now Grown in Sheets

The single-crystal raw materials for semiconductor devices usually are grown from molten material as short thick ingots. These ingots must be sawed into thin slices and the slices ground and polished to obtain the smooth surfaces necessary for device fabrication. A new experimental technique eliminates much of this processing by growing semiconductor crystals in long sheets that need only be cut into convenient lengths.

The sheets have smooth parallel surfaces and a bulk perfection better than that of ingot material. One is shown approximately actual size in the photograph at left.

Scientists at the Westinghouse Semiconductor Department and the Research Laboratories have grown sheets of germanium, silicon, and indium antimonide. They have studied sheet growth and properties and have proposed a growth mechanism.

Briefly, sheet growth somewhat resembles a combination of the conventional Czochralski growth and controlled dendritic growth. (Dendrites are crystals in the form of long narrow ribbons, grown by lifting a small seed crystal from a supercooled molten pool of semiconductor material.) Sheet material is grown between two parallel dendrites. Surface tension pulls molten material up between the dendrites as they rise, and this material freezes to form a sheet between the dendrites. The parallel dendrites support the sheet, and their spacing determines its width. Thickness is determined by the temperature of the molten material and the speed of pulling.

The investigators have made experimental transistors, diodes, solar cells, and controlled rectifiers from silicon sheet and have found that it serves at least as well as silicon slices prepared by conventional methods. They have grown the silicon sheet in a variety of dimensions—up to ½ inch wide and from 0.0005 to 0.035 inch thick.

The silicon sheet program was supported in part by the U. S. Air Force Logistics Command, Aeronautical Systems Division, Wright-Patterson Air Force Base, Dayton, Ohio. ■ ■ ■

Functional Electronic Blocks For Experimental Uses

A number of molecular-electronic functional blocks with broad systems applications have been developed by research efforts. Facilities to produce some of them commercially have now been set up at the Westinghouse Semiconductor Division, Youngwood, Pennsylvania, so that industry can study their uses.

Functional blocks integrate, in a solid block of material, functions ordinarily performed by an assembly of electronic components. Therefore, they occupy much less space than equivalent circuitry. Another advantage is that they reduce the number of connections between components, with a consequent reduction in pickup of random electrical signals and increase in circuit reliability.

The devices are parts of several molecular-electronic systems investigated by Westinghouse while developing a radio receiver containing functional blocks for the U. S. Air Force. Components being made available initially are:

1. A kit with six functional blocks assembled in a plug-in test bed. The kit is called FEB-PAK and includes the basic parts of a fixed-frequency radio receiver—a high-frequency oscillator mixer, a low-level Darlington amplifier, three high-frequency low-level tuned amplifiers, a double detector amplifier, and a fixed-frequency quartz crystal. The blocks can be removed for use in other circuits.

2. A three-stage Darlington amplifier with current gain up to a million and input impedance up to five megohms. Power gain from input to output is 50 decibels, power dissipation is 0.5 watts, voltage rating is 45 volts, and frequency response ranges up to 15 kilocycles. The block measures 0.375 inch square by 0.040 inch thick. It performs the function of three cascaded transistors in a common emitter circuit.

3. A push-pull power amplifier with an audio-frequency range up to 10 kilocycles and power output up to 30 watts. Operating voltage range is 50 to 200 volts and current gain is 500. It performs the function of a pair of two-stage Darlington amplifiers with a common collector output. The block is sealed in a metal case, 0.75 inch in diameter by 0.19 inch thick, with radial leads.

4. Single and double stroke-gate logic elements capable of accepting five input signals and controlling five output signals. Propagation delay is 0.25 microseconds and power dissipation is less than 20 milliwatts at 7.5 volts. The blocks perform the function of an AND gate followed by an inverter. Any desired logic function can be performed by combining several of them. Each block replaces 14 diodes, 6 resistors, 2 transistors, and 26 soldered connections. They are sealed in packages measuring 0.375 by 0.250 by 0.040 inch.

5. Flat packages for encapsulating functional blocks and other microcircuit devices. They are made in several standard sizes and lead configurations, with either metal or ceramic bases and covers. Encapsulation temperatures to 750 degrees F can be used. ■ ■ ■

More Lumens per Watt

A new type of mercury-vapor lamp in development has a light output 50 percent greater than that of mercury lamps now in use. This is an efficiency improvement achieved only twice before in lamp history—when mercury and fluorescent lamps were introduced.

The lamp produces 78 lumens per watt compared with 54 for ordinary mercury-vapor lamps and 17 for incandescent lamps. The breakthrough stems from the discovery that a rare metal, thallium, can be added to mercury to produce a more efficient transducer for converting electrical energy into light. Scientists are improving color rendition, which now favors the green side of the spectrum.

The prototype lamps now being field tested are rated at 400 watts. They are interchangeable with present 400-watt lamps on existing ballasts providing 300 volts for starting.

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ABOUT THE AUTHORS . . .

Throughout the course of his career, GEORGE W. JERNSTEDT has been associated with groups whose main objective has been to conceive or develop new concepts and techniques. His present assignment as manager of the Manufacturing Planning Department is no exception, as a reading of his article will indicate.

Jernstedt is a graduate of Newark College of Engineering, where he earned his BS in chemical engineering in 1937. Even before graduation, in 1936, he went to work in the engineering department of the Meter Division. Later he continued his studies at Polytechnic Institute of Brooklyn. In 1940, he earned his master's degree at Michigan State College, under a Westinghouse Lamme Fellowship.

In 1942 Jernstedt became a member of the liaison engineering group at East Pittsburgh, whose responsibility was to coordinate engineering effort throughout the Corporation. In 1946, he became manager of Electroplating Projects, and earned many patents in this field. In 1951, he became engineering manager of the special products department, whose prime function was to develop new ideas into products. In 1954 he joined the manufacturing organization as director of the Headquarters Manufacturing Laboratory, where new manufacturing techniques and equipment are developed. In 1957, Jernstedt assumed his present position, which includes responsibility for the Laboratory and other planning functions such as plant layout, facilities, and similar tasks. His work in this area earned him the Westinghouse Order of Merit in 1961.

W. H. LEONARD is a Senior Engineer in the computing systems section of the Air Arm Division. He has participated in computer system analysis for such varied applications as defense for advanced bomber aircraft, the USAF Bomarc seeker, an advanced shipborne radar system, and an orbiting astronomical observatory.

Leonard graduated with a BS from State Teacher's College, Frostburg, Maryland in 1952. After a tour of duty with the U. S. Army Field Artillery and Corps of Engineers, which included Officer's Candidate School, he took a teaching position in mathematics and science for secondary schools, Prince George's County, Maryland. He came with Westinghouse in 1956 as an Associate Mathematician.

R. F. BOOZER and E. C. FOX, JR., combine varied experience in industrial design with interest in advanced control systems.

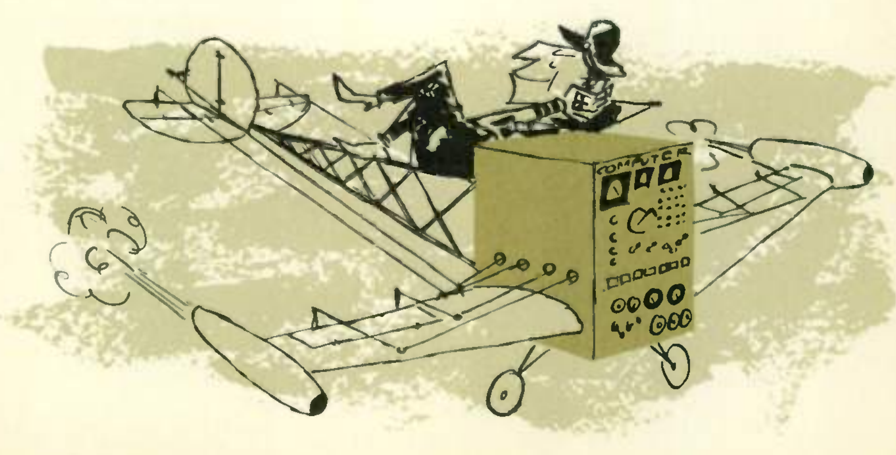
Boozer earned his BSEE degree in 1953 at Auburn University and then joined the Westinghouse Electronics Division. He served as a design engineer and liaison engineer in the development program for the Bomarc missile control system. In 1957 he was assigned to the Cincinnati district office as a consulting and application engineer and in 1961 moved to the Industrial Engineering Department, where he serves in the advanced development group, general mill section. Boozer has contributed to the development of a number of industrial control systems, including the digester control described in this issue. He is an alumnus of the Graduate Student Course and is now taking graduate work in electrical engineering at the University of Pittsburgh.

Fox graduated from Duke University in 1951 with a BSEE and received his MSEE from the University of Pittsburgh in 1959. He joined Westinghouse on the Graduate Student Course in 1951 and was assigned to the general mill section, Industrial Engineering Department. He has worked on application of electrical equipment in the textile, rubber, paper, and glass industries and is now engineer in charge of advanced development. Fox received a most Meritorious Disclosure Award in 1961 for his part in a joint disclosure concerning acceleration control of digital speed regulators.

R. W. FLUGUM makes his second appearance here in less than a year, joined this time by P. W. BOGNER, to discuss lightning arresters.

Flugum, an Advisory Engineer in the Distribution Apparatus Department, came with Westinghouse from the University of Wisconsin in 1948. He completed the company's consulting and application engineering training course in 1949, and went to work as an Electric Utility C & A Engineer in Chicago and Milwaukee. Flugum joined the Distribution Apparatus Department in 1958.

Bogner graduated from the University of Notre Dame with a BSEE in 1949, and came immediately on the Graduate Student Course. He joined the lightning arrester design section of the Distribution Apparatus Department in September 1949. He is presently manager of the lightning arrester and fuse cutout design engineering section.



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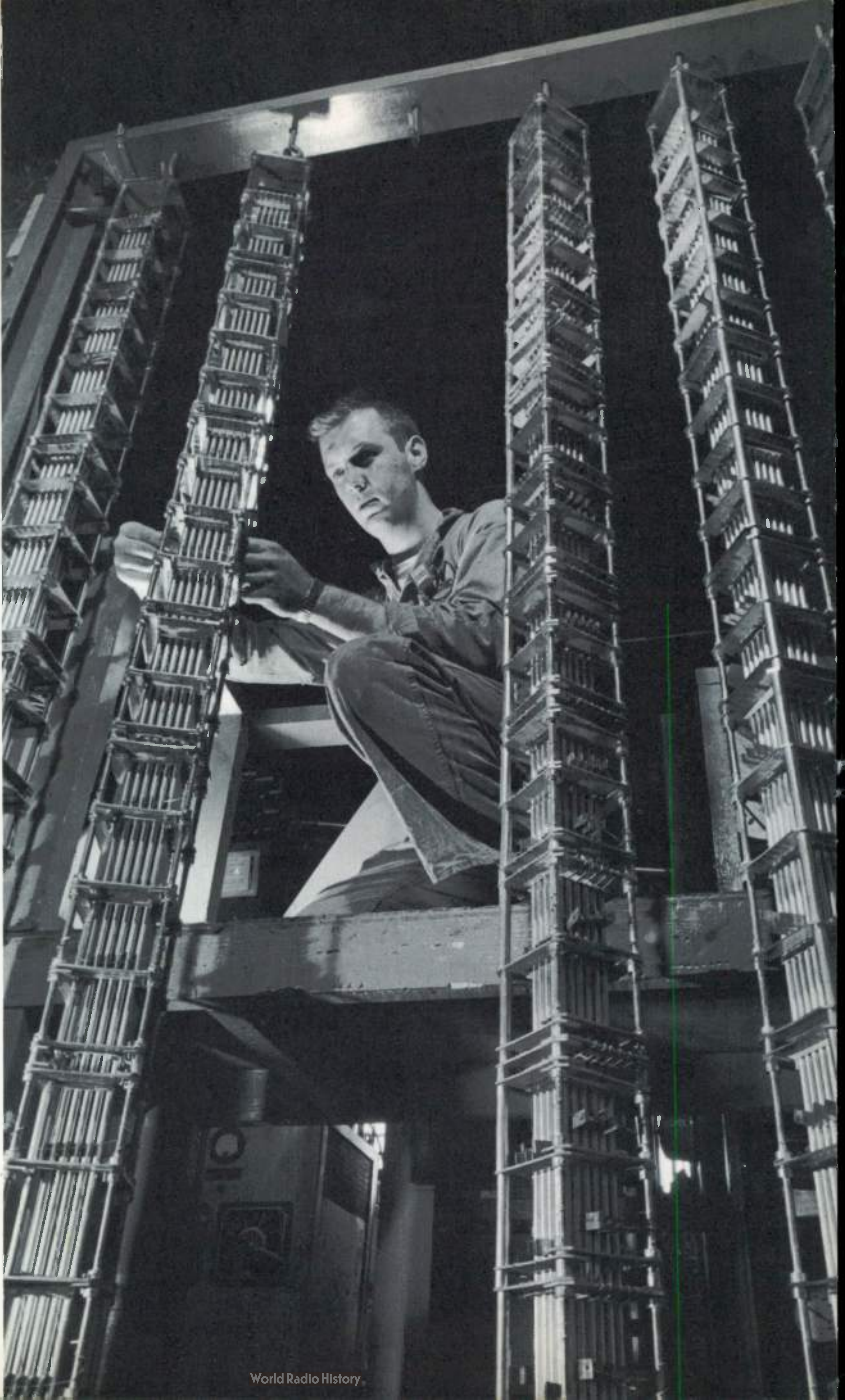
These are fuel bundles for Yankee Atomic Electric Company's nuclear plant at Rowe, Massachusetts, being checked by a technician. Approximately 25 tons of uranium oxide have been used in the manufacture of the plant's second fuel charge, which will be installed in the reactor early this spring. The first nuclear core established a record when the plant achieved a total power output of one billion kilowatt-hours in mid-January. In doing so, Yankee became the first atomic generating station in the nation to reach the one billion mark on its original fuel.



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