Westinghouse ENGINEER

JULY 1963

New Electronic Eye for Research

Scientists are getting a better look at the atomic make-up of matter with the help of this new electron diffraction camera. Some two to five times more powerful than the usual electron diffraction camera, the new instrument will provide more detailed pictures and brighter images, and will make possible the study of thinner surface films and thicker transmission specimens.

An extra-high voltage—250 000 volts produced with an electrostatic generator—is used to accelerate electrons released from a tungsten filament to 90 percent of the speed of light. (The wave length of these accelerated electrons is about 200 000 times shorter than that of light.)

These high-speed electrons are focused by magnetic and electric lenses, and beamed onto a material specimen under study. The electrons are diffracted as they pass through the material's atomic structure, and the atomic arrangement of the material is determined from the patterns produced on a fluorescent screen or photographic film. Structural materials for space vehicles and nuclear reactors will be the first specimens to go under the eye of this new test instrument.

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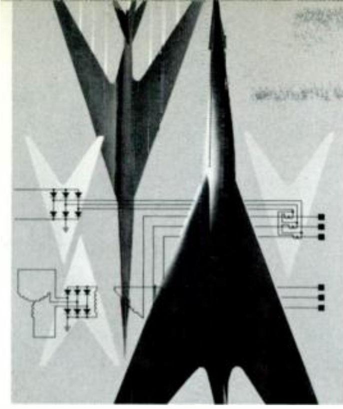

Cover Design: Electric power systems for supersonic transport aircraft are the subject of this month's cover design by Dick Marsh.

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Electric Power Systems for Supersonic Transports

R. D. Jessee and R. A. Mintz, Aerospace Electrical Division, Westinghouse Electric Corporation, Lima, Ohio.

Present technology is adequate, and further design advances are being made.

Aircraft designers agree that supersonic transport aircraft are technically feasible, and several designs are well along both in this country and abroad. Such aircraft obviously will require an electric power system capable of reliable operation in the environment created by high-altitude Mach-3 flight. The power system must also meet the requirements imposed by such flight, although opinions differ as to what these requirements will be.

A primary concern, certainly, is the maximum temperature at which the equipment will be required to operate. Equipment operating temperature is definitely not the same as ambient temperature; it may be higher or lower depending on the cooling method used and the temperature to which the equipment is cooled.

The penalty paid for heat dissipation can be extremely acute in supersonic aircraft. It is often the governing factor in selection of equipment because of the strong interdependence between the electric system and the other parts of the aircraft. Cooling systems and heat exchangers, for example, can profoundly influence aircraft aerodynamics.

This interrelationship between the electric power system and other subsystems requires that the entire supersonic transport be viewed as a single system. As in all integrated systems, intelligent compromises are the basis for obtaining good overall system performance. The aircraft manufacturer is in the best position to perform the required system integration. However, subsystem suppliers must participate in the early design stages so that final system integration can be accomplished with confidence.

This article discusses the new power-system design considerations that result from the major differences in requirements between the proposed Mach-3 transport and present Mach-2+ aircraft. It then describes and compares the two basic types of oil-cooled brushless electric power system being considered—constant-speed constant-frequency (CSCF) and variable-speed constant-frequency (VSCF). These two are being considered because designers have much experience with the CSCF system and because they find the VSCF system attractive in principle since it does not require a constant-speed drive.

General Design Considerations

Ambient Temperatures—The location of electric power system components will determine the ambient temperature in which they will operate. Location probably will not differ greatly from that in present-day supersonic aircraft. The generator (and constant-speed drive, if one is used) will be near the engine in an engine accessory bay. This bay is neither cooled nor pressurized. The other components will be in an electronic equipment bay that is pressurized and cooled to provide an environment within acceptable limits for lightweight electronic equipment.

Commercial aircraft equipment now is designed to start and operate at −40 degrees F, and this requirement should hold for the supersonic transport. Maximum ambient temperatures in some parts of the aircraft will be higher than present maximums because of higher aircraft speed. Aircraft manufacturers have indicated that the electronic equipment bay will be refrigerated to keep maximum ambient temperature below 160 degrees F. The bay's ambient temperature can be expected, then, to vary from −40 to 160 degrees F. This is within the range specified for some present military aircraft and should not present a problem.

Estimates for the maximum ambient temperature of the engine accessory bay range from 300 to 550 degrees F. For this discussion, the bay's ambient temperature is taken to vary from −40 to 550 degrees F. Estimated change in maximum ambient temperature as a function of altitude and aircraft speed is shown in Fig. 1. The maximum ambient temperature exceeds the 300-degree requirement of some present-day supersonic aircraft. However, it will exist only while at high altitude, so it may not be a major problem because of low air density and consequent low heat transfer (by air conduction and convection) from the aircraft skin to the equipment. The cooling method and the temperature to which the equipment is cooled must be decided before the effect of this high ambient temperature can be evaluated.

Equipment Cooling—Continuing development is increasing the temperature tolerance of electronic and electrical apparatus. However, increasing the allowable operating temperature does not alleviate the problem of removing all power losses from the equipment. Cooling will be needed, and the type selected will greatly influence equipment design.

Aerodynamicists have stated that ram air cannot be used for cooling because of the excessive drag that would result. Even if it could be used, at Mach 3 the temperature would be 640 degrees F; if an oil-to-air heat exchanger were used, the cooling oil temperature would be about 700 degrees F. Major development would be required to provide suitable equipment that could operate at this tempera-

The authors acknowledge the important contributions of members of the Westinghouse Aerospace Electrical Division engineering staff, who provided most of the data contained in this article.

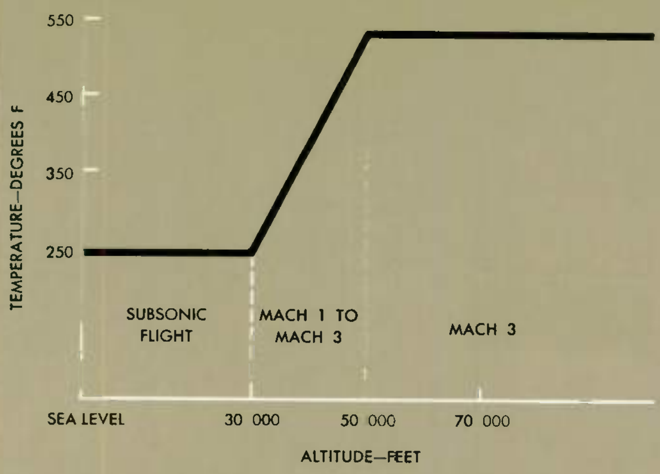


Fig. 1—The maximum ambient temperature in a supersonic transport engine accessory bay is expected to vary with altitude and aircraft speed as shown here.

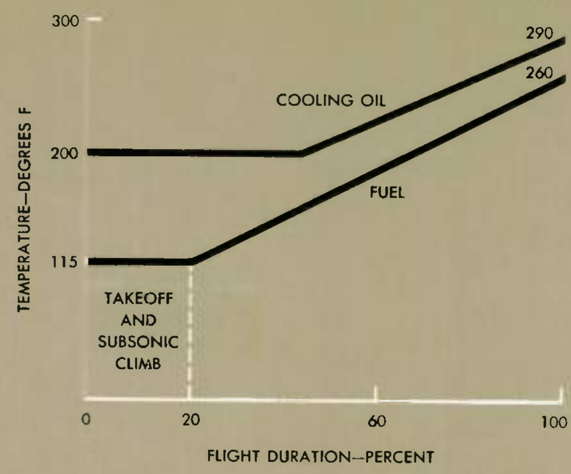


Fig. 2—Aircraft fuel temperature would increase throughout a flight if the fuel were used as a heat sink for refrigeration. Even so, the fuel temperature would be low enough to cool the oil that cools the generator and constant-speed drive.

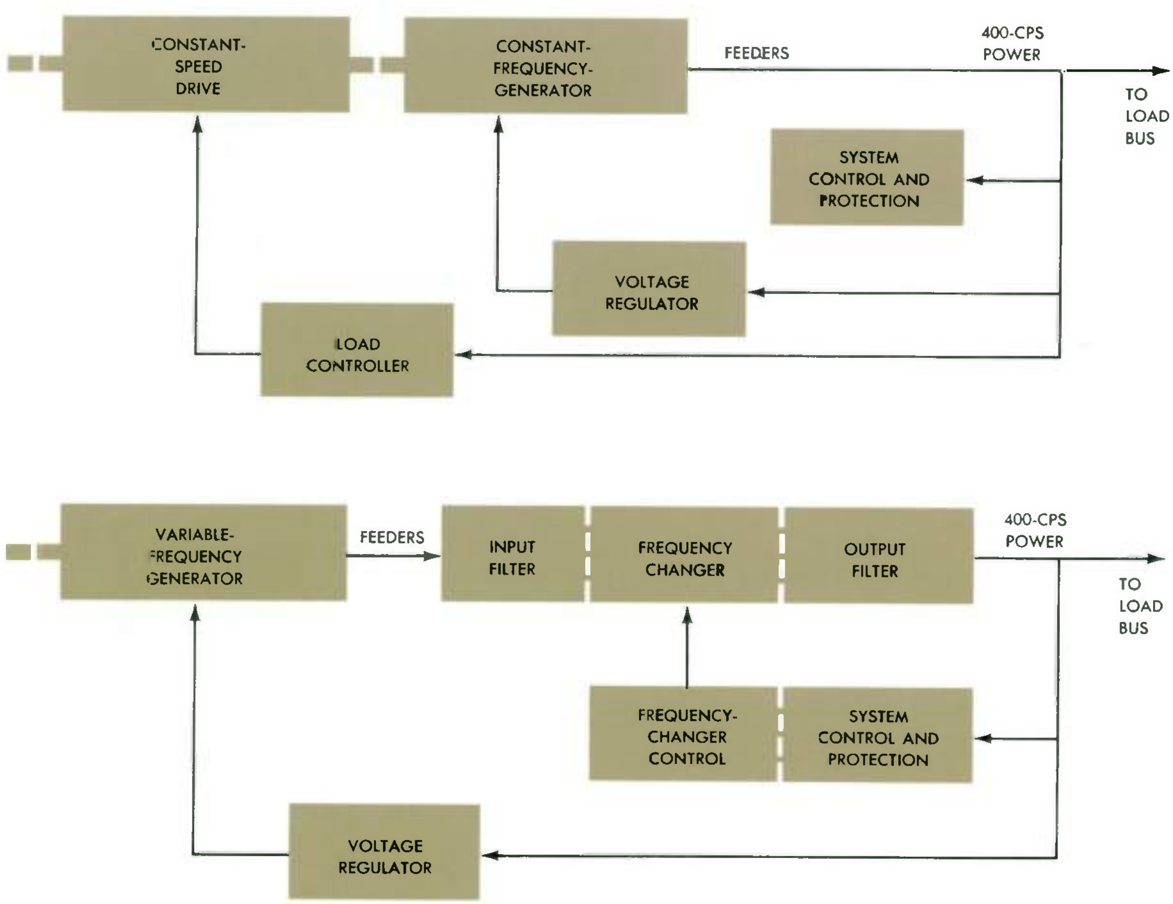


Fig. 3—These diagrams show the main components of the two electric power systems being considered for supersonic transports. They are the constant-speed constant-frequency (CSCF) system (top) and the variable-speed constant-frequency (VSCF) system (bottom).

Table I—System Parameters and Requirements

Number of Systems per Aircraft	Four, operated in parallel
Engine Pad Speed Range	Two to one
Equipment Cooling	Fuel heat sink
Engine Accessory Bay Temperature	−40 to 550°F
Electronic Equipment Bay Temperature	−40 to 160°F
Rated Load	60 kva at bus
Frequency	400 (±4) cps
Voltage at Bus	115 volts (±1%) line to neutral
Type	Three-phase four-wire
Rated Power Factor	0.75 lagging to 0.95 leading
Maximum Total Harmonic Content	3%
Overloads:	
150% of rated	5 minutes
200%	15 seconds
300%, 0 power factor	5 seconds
Minimum Three-Phase Fault Current	300% rated for 15 seconds
Minimum Efficiency at 0.75 Lagging Power Factor and Rated Load	70% (from engine pad to load bus)

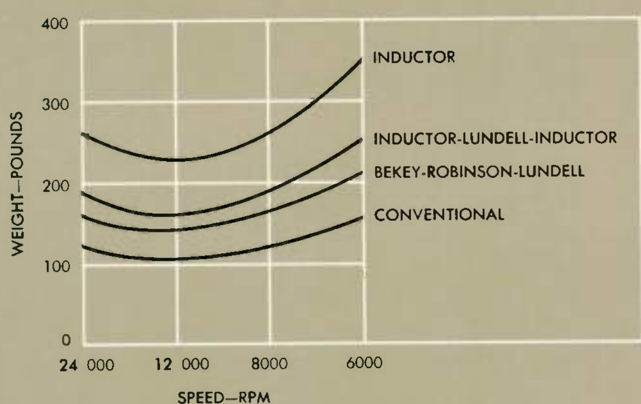
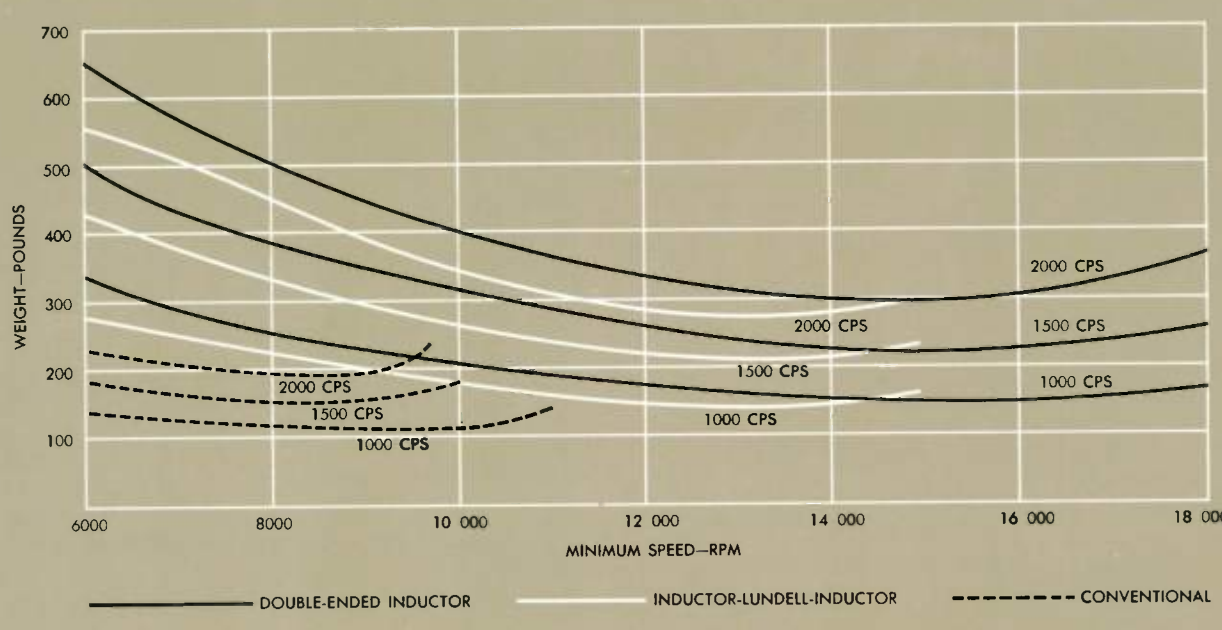


Fig. 4—Generator weights as functions of operating speed are compared here for a conventional generator and three solid-rotor generators evaluated for use in a CSCF system. The generators are brushless oil-cooled units rated 60 kva at 400 cps.

Fig. 5—Generator weights as functions of minimum operating speed and minimum output frequency are compared here for a conventional generator and two solid-rotor generators evaluated for use in a VSCF system. Speed and frequency range for all three generators is two to one. The generators are rated at 78.5 kva, the rating required for a 60-kva VSCF system.



ture. Disposable cooling water could be used for small units and short flight times. However, the volume and weight of water required for larger units such as the generator would be excessive.

An oil-to-fuel heat exchanger, similar to those presently used on supersonic aircraft, appears to be a good choice for cooling the generator and constant-speed drive. Studies have determined the weights of the heat exchangers that would be required to provide cooling oil at 300 degrees F and at 600 degrees F, with a maximum fuel temperature of 260 degrees F. Cooling four 60-kva generator and constant-speed-drive packages would require a heat exchanger weighing 15 pounds for 300-degree oil and 11 pounds for 600-degree oil. The additional weight of the equipment that would have to be designed for operation with 600-degree coolant would far exceed the additional four pounds of heat exchanger required for 300-degree coolant. Also, present-day equipment can operate continuously with 300-degree coolants, while many problems would be encountered in developing light and reliable equipment to operate with 600-degree coolants.

The design task would be significantly reduced, therefore, if oil at 300 degrees F could be used to cool the generator and constant-speed drive. However, two other factors must be considered before selecting this as the coolant temperature. First, how much heat will be absorbed by the generator and drive when they are cooled to a temperature lower than ambient? Second, will the aircraft fuel temperature remain low enough to limit the coolant temperature to 300 degrees F?

The maximum quantity of heat that could theoretically be absorbed by the equipment in the accessory bay because of radiation from the aircraft skin and convection from the ambient atmosphere was calculated at 36 Btu per minute per square foot of exposed equipment surface. (Calculations were based on skin temperature of 650 degrees F above 50 000-foot altitude.) This additional heat is negligible compared with normal equipment operating losses.

With the fuel being used as a heat sink for aircraft refrigeration loads, its temperature will continually increase during a flight. The estimated maximum fuel temperature is 260 degrees F, so the cooling oil would reach an estimated maximum of 290 degrees F (Fig. 2).

High-Temperature "Soak"—Generators and constant-speed drives generally are not cooled when idle, because the cooling-oil pumps are part of the drive. When engine rotation stops, then, removal of heat from the generator and drive ceases and both units are subjected to ("soaked in") the ambient temperature.

Landing after maximum-speed flight would result in a soak starting at 550 degrees F. An engine failure, with locked rotor, during maximum-speed flight would cause a continuous soak at 550 degrees F. The main concern in both cases is that rectifiers in the generator may be damaged by the high temperatures. However, tests performed on present oil-cooled generators and an analytical study have shown that neither condition presents a problem.

In normal operation, ambient temperature would start to fall as soon as the aircraft landed. With a reasonable rate of engine cooling, rectifier temperature would never reach 450 degrees F (the melting point of the solder used to seal present rectifiers). If engine failure with locked rotor existed longer than an hour, the generator rectifiers would be heated above 450 degrees F. High-power rectifiers now in production, however, have components joined at 1023 degrees F. These rectifiers can withstand even the soak temperatures expected after engine failure.

Electric Loads—Most of the loads will be large electric motors for fuel pumps, hydraulic pumps, and refrigeration compressors. A parallel-generator system definitely is required, as preliminary estimates indicate that a compressor motor rating will approach the rating of one generator and that two compressors may be operating at the same time. To assure capability of starting the compressor motors, the generator overload ratings must exceed the normal 200 percent for five seconds at rated voltage required of present generators. The generator probably will have to supply 300 percent of rated load for five seconds at rated voltage and at highly lagging power factors (approximately 0 to 0.4 lagging). This will increase generator weight by approximately 10 percent.

Proposed Power Systems

In the CSCF system, the constant-speed drive operates from an engine gearbox at input speeds varying approximately two to one (Fig. 3). The drive output speed is constant, so the generator supplies power at a constant frequency of 400 cycles per second (cps). Generator excitation is controlled by the voltage regulator to maintain the load bus voltage at the rated value over the load range. The control and protection unit protects the utilization equipment from abnormal system operation (such as a prolonged over-voltage), performs control functions such as automatic system buildup and shutdown, and provides line contactor control. The drive speed controller and the voltage regulator control real-load and reactive-load division among generators in parallel operation.

In the VSCF system (Fig. 3), a generator with a wide speed range is driven directly from the engine gearbox. Consequently, generator frequency varies approximately two to one. Silicon controlled rectifiers in a frequency changer switch the variable-frequency voltages in such a way as to develop a constant-frequency voltage. This is filtered to reduce harmonics and supplied to the load bus. A voltage regulator controls generator excitation to maintain the proper bus voltage level. The frequency-changer control provides frequency control, unbalanced voltage control, real- and reactive-load sharing, and controlled-rectifier gate control. (The basic operation of frequency changers—or cycloconverters—is described in reference 2.) A control and protection unit performs essentially the same functions as in the CSCF system.

These two systems were compared for application in the supersonic transport. The system requirements assumed are shown in Table I. They reflect the conclusions of the previous discussion and are in close agreement with estimates obtained from several aircraft manufacturers. The requirements for electric power at the load bus are as specified in MIL-STD-704 except where modified by the requirements of Table I.

CSCF System Design Considerations—The wound-rotor synchronous generator, often referred to as the conventional generator, is the type most often used in CSCF systems. Nonconventional generators, such as the so-called solid-rotor generators, are often evaluated for possible use when a new application arises. They have no rotating windings and require no internal rectifiers for brushless operation, so they can operate at higher temperature.

A conventional generator and three types of solid-rotor generators, all based on the requirements of Table I, were compared (Fig. 4). The weights shown are higher than would be expected, a direct result of the 300-percent, zero-power-factor load requirement. The weight penalty is largest for the nonconventional generators, which require a greater increase in excitation because of their much higher field flux leakages.

Minimum generator weight is achieved at 12 000 rpm. Increasing speed to 24 000 rpm increases generator weight because a two-pole machine is needed at this speed. Weight must be added to overcome mechanical or magnetic unbalance in the nonconventional generators and to contain the rotating field windings in the conventional generator.

The conventional generator was found to be the best type from the standpoint of size, weight, performance, and efficiency. A weight breakdown of a system with a generator operating at 12 000 rpm follows:

Generator	110 pounds
Voltage regulator	4 pounds
Control and protection panel	8 pounds
Current transformers	4 pounds
Total	126 pounds

The generator weight is based on use of silicon steel and the control equipment weights on standard semiconductor devices presently used in high-performance aircraft.

VSCF System Design Considerations—Three generator types were evaluated: a conventional generator and two solid-rotor types (double-ended inductor and inductor-Lundell-inductor).

Fig. 6—A VSCF system weight analysis made with the generators compared in Fig. 5 is illustrated here. System weights, in pounds, are shown as functions of generator type and frequency range required to produce 60-kva 400-cps bus power. Operating frequency as well as generator type affects total VSCF system weight, so the lightest generator does not necessarily result in the lightest system.

VSCF system input frequency to the frequency changer should be at least 1000 cps to reduce the task of filtering the harmonics in the output power. Therefore, generator shaft speed must be high. Generator weight varies with shaft speed and with output frequency as shown in Fig. 5. The curves are for a generator rating of 78.5 kva, the rating required for a 60-kva VSCF system. (The additional rating is needed to supply conversion losses.) The curves are based on data from test models and computer studies.

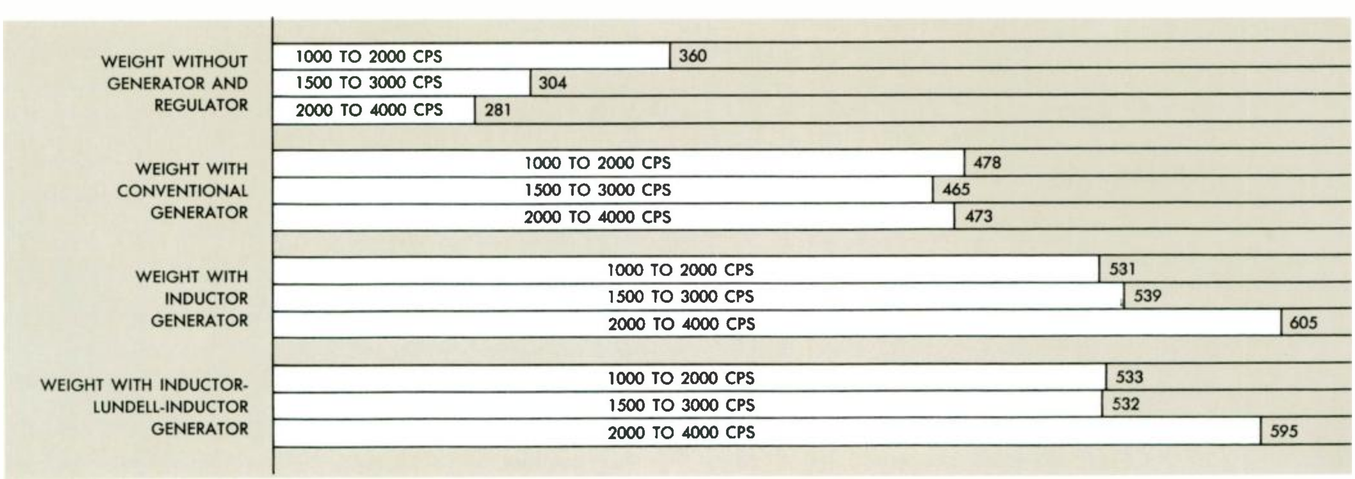
Generator subtransient reactance is a major factor in successful operation. It should not exceed 0.3 per unit, and a lower value is desirable if it can be obtained without excessive increase in generator weight. A second major consideration is overload capacity, which must be between 200 and 250 percent of rated load depending on the frequency range. With frequency-changer operation, the 200-percent, 0.75-power-factor bus load represents a larger load to the generator than the 300-percent, zero-power-factor bus load. While all the generators compared in Fig. 5 have these capabilities, the nonconventional types are necessarily heavier than the wound-rotor synchronous generator.

The weight-speed curves are based on use of Hiperco 27, a cobalt-iron magnetic material that carries 25 percent more magnetic flux than conventional silicon steels. It reduces the amount of magnetic material required, and consequently reduces the amount of copper required. If silicon steel were used, as it was in the CSCF-system generators that were compared, generator weight would increase by about 15 percent.

At any rating and operating speed, generator weight increases as operating frequency is increased because generator reactances increase with frequency. To keep the same performance, the reactances are lowered by increasing generator stack length.

Generator rating increases with speed; hence, with rating held constant, weight decreases as speed increases—up to a point. Beyond this point, weight must be increased to maintain the required reactance and mechanical strength.

The lowest generator weight is obtained with a wound-rotor synchronous generator operated over a speed range of 10 000 to 20 000 rpm and an output frequency range of 1000 to 2000 cps. In a VSCF system, however, the weight



of the other system components varies as a function of the frequency range and must be considered before selecting a generator.

A system weight analysis was performed for three input frequency ranges to the frequency changer: 1000 to 2000 cps, 1500 to 3000 cps, and 2000 to 4000 cps. The generator weights used were the minimum weights in Fig. 5, adjusted for feeder losses to obtain 60 kva at the load bus. The results of this analysis are shown in Fig. 6. Minimum system weight was obtained with the wound-rotor synchronous generator operating over a frequency range of 1500 to 3000 cps. The weight breakdown of a VSCF system using this generator with a 9000- to 18 000-rpm speed range follows:

Generator	157 pounds
Frequency changer	80 pounds
Output filter	36 pounds
Input filter	97 pounds
Control and protection panel	8 pounds
Frequency-changer control	25 pounds
Voltage regulator	4 pounds
Current transformers	4 pounds
Total	411 pounds

The generator for this 60-kva VSCF system is considerably heavier than that for the CSCF system. The reason is that it must actually provide 81.5 kva to supply conversion losses and the higher feeder losses that result from operation at higher frequency.

Comparison of CSCF and VSCF Systems—Weight comparisons for the two systems are shown in Table II. The feeder weights differ because of the different generator frequencies.

The maximum allowable cooling-medium temperature for the frequency changer would be 160 degrees F for air cooling and 200 degrees F for liquid cooling. Since the aircraft fuel will reach 260 degrees F, frequency-changer refrigeration would be required. The losses of the frequency changer and filters will be 5.1 kilowatts, assuming the predicted efficiency of 85 percent. The weight added to the aircraft's refrigeration system for removing these losses is estimated at 50 pounds per system (approximately 10 pounds per kilowatt).

Table II—System Weight Comparisons

COMPONENT	CSCF (lb)	VSCF (lb)
Generator	110	157
Constant-Speed Drive	64	
Voltage Regulator	4	4
Protection Panel	8	8
Load Controller	5	
Current Transformer	4	4
Frequency-Changer Control		25
Frequency Changer and Filters		213
Feeders (50 feet)	32	54.5
Frequency-Changer Cooling		50
Total System Weight	227	515.5
Total Aircraft Weight (four systems)	908	2062

These estimates indicate that the weight of a four-generator electric power system would be 2062 pounds for the VSCF system and 908 pounds for the CSCF system, a difference of 1154 pounds. Besides the weight penalty, the VSCF system would require extensive development for application on a supersonic transport, whereas the CSCF system could be developed from service-proven designs. The design of a VSCF system requires many compromises that have not yet been fully evaluated; a few of these are generator weight versus input filter weight, system weight and complexity versus power quality, and generator frequency versus number of phases.

However, the VSCF system shows real promise for some applications. The system is still in the early stages of development and rapid progress is being made with it. Longer life and better reliability should result from replacement of a constant-speed drive with a completely static frequency changer. Another advantage is the potential for better weight distribution and streamlining because the frequency changer, unlike a constant-speed drive, can be located anywhere in the airframe.

To take advantage of the desirable features of the VSCF system, its inherent characteristics must be recognized and put to use instead of being modified to conform to existing standards. There is little chance that the system can ever be a direct replacement for systems using constant-speed generation without imposing a severe weight penalty. The weight penalty is largely the result of commutation kva loss and the need for energy-storage capacity to compensate for generator voltage distortion. Additional weight penalties are imposed by high-quality power specifications in waveform, overload capacity, phase voltage balance, and modulation. (Power-quality standards have been written to the capabilities of constant-speed systems developed through continual refinement, and aircraft designers customarily specify these standards.)

On the other hand, a realistic appraisal of actual load requirements reveals that such power quality, so inexpensive in terms of weight and complexity with constant-speed generation, is not actually needed for the great bulk of loads. For example, the performance of a motor operating from nonfiltered VSCF-system output voltages is not appreciably different from that obtained with pure sine-wave voltages. Filters can be provided for those loads that do require high-quality voltage with much less weight than is required to filter the total system output power.

Conclusions

The conventional wound-rotor synchronous generator would provide the lightest total weight for either type of power system presently being considered for the supersonic transport. No requirements are foreseen that would require major improvement in materials or components for a CSCF system. Design and development of this power system can be accomplished entirely within the current state of the art.

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[2]*Mercury-Arc Current Converters* (book), H. Rissik, pp. 247–256, Sir Isaac Pitman & Sons, Ltd., 1941.

A New Insulation System for a New Line of Switchgear

T. F. Saffold, Engineering Manager, Assembled Switchgear and Devices Division, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania.

An improved high-strength electrical porcelain is the key ingredient in a new insulation system developed for metal-clad switchgear.

Porcelain is one of the oldest of the electrical insulating materials and the most favored for numerous applications. Porcelain's widespread use as electrical insulation lies in the fact that in addition to its dielectric strength, porcelain is positively noncombustible, nontracking, and essentially nonhygroscopic.

These properties are ideal for the insulation between live parts and ground of metal-clad switchgear and magnetic air circuit breakers. However, for porcelain to be used as insulation to ground throughout the metal-clad switchgear and the breaker, it must possess some additional properties: It must have high strength to withstand the mechanical forces encountered, ability to retain its insulating properties in high operating temperatures, and resistance to thermal shock.

Recent advances in porcelain technology have shown that porcelain can be produced in special high-strength bodies that meet all of these environmental requirements. These developments made the long-desired objective of an all-porcelain-to-ground metal-clad switchgear insulation system entirely feasible. Such a system offers the highest degree of reliability yet attained in years of technological advances in switchgear and magnetic air circuit breaker design. For these reasons, the design and development of a new line of metal-clad switchgear with a new insulation system was undertaken. Called Porcel-Line switchgear, the new line includes a porcelain-insulated magnetic air circuit breaker (Type DH-P).

The Porcel-Line Switchgear Insulation System

Metal-clad switchgear consists of an assembly of grounded metal enclosures, which accommodate withdrawable types of circuit breakers and their associated circuitry. The design of the switchgear is such that each circuit element is separated from all other elements by

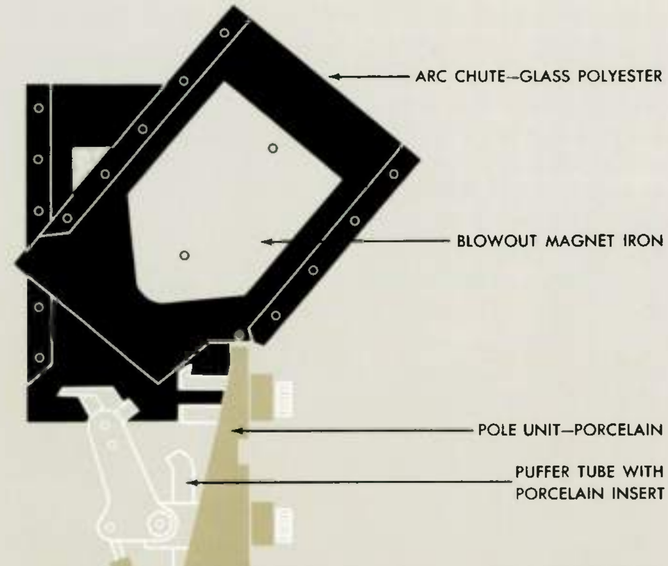


Fig. 1—Cross-section view of DH-P breaker shows the use of porcelain insulation between live parts and ground.

Photo—The 5-kv, 250-mva magnetic air breaker undergoing short-time current-carrying and interrupting tests.

metal compartmentation. Buses are specified as insulated group-phase structures.

The insulation system of metal-clad switchgear can thus be divided generally into two parts: that part associated with the stationary units enclosing the bus structure and the stationary receptacles for the breaker terminals, and that part associated with the withdrawable breaker. Each of the two parts of the system is subject to the operating and environmental conditions unique to its associated functioning parts. In the complete switchgear, a wide range of insulating functions exist, which are subject to a variety of operating conditions.

Porcelain for the Magnetic Air Circuit Breaker

The basic concept for the new circuit breaker insulation system is shown in Fig. 1. A massive all-porcelain pole unit support of high-strength porcelain supports the main conductors and arc chute. The pole support is babbitted to a malleable iron shoe, and the shoe is in turn bolted to a flat chassis.

The operating rod for the breaker movable contacts and the lower portion of the puffer tube are also made of porcelain, so that porcelain is the only insulation between any live breaker part and ground. Furthermore, the flat chassis design and the use of porcelain to support the main conductors and the arc chute prevent grounded or metallic parts from extending upward into the vicinity of live parts.

For the arc chute, a new zircon type of ceramic material was developed for the interrupter plates. The new material provides greater volts-per-plate interrupting ability and higher mechanical strength, which permits an improvement in overall interrupting capability with reduction in overall arc-chute size.

The arc-chute enclosure, which completes the breaker insulation system, is made of molded, flame-retardant, arc-resistant glass polyester formed in two halves and held together by retaining bolts.

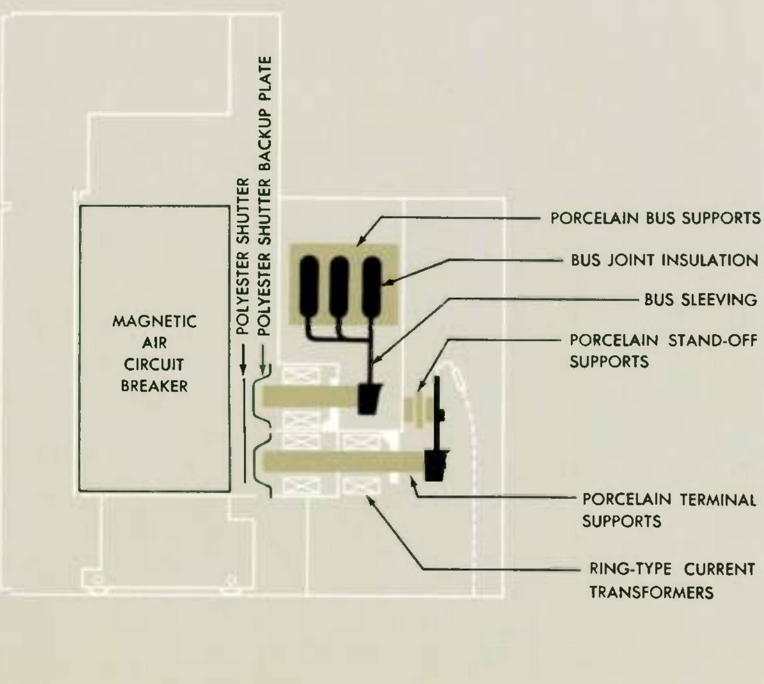
The development of the porcelain insulation system was a joint effort of switchgear designers and ceramic design engineers of the Westinghouse Porcelain Division. In the development of the porcelain insulating parts, primary emphasis was placed on reliability. All environmental and operating conditions likely to be encountered were anticipated and carefully evaluated. Test schedules for both test specimens and full-sized parts were established to test the ability of various high-strength porcelain bodies to meet the extremes of operating forces and environmental conditions.

Tensile, compression, and cantilever loading tests were used to evaluate the static strength of various porcelain bodies. Impact resistance was determined on both material test specimens and in full breaker tests. Thermal shock and thermal cycling tests were applied to full-sized assembled parts. A single-phase momentary test with two poles in series demonstrated that the pole-unit design could withstand current with a momentary value of 81 000 amperes rms for 15 cycles—compared to the rating for this design of 60 000 amperes momentary.

With the design concept and adequacy of the porcelain pole-unit structure and operating rod firmly established, other breaker components were developed. The contacts, mechanism, puffer, chassis and other parts were designed to assure, in the complete breaker, the same degree of

Fig. 2—The insulation system for the 15-kv DH-P breaker and cell illustrates use of porcelain for insulation to ground.

Photo—Modular design of housing provides flexibility in meeting application requirements.



reliability as its insulation system. Exhaustive tests have verified the complete breaker design.

Insulation for the Stationary Enclosure

The conceptual approach to the design of the stationary enclosure was to apply the same basic insulation improvements that were used on the breaker to provide a balanced insulation system.

A section view of a typical indoor breaker housing is shown in Fig. 2. The insulation in the housing consists of bus supports, contact supports, bus sleeving, and bus-joint insulation. Insulated bus bars are held and positioned by porcelain bus supports to preserve the integrity of compartmentation between adjacent section units. Porcelain is used for these bus supports because it is nontracking and noncombustible. Inasmuch as separate bus supports completely surround each bus bar, hidden creepage paths are avoided.

The contact supports (bottles) position the stationary parts of the disconnecting contacts and act as receptacles for the bushings of the withdrawable circuit breaker. Like the bus supports, they are primary line-to-ground insulation and provide integrity of compartmentation. And, like the bus supports, they are made of porcelain for the same reasons. Standoff porcelain supports are used to brace bus and line conductors in the 15-kv rating. Insulation for bus and connections have been selected to form an insulation system that meets the requirements of applicable standards.

An automatic shutter, which protects personnel from accidental contact with live parts when the breaker is removed, is also part of the insulation system. The shutter and a shutter backup plate are both made of flame-retardant glass polyester. Use of this material effectively removes grounded metal from the proximity of breaker live parts and the stationary contacts. Full air clearance is maintained between the shutter members and the stationary contacts deeply recessed within the porcelain bottles. The air gap between shutter members and the end of the porcelain contact bottles eliminates the possibility of electrical charge buildup on the shutter or shutter backup plate. Thus, the path to ground is much greater than if a metal shutter were applied, reducing even further the possibility of a flashover to ground.

Design Features of Porcel-Line Switchgear

The new line of metal-clad switchgear consists of ratings up to and including 250 mva in the 5-kv class, and 500 mva in the 15-kv class. Only two housing widths are used for the complete indoor line; 26 inches for 5-kv breakers, and 36 inches for 15-kv breakers. All breakers are contained on two basic chassis sizes, one for each voltage class. The new line has the advantages of smaller size and less weight.

In addition to the improved insulation system, a number of installation and operational features have been developed in the new switchgear equipment.

Modular Construction—The new switchgear assembly consists of bolted-together modules: the breaker-bus module, line module, control module, and a rear superstructure module if required. Complete grounded-metal barrier isolation is provided. In the breaker and bus module, barriers separate the bus and line compartments

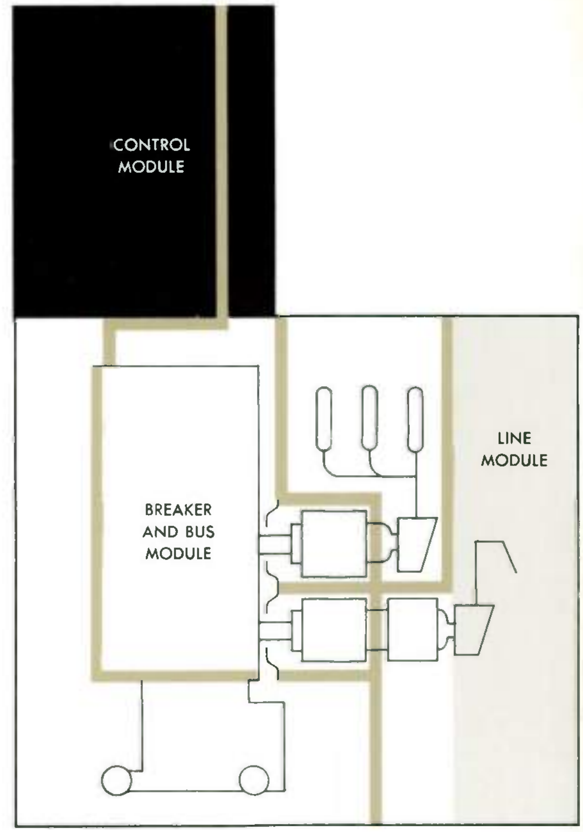
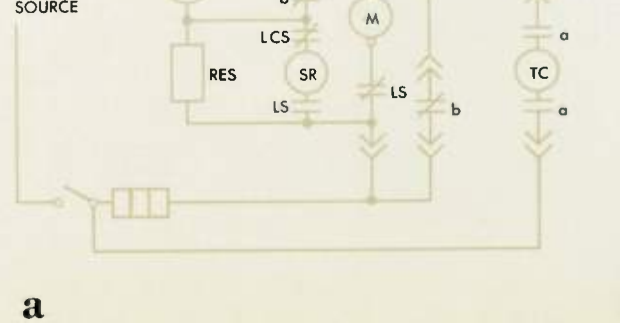


Fig. 3—Modular construction isolates all major compartments from each other with metal barriers.

Fig. 5—The control circuit simplification obtained in the new line of magnetic circuit breakers is demonstrated by these simplified wiring diagrams for dc spring-stored-energy closing for (a) the new Porcel-Line and (b) previous metal-clad magnetic circuit breaker.



a

Right—The 5-kv porcelain pole unit support shown in process of manufacture (above), and undergoing design inspection (below).

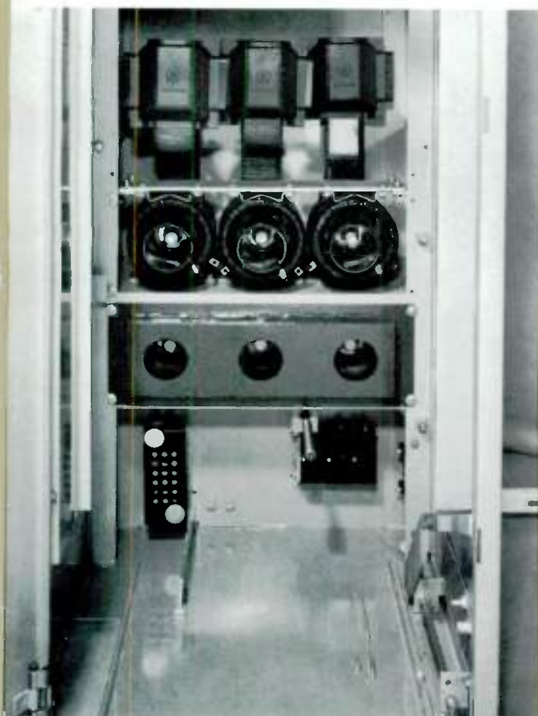
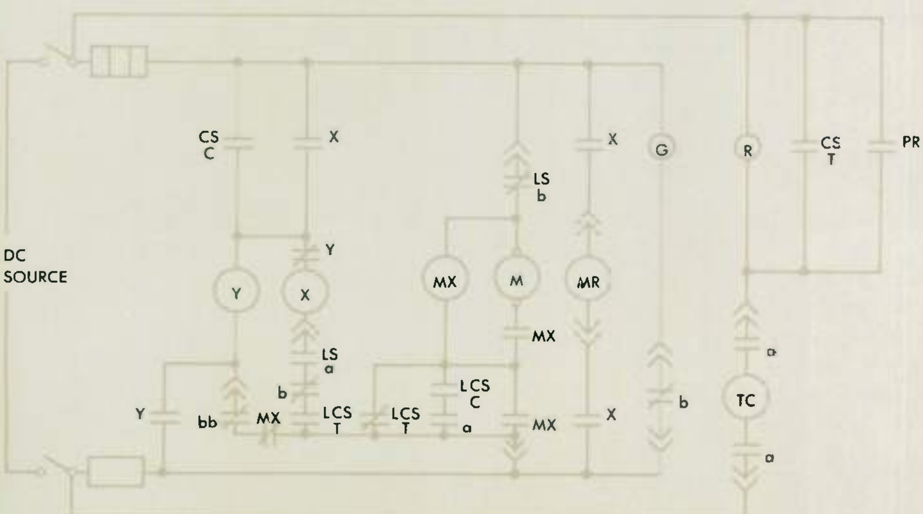


Fig. 4—Closeup of a 5-kv indoor breaker house with shutter, bus backup plate, and bus barrier removed illustrates accessibility to all major components.



LEGEND

CS —Control Switch
C —Close
T —Trip
PR —Protective Relay
G —Green Light
R —Red Light
X —Closing Contactor
Y —Control Relay
M —Spring Motor
MR —Spring Release
MX —Auxiliary Relay
SR —Spring Release
TC —Trip Coil
LS —Spring Limit Switch
LCS—Latch Check Switch
a —Auxiliary Contact
b —Auxiliary Contact
bb —Cut-off Switch
RES—Limiting Resistor

b

from the breaker compartment. Sectional removable barriers around the main contact supports complete the metal isolation of the breaker compartment from the bus and line compartments. In all compartments, low voltage is isolated from high voltage.

Improved Safety and Accessibility—Maintenance and inspection of Porcel-Line switchgear have been simplified in several ways. The main bus structure is readily accessible from the front; current transformers are also accessible from the front, as shown in Fig. 4, so that the bus compartment need not be exposed, or the insulated joints disturbed. Current transformers are of the ring type, and are available in ratios from 50/5 up. As many as nine can be mounted around the main contact bottles, six on the line side and three on the bus side.

Potential transformers, fuses, and control power transformers are trunnion-mounted and automatically disconnected and rotated as the side-hinged compartment door is opened, providing both accessibility and safety. Transformers and fuses can be located in auxiliary housings, or potential transformers can be located in the rear superstructure module.

The levering-in device is of the screw type, and simplifies levering the breaker from the test to operating position. For greater safety, an access opening in the breaker module door permits levering the circuit breaker with the door closed.

Operating Mechanisms—Each magnetic air circuit breaker chassis can be equipped with either a solenoid or a motor-charged spring type stored-energy mechanism. Each mechanism will perform under existing and proposed ASA Standards. The solenoid mechanism is of a basically conventional type and is trip-free in all positions. The closing-coil design depends upon the breaker interrupting and momentary ratings.

In the stored-energy mechanism, which is trip-free in all positions, the spring is charged by a universal motor by ratchet action. The closing spring acts through a cam in the lever system to exert a relatively low force at the beginning of the closing stroke and a high closing force toward the end. The spring travel is a reciprocating motion derived from a crank attached to the ratchet and cam. This provides for excess closing energy to be absorbed in partially recompressing the closing spring. This relieves the entire unit of considerable mechanical shock on spring closing.

Breaker Controls

Breaker control circuitry in the new switchgear has been simplified and made more reliable and maintenance-free through elimination of several relays and contacts. The new control schemes comply with applicable ASA and NEMA Standards.

Dc tripping is standard for both solenoid and spring stored-energy types. This recognizes the common usage of a reliable dc power source such as a battery for tripping. Other forms (such as capacitor tripping) are available.

For circuit breaker closing, the new controls provide for dc power only in the case of solenoid mechanisms, and a choice of either ac or dc closing in the case of the spring stored-energy breakers.

The simplicity of the new control circuitry is apparent when it is compared with the same control scheme in present switchgear. A schematic of the new control circuit for dc closing of a spring stored-energy breaker is shown in Fig. 5a; the superseded scheme is shown in Fig. 5b. As an indication of the degree of simplification, the new control has 38 percent fewer wire connections than its predecessor. Other standard control schemes have reduced wiring connections by about 20 percent.

Outdoor Switchgear

The sheltered-aisle outdoor breaker housing consists basically of the new indoor circuit breaker unit, to which is added a rigid base, weatherproof sides, and a weatherproof roof. A weatherproof aisle enclosure is fastened to the front of the unit.

The housing components are formed so that all seams are weatherproof. Ventilation is simple and efficient: Cooling air enters from underneath through a labyrinth formed by the base and side covers; air passes through the equipment and is expelled through labyrinths at the peak of the roof and at the rear roof overhang. There are no ventilating grills or louvers.

Foundation requirements are minimized by a structure that is supported by three base channels. Pier mounting is possible, and a breaker drawout pad is not required. The liberal sheltered aisle permits weather-protected maintenance and inspection of breakers.

The aisleless outdoor housing design consists of the indoor breaker unit, unit base, and weatherproof sides and roof identical to those parts on the sheltered-aisle gear. A weatherproof front module of welded construction is bolted to this assembly. Foundation requirements are also similar, except that pier mounting requires a breaker drawout pad.

Both the sheltered-aisle and aisleless outdoor switchgear incorporate all of the features of the new indoor gear and have the same ratings.

Verification Tests

The development and verification of the new DH-P Porcel-Line design has involved hundreds of tests on materials, components, and complete units. Breakers and switchgear have been tested separately and in combination to establish performance in the complete assembled switchgear environment.

Equipment tests were carried out to ASA Standards. Momentary tests on breakers and enclosures were made unusually severe. Although not actually required by Standards, the breakers were closed and latched against momentary rating. These tests proved the ability of the equipment to withstand the severe electromechanical forces associated with short-circuit currents.

Breakers were subjected to 20 000 operations on mechanical life tests. Porcelain pole supports were given high-potential tests, 60 cycles, impulse, and power factor at 10 kv over the temperature range 25 to 125 degrees C, in addition to mechanical tests.

These verification tests, carried to extremes of operating conditions, have shown the new insulation system, with its use of porcelain for all live parts to ground, and the associated switchgear and breaker design to be highly reliable and fully capable of meeting the demands of ever increasing system loads.

The Autoplot Computer-Plotter

Joseph T. Laing, Manager, Ocean Survey Systems, Ordnance Division, Westinghouse Electric Corporation, Baltimore, Maryland.

This multi-purpose data handling instrument is suited to many tasks in oceanographic research.

About seven tenths of the earth's surface—the area under the seas and oceans—is still a relatively unexplored frontier. The contours of ocean floors, the flow of undersea currents, and the distribution of physical parameters, such as temperature, are typical ocean characteristics that are only generally known. More specific information will come through expanding oceanographic research and survey programs. The vast quantities of data required can best be gathered and analyzed with the help of modern computer techniques. The Autoplot, an integrated computer-plotter originally built for the U. S. Navy Bureau of Ships for navigational computation and position plotting, is an instrument capable of assisting in a wide range of tasks in oceanographic work. The universal input-output system, the capacity of the internal computer, and the precision of the plotter make the instrument suitable for oceanographic survey work, and for real-time processing and plotting of such oceanographic research data as temperature, depth, sound velocity, and water currents.

Two equipments of the type to be described have been built and have proved successful in many sea operations over the past two years.

Autoplot Equipment

The Autoplot consists of an integrated computer-plotter console and peripheral equipment, including data displays and a Flexowriter. The base of the console, shown in Fig. 1, contains a general-purpose (but specially designed) solid-state digital computer and a substantial amount of input-output equipment. On top of the console is a 30-inch precision x-y plotter, operated by the computer. An important objective in the equipment design is a high degree of physical and logical compatibility between the computer and the input and output functions that communicate with it, so that the system is compact and efficient, yet functionally complete.

The construction generally used throughout the console is shown in Fig. 2, which displays a portion of the digital computer. Since the instrument is designed for operation at sea, all circuits are solid state; standard modular components can be replaced easily. To further insure shipboard reliability, general conformity to appropriate military specifications (MIL-E-16400) has been practiced in overall packaging and component design.

Characteristics of the digital computer include: Drum storage capacity of 5444 words, with a word length of 23 bits plus sign; number representation is binary, fixed point, and fractional; input circuits can transfer up to thirty-two 23-bit inputs in parallel; output circuits can transfer up to 512 outputs; clock rate is 300 kilocycles per second. A block diagram of the data processing and display system is shown in Fig. 3.

Operation

In its principal mode of operation, the Autoplot computer-plotter accepts analog data in the form of ranges or bearings from a navigational reference station, computes the precise geographical position of the ship, and plots this

Fig. 1—The Autoplot console consists of a digital computer in the base, and a plotter on top. The master control panel governs operational mode selection, and the insertion of operational constants, such as the geographical coordinates of the navigational reference stations and chart scale factor.

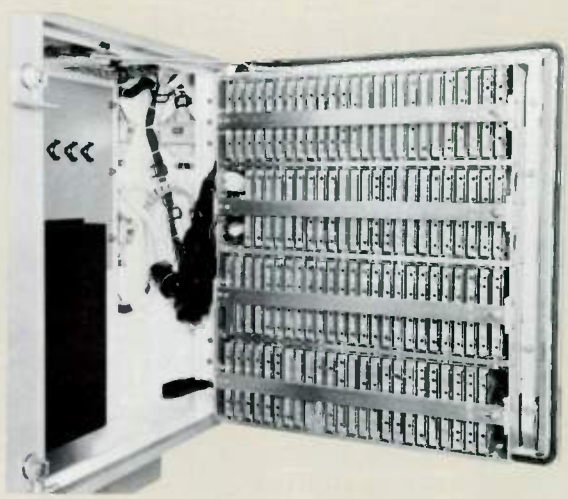


Fig. 2—The computer is subdivided into printed-card chassis, which are mounted on the cabinet doors and hinged on one side to provide access to chassis wiring at the back. The computer contains five such chassis, including input-output units, in addition to other subassemblies containing power supplies and memory circuits in the interior of the cabinet.

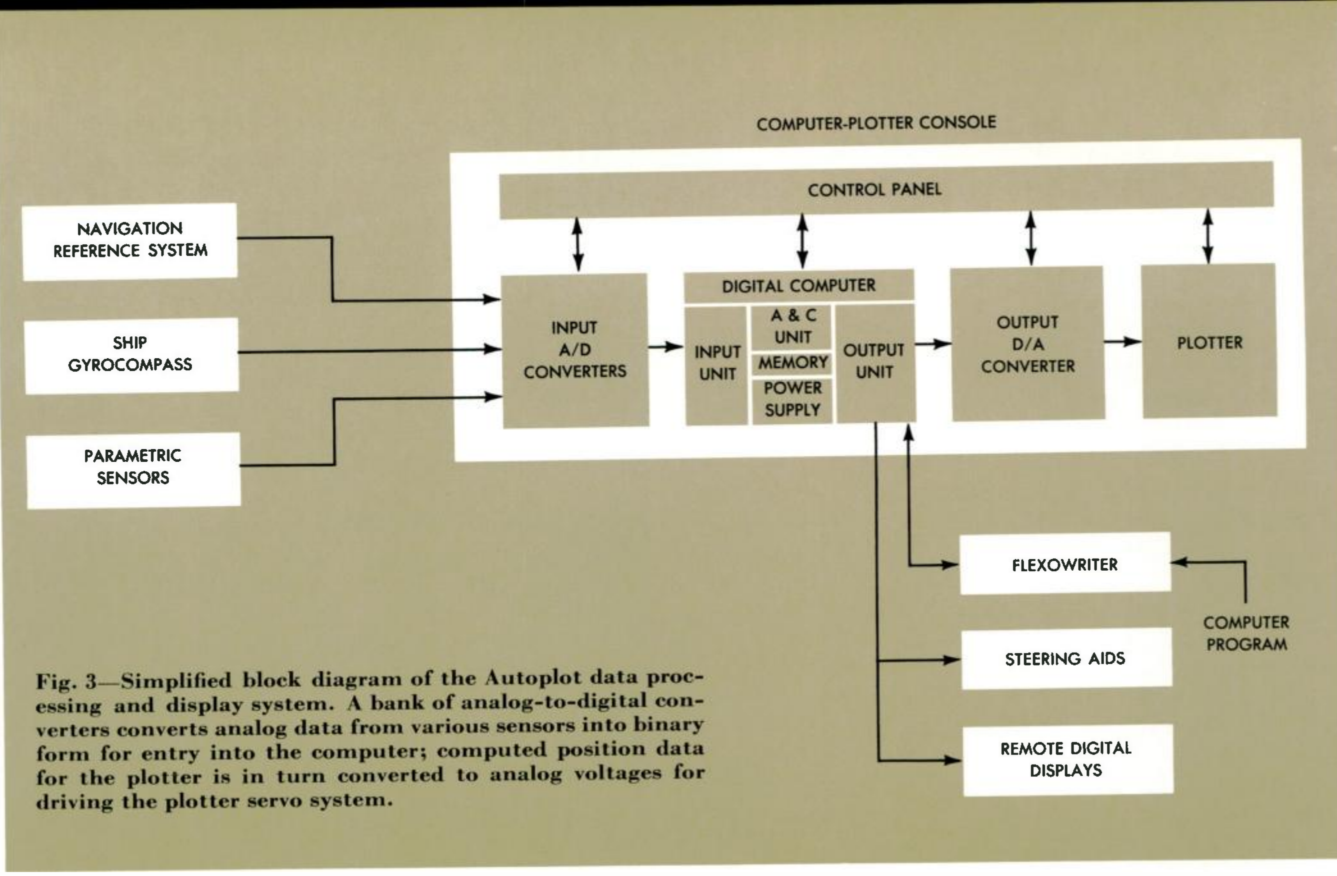


Fig. 3—Simplified block diagram of the Autoplot data processing and display system. A bank of analog-to-digital converters converts analog data from various sensors into binary form for entry into the computer; computed position data for the plotter is in turn converted to analog voltages for driving the plotter servo system.

position on a nautical chart. The navigational reference system may be any one of a number of radionavigation systems (such as Shoran or Loran), sonar, radar, dead reckoning, or some combination of these.

The function of the Autoplot computer-plotter in a typical navigational problem is illustrated in Fig. 4. Suppose that in a given survey operation, the ship is required to proceed along a survey line from A to B. The geographical positions of A (X_A, Y_A) and B (X_B, Y_B) are stored in the computer prior to the start of the operation. As the operation proceeds, the computer continuously computes from the incoming navigational coordinates the geographical position of the ship (x,y), which is then automatically plotted in real time on the x-y plotter. Simultaneously, the computed position is compared to the desired position (x',y') and error signals are generated to indicate distance off course (d) and distance to go to the end of the survey line (D). These distances are displayed numerically to the helmsman or conning officer as a ship steering aid. Positional data are simultaneously transmitted to the Flexowriter, which preserves the information to full digital accuracy in typewritten form and on punched paper tape.

The net accuracy of the instrument in the type of operation described, assuming suitable programming, is about one part in 18 000. This figure includes the shaft-to-digital encoders that convert the input information to digital form for entry into the computer. The computer itself is capable of about one order of magnitude higher precision. These accuracy figures refer to the output data preserved digitally; plotted data, because of the digital-to-analog conversion required, are accurate to one part in 1000.

Operational accuracy is clearly limited only by the quality of available navigational reference data. On either research or survey cruises, navigational control will be-

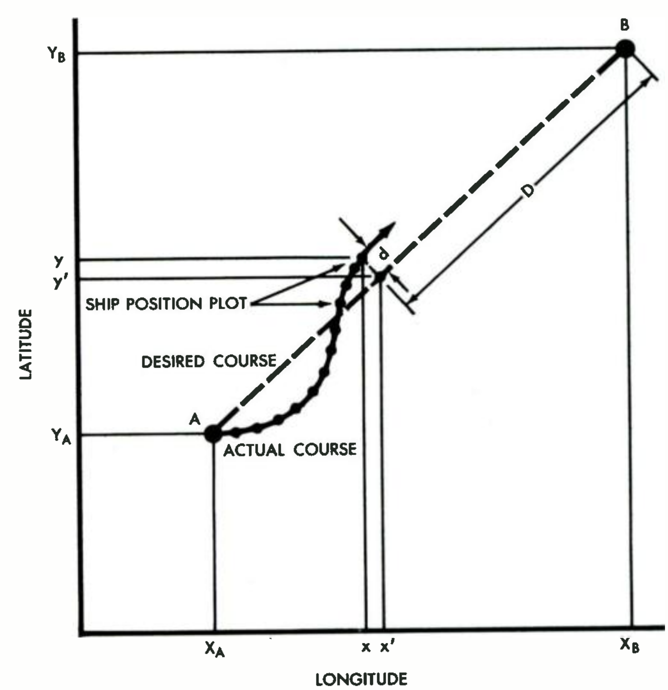


Fig. 4—Diagram of a typical navigational aid operation.

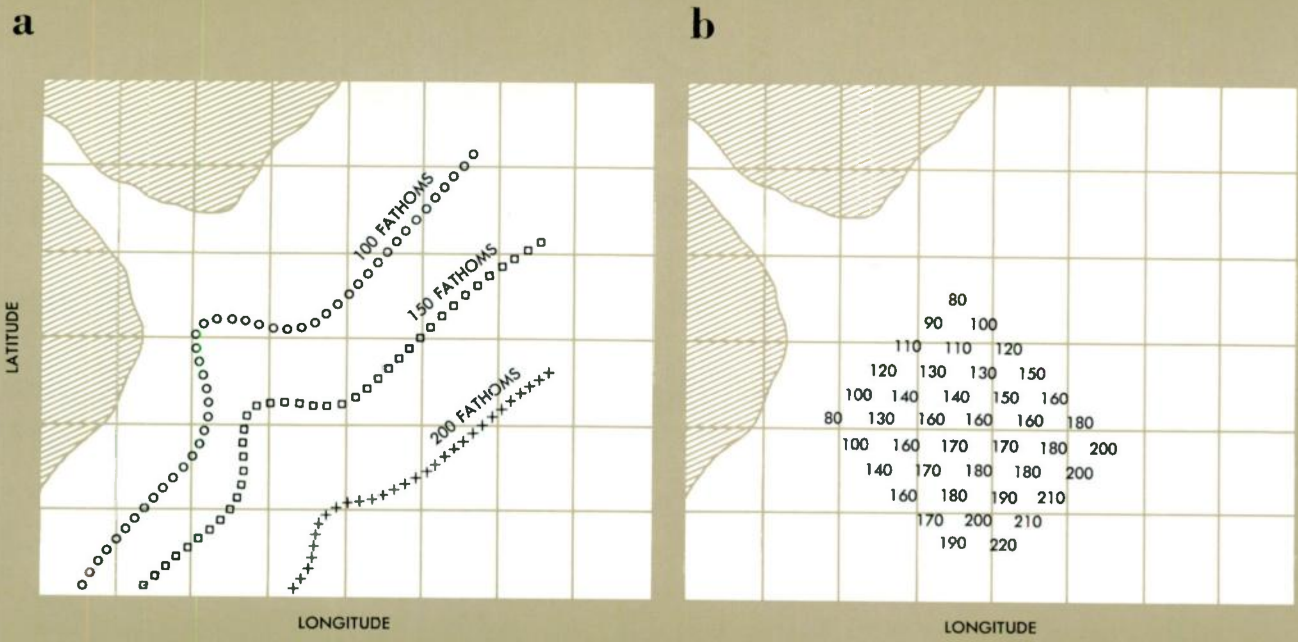


Fig. 5—(a) A depth contour plot can be generated in real time during a survey. The computer is programmed to recognize preselected contour intervals and plot them accordingly with chosen symbols. The symbol printer permits the use of any of twelve different symbols. (b) The printer can be modified to select and print numbers rather than abstract symbols to produce a hydrographic plot.

come increasingly important as more precise long-range navigational reference systems (such as the satellite navigation system[1]) become available.

Oceanographic Application

The computer program is the key to effective use of the instrument for oceanography. The computer can be considered a general purpose machine to the extent that the desired functions fall within its storage and arithmetic capacities. Programs that have been previously written, coded, and prepared on punched paper tape are loaded through the tape reader on the Flexowriter. Hence, a change from one mode of operation to another can be achieved with convenience and minimum down time. To make most efficient use of the instrument at sea, a library of program tapes can be prepared in advance for use under different conditions.

For example, when used for navigational control, the computer may operate in a dead reckoning routine between intermittent fixes from the navigational reference system. Therefore, the computer has time for additional tasks, such as oceanographic data reduction. A logical program for underway operation could include, in addition to the navigational control routine, routines for initial processing, recording, and plotting of bathymetric depth data. A bottom contour map that could be generated from depth data in real time during a survey is shown in Fig. 5a. The computer is instructed by its internal program to recognize preselected contour intervals and plot them accordingly with chosen symbols. Alternatively, the printer can be modified to select numbers rather than abstract symbols. This would result in a depth plot similar to a hydrographic smooth sheet, as shown in Fig. 5b. Other oceanographic data could be similarly plotted. Recording depth in this fashion is not a substitute for accurate recording of all data, by magnetic tape or other means, for final reduction ashore. It does, however, provide a convenient visual reference for the conduct of shipboard operations. Computer-generated hydrographic charts or contour plots can provide a quick look at the depth data on a geographic basis; interesting bottom contours can be visualized and detailed surveys can be planned immediately. To make this quick-look data as accurate as possible, the computer can be programmed to make corrections for vertical sound velocity variations and (if needed) refraction corrections for scanning sonars. Data for these corrections can be obtained from the best available bathythermograph or sound velocity information for the area.

For occupying oceanographic stations at sea, a different computer program can be inserted to allow the processing of the data from cable-lowered instruments and, if desired, the plotting of such data as a function of depth on the x-y plotter. Point plotting can be performed at rates up to one point per second.

Navigational control and oceanographic data handling can be substantially expedited and simplified by effective use of a multipurpose digital computer and display instrument, such as Autoplot. The instrument has been designed for reliable shipboard use, with sufficient accuracy for precise navigational control, and programming flexibility and reserve capacity for other tasks. Preliminary shipboard processing of oceanographic data can provide significant savings in two areas; cost of subsequent data reduction ashore can be lowered, and maximum use of ship time through rapid assessment of processed data is assured.

[1] "Ship Navigation with Satellites," E. S. Keats, *Westinghouse ENGINEER*, Jan 1963, p 23-6.

Modular Arithmetic . . . An Ancient Science for a New Computer

Mathematicians and computer designers are investigating an ancient but seldom used form of arithmetic for use in modern digital computers. Interest in modular (or residue class) arithmetic stems from the fact that no carries are required in addition and multiplication, whereas both decimal and binary arithmetic involve delays in transmission of carries from digit to digit. Hence, a computer operating under the rules of modular arithmetic could avoid the time-consuming steps of propagating carries from stage to stage, and deciding whether a previous carry causes a further carry.

The rules of residue arithmetic were not formally introduced into number theory until 1801, when the German mathematician and scientist, Carl Friedrich Gauss, set forth the *theory of congruences* in the early part of his most important work on number theory, *Disquisitions Arithmeticae*. However, many of the principles of modular arithmetic had been used for centuries for checking numerical calculations. Many of these checks were of ancient origin, dating as far back as the ancient Chinese. Sun-Tsu, in a Chinese work *Suan-ching* (arithmetic), about the first century AD, described one of the basic rules of modular arithmetic in the form of an obscure verse, from which the Chinese Remainder Theorem (to be described) gets its name. "Casting out nines" is based on modular arithmetic principles. Today, most of these numerical checks have gone out of use. But the digital computer, which often operates most efficiently in ways that are extremely backward to man, may put modular arithmetic back to work.

Modular arithmetic is based on a number representation that consists of a set of residues or remainders. For example, to represent a decimal number, a set of *moduli* are chosen which are pairwise prime (the greatest common divisor of any pair is 1), and whose product exceeds the number. For example, using moduli 2, 3, and 5, the modular representation of 25 is written:

$$25 \equiv 1,1,0 \pmod{2,3,5}.$$

This statement is expressed, "25 is congruent to 1, 1, 0 moduli 2, 3, 5," and means that 25 upon division by 2 leaves residue (remainder) 1, upon division by 3 leaves residue 1, and upon division by 5 leaves residue 0. The modular representation of decimal numbers 0 through 29 with this same set of moduli is illustrated in Fig. 1. Any set of consecutive numbers of length equal to the product of the moduli, in this case, $2 \times 3 \times 5 = 30$, can be represented uniquely.

The potential advantages of modular arithmetic come from the fact that arithmetic operations in one modulus are independent of those in another modulus. Thus, operations on numbers in modular form may proceed in parallel with respect to the various moduli with no delay for carries from one modulus to another. For example, to perform addition in modular arithmetic, residues with respect to each modulus are added independently and in modular fashion. To perform the addition $11+10=21$:

$$11 \equiv 1,2,1 \pmod{2,3,5}$$
$$10 \equiv 0,1,0 \pmod{2,3,5}$$
$$\therefore 11+10 \equiv 1+0,\ 2+1,\ 1+0 \pmod{2,3,5}$$
$$\equiv 1,0,1 \pmod{2,3,5}$$

which is the modular representation for decimal 21 (Fig. 1). (Note that since the residue for modulus 3 is $1+2=3$, the residue becomes 0.) If the sum is less than the product of the moduli (here, less than 30), this modular number may be reconverted to its unique decimal equivalent.

Multiplication by modular arithmetic proceeds in the same parallel fashion. For example, the product of $2 \equiv 0, 2, 2 \pmod{2, 3, 5}$ and $9 \equiv 1, 0, 4 \pmod{2, 3, 5}$ is:

$$2 \times 9 \equiv 0 \times 1,\ 2 \times 0,\ 2 \times 4 \pmod{2,3,5}$$
$$\equiv 0,0,3 \pmod{2,3,5}$$

which is the modular equivalent of decimal number 18 (Fig. 1). (Again, note that since the modulus 5 product ($2 \times 4 = 8$) is greater than the modulus, it becomes the remainder of 5 into 8, or 3).

Although a digital computer would normally use an adding process to perform subtraction, subtraction can be accomplished in this same modular fashion. Thus:

$$27-19 \equiv 1-1,\ 0-1,\ 2-4 \pmod{2,3,5}$$
$$\equiv 0,2,3 \pmod{2,3,5}$$

which is the modular equivalent of decimal number 8 (Fig. 1). (Note that when a modulus subtrahend is greater than the minuend, the modulus value is "borrowed.")

Unfortunately, while addition, subtraction, and multiplication are easily accomplished in modular form, other numerical operations are not so easy. This is illustrated by considering magnitude comparisons of modular numbers. For example, it is not immediately apparent with modular representation shown in Fig. 1 that $(0,1,3) = 28 > 3 = (1,0,3)$.

Likewise, division is much more difficult than the other three arithmetic operations, although methods for accomplishing division employing the other modular operations are known.

The Chinese Remainder Theorem—Numbers in modular form can be reconverted to decimal form via the Chinese Remainder Theorem. If we consider the modular number in its symbolic form, $N = r_1, r_2, \ldots, r_n \pmod{m_1, m_2, \ldots, m_n}$, where N is the decimal number to be represented, and r_i is the residue for each modulus m_i ($i = 1, 2, \ldots, n$), the Chinese Remainder Theorem can be stated: $N = c_1r_1 + c_2r_2 \ldots + c_nr_n \pmod{M}$, where M is the product of the moduli $m_1 \times m_2 \times \ldots \times m_n$, and c_i is an integer which must be derived: $c_i = b_i\, M/m_i$. The b_i integer must first be found by satisfying a congruence relationship:

$$b_i\ M/m_i \equiv 1 \pmod{m_i}, \text{ where } 0 < b_i < m_i.$$

DECIMAL	BINARY	MODULAR (MOD 2,3,5)	BINARY CODED MODULAR NUMBER		
0	0	0,0,0	0	00	000
1	1	1,1,1	1	01	001
2	10	0,2,2	0	10	010
3	11	1,0,3	1	00	011
4	100	0,1,4	0	01	100
5	101	1,2,0	1	10	000
6	110	0,0,1	0	00	001
7	111	1,1,2	1	01	010
8	1000	0,2,3	0	10	011
9	1001	1,0,4	1	00	100
10	1010	0,1,0	0	01	000
11	1011	1,2,1	1	10	001
12	1100	0,0,2	0	00	010
13	1101	1,1,3	1	01	011
14	1110	0,2,4	0	10	100
15	1111	1,0,0	1	00	000
16	10000	0,1,1	0	01	001
17	10001	1,2,2	1	10	010
18	10010	0,0,3	0	00	011
19	10011	1,1,4	1	01	100
20	10100	0,2,0	0	10	000
21	10101	1,0,1	1	00	001
22	10110	0,1,2	0	01	010
23	10111	1,2,3	1	10	011
24	11000	0,0,4	0	00	100
25	11001	1,1,0	1	01	000
26	11010	0,2,1	0	10	001
27	11011	1,0,2	1	00	010
28	11100	0,1,3	0	01	011
29	11101	1,2,4	1	10	100

Fig. 1—The modular representation for numbers 1 through 29 is shown for moduli 2, 3, and 5. In a digital computer, a certain number of bit spaces would be allocated to each modulus, as shown in the three right-hand columns. The space required to store a binary coded modular number (col. 4) is slightly greater than required for a binary number (col. 2).

MODULUS 3 ADDER TRUTH TABLE

ADDENDS	X	0	0	0	1	1	1	2	2	2
	Y	0	1	2	0	1	2	0	1	2
SUM	S	0	1	2	1	2	0	2	0	1

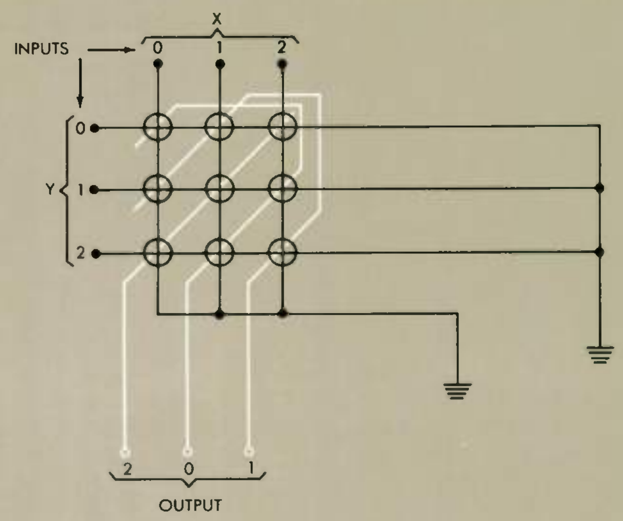


Fig. 2—Mechanization of the functions of modular addition and multiplication can be readily accomplished with magnetic core matrices. A modulus 3 matrix adder is shown here. The cores are coincident-current cores which will produce an output pulse on the proper output sense line when current pulses appear coincidently on X and Y input lines. Since residues will normally be stored in binary notation in memory, decoding and encoding networks are required to communicate between the arithmetic unit and memory. Matrix modular multipliers can be constructed in a similar fashion.

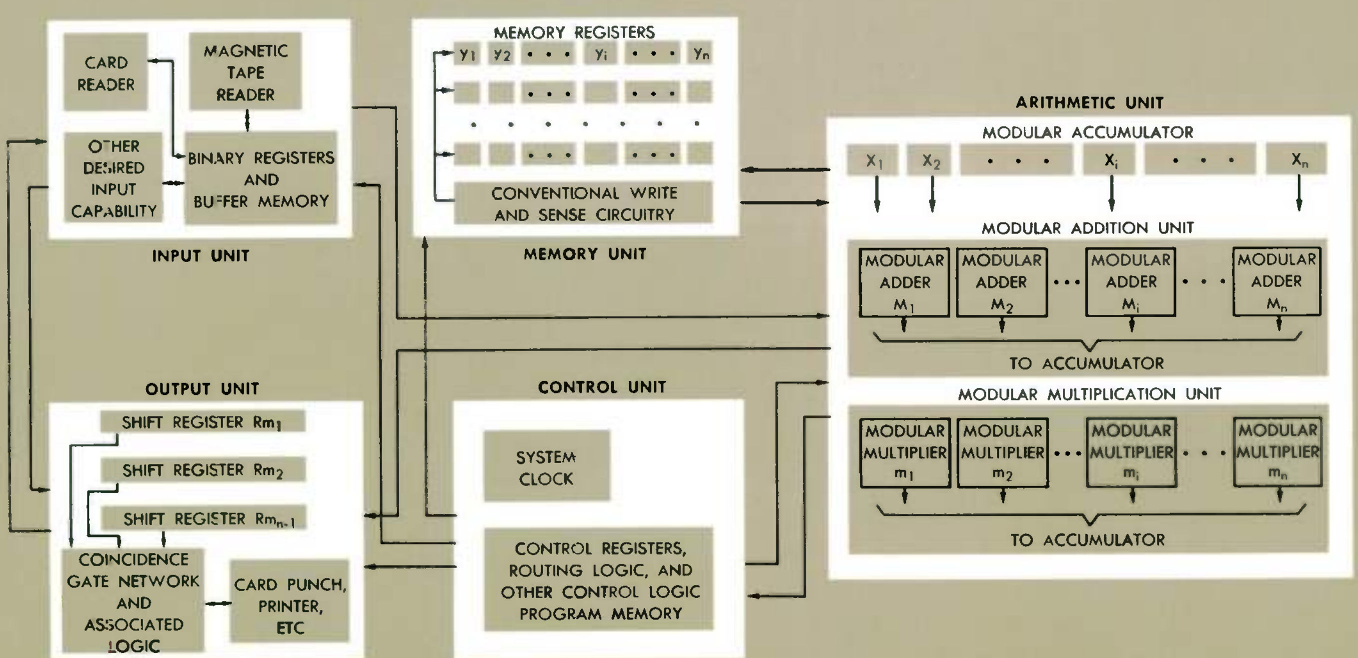


Fig. 3—Simplified diagram of a modular arithmetic computer.

The operation of this theorem can be illustrated by considering a numerical example, $N \equiv 1, 2, 3$ (mod 2, 3, 5). (From Fig. 1, note that this is the modular expression for decimal 23.)

Applying the Chinese Remainder Theorem, $N \equiv c_1 1 + c_2 2 + c_3 3$ (mod $2 \times 3 \times 5$). First solving for the c_i constants:

$$c_1 = b_1 30/2 \equiv 1 (\text{mod } 2).$$

As previously stated, b_1 must be chosen in the range, $0 < b_1 < 2$, to satisfy the congruence (i.e., provide a remainder of 1 for the term b_1 30/2 when divided by the modulus 2). We see that $b_1 = 1$ will satisfy the congruence, so that $c_1 = 15$.

The constants c_2 and c_3 can be similarly determined: $c_2 = (b_2\ 30/3) \equiv 1$ (mod 3), and $c_3 \equiv (b_3\ 30/5) \equiv 1$ (mod 5), so that $c_2 = 10$ and $c_3 = 6$.

Substituting these constants in the Chinese Remainder Theorem, $N = (15 \times 1) + (10 \times 2) + (6 \times 3)$ (mod 30). Since the residue must be less than modulus 30,

$$N \equiv 53 - 30 \ (\text{mod } 30), \text{ or}$$
$$\equiv 23 \ (\text{mod } 30).$$

Hence, the unknown number is 23. Once the c_i constants have been determined for a given set of moduli, they can be used in the Chinese Remainder Theorem to decode any modular number that is expressed in terms of these same moduli.

This description of modular arithmetic has been necessarily abbreviated, but it illustrates the basic advantage of modular arithmetic: Arithmetic operations in one modulus are independent of those in another modulus, so that operations on numbers in modular form may proceed in parallel with no delay for carries from one modulus to another. With proper mechanization of modular adders and multipliers, either function can be performed as a single pulse operation. One method is illustrated in Fig. 2. Thus, a modular computer is potentially much faster than an equivalent conventional computer. Furthermore, straightforward operations of addition and multiplication yield a result containing the same number of digits as the original data, providing the same order of precision.

A Modular Arithmetic Computer

The fundamental elements of a modular arithmetic computer are shown in Fig. 3. A number is placed in the computer by reading it into a binary input register, probably from magnetic tape. This binary number is fed simultaneously to each modulus element in the arithmetic unit, where a residue is independently calculated for each modulus, and placed in memory in binary code. All of the arithmetic operations can now be performed in parallel for each modulus.

Output is obtained by converting the modular number back into decimal (or binary) form. This can be accomplished in a number of ways. One of the fastest methods employs the Chinese Remainder Theorem. Since the c_i values are fixed quantities for any particular set of moduli, these constants can be permanently stored in computer memory, to be retrieved when required. An even faster conversion can be obtained by storing all possible $c_i r_i$ values, since there are only m_i possible values for each modulus $[0, 1c_i, 2c_i \ldots, (m_i - 1)c_i]$. If these constants are stored in read-only memory, the conversion process is a series of memory retrievals and additions.

Obviously, three moduli such as 2, 3, and 5 do not give enough range to solve practical problems, and a modular arithmetic computer would require many more. If, for example, the moduli consisted of primes 2 through 31 (2,3,5,7,11,13, etc.) the machine would have a number range of about 10^{11}. The reconversion approach just described would require storage of 150 predetermined $c_i r_i$ constants of about 40 bits each, or a total of 6000 bits.

Note that in Fig. 1 the number of bits required to store a binary coded modular number is greater than for a straight binary number.

Modular Arithmetic Research

At the Westinghouse Air Arm Division, designers of advanced data processing systems, under the direction of Dr. D. L. Slotnick, are presently investigating techniques and computer systems for using modular arithmetic. Some typical problems under study include division, overflow, conversion of binary or decimal numbers from or to modular form, magnitude comparison, and the development of suitable residue class computational methods.

A modular arithmetic simulation program has been developed by Air Arm engineers as an experimental tool for investigating the practical application of a modular arithmetic computer. The functions of a modular arithmetic computer are simulated on a conventional IBM 7090 digital computer, and normal arithmetic subroutines are replaced by their modular counterparts. Computer engineers are presently using this simulation program in their search for radically new numerical procedures that will permit them to take full advantage of the unique properties of modular arithmetic.

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Mine Hoist Drives

Clark B. Risler and Walter E. Thomas,
Mining Systems Engineers, Industrial Systems,
Westinghouse Electric Corporation, Pittsburgh, Pennsylvania.

These vital electric drives are continually improved to keep pace with the technological developments occurring in other mine subsystems.

A modern mine is a material-handling system that begins with extraction of ore at the working face and ends with delivery of the shipping product. Hoist drives are integral parts of this system. While they may appear to operate as independent entities, they must be coordinated with and integrated into the physical flow of material, and they must be compatible with the electrical loads and power supplies of the other mine subsystems.

Many factors influence the choice of a mine hoist drive system; the main ones are shaft depth, desired capacity, type of duty (production or service), type of operation (manual or automatic), available power supply, mine life expectancy, and various economic considerations. Consequently, the drives cannot be bought "off the shelf" but must be tailored to the requirements of the job. The result is that several drive systems have been developed. These fall into two main categories—dc adjustable-voltage drives and ac drives.

DC Drives

The dc adjustable-voltage, or Ward-Leonard, system has long been the "Cadillac" of drives for mine hoists. (See Fig. 1.) It is a premium drive, with its reputation for reliability, flexibility, and performance well established. It is readily adjusted in the field to meet changing hoist requirements resulting from changing mining patterns.

The drive consists of a dc motor driven from a dc generator powered by an ac motor (Fig. 2). Hoist speed is controlled by adjusting the excitation—and thereby the output voltage—of the dc generator.

Such drives range from 50 to 7000 hp, with motor speeds from 1750 to 70 rpm. Motor speed is related to hoist speed, required drum diameter, and gear ratio. For long-range projects and where minimum maintenance and maximum reliability are foremost considerations, direct-drive ("first-motion") hoists with motors of 70 to 100 rpm are used. (The armature is connected to the hoist drive shaft, with no intermediate gearing.)

In the lower horsepower range (50 to 250), the dc power loop between the generator and motor is generally operated at about 250 volts at full speed. In larger ratings, it is 700 volts. The higher voltage permits use of smaller cables or buses in the dc power loop. Prefabricated bus duct is often used when the m-g set and hoist drive motors are in the same building.

Motor-generator sets with synchronous motors are used with the larger hoists since they can be operated at a leading power factor, which improves the system power factor. In smaller hoists where the power-factor correction would not be significant, squirrel-cage induction motors can be used. This reduces initial costs in the ac motor and its starting equipment.

At remote locations, the power supply is sometimes unable to accommodate the cyclical fluctuations in power demand associated with mine hoist operation. As a corrective measure, a large flywheel can be installed between the driving motor and the generator. (The driving motor must be a wound-rotor type with adjustable external secondary resistance.) The m-g set can then slow down during heavy power demand to use the stored energy in the flywheel instead of drawing these power peaks from the electrical source. Such a drive requires an elaborate regulating system for controlling the power demand of the wound-rotor motor. Initial cost and higher maintenance requirements speak against the use of flywheel m-g sets where they can be avoided. Modern developments in regulated control systems and improved electric-utility power systems have largely eliminated the need for flywheel m-g sets.

Hoists can have either single- or multimotor drives. A single high-speed motor is most economical for smaller hoists, but, as hoist sizes increase, problems of balancing stresses and maintaining practical pinion and gear sizes exceed the added cost of multiple motors. Twin generators are used with dual-motor drives, and the motors and generators are connected alternately in the adjustable-voltage power loop.

Besides the mechanical advantages of a dual drive, spare parts for the rotating apparatus are of smaller ratings and thus less expensive. It is sometimes possible to provide interchangeable parts for the dc motors and generators. Further, if one motor requires attention, hoist operation can be continued with a single motor driving at rated speed with reduced skip loading. If a generator requires attention, it can be cut out of the loop and the hoist operated with normal loading but at reduced speed.

The smaller hoist drives (50 to 150 horsepower) lend themselves to a package type of construction in which the m-g set is in the same cabinet as the control equipment. This reduces space and wiring requirements, and concentration of equipment encourages effective maintenance.

Excitation and control systems have been improved through the years. In the early stages, generator field excitation was maintained at the desired level by fluttering relay systems. These were complex and required considerable maintenance. They were followed by rotating regulator-exciter systems (Rototrol) that gave improved control characteristics, such as current limit and voltage regulation, and reduced maintenance. Static magnetic amplifiers began to replace rotating regulators about 1949, although their limited output capacity necessitated retention of rotating exciters for the final stage of generator field excitation. Magnetic amplifiers also were used to supervise acceleration and deceleration rates and regulate speed instead of loop voltage.

Transistors and silicon controlled rectifiers now provide completely static solid-state excitation and regulating circuits. Their use improves regulator performance and reduces the number of moving parts. The ignitron type of static ac-to-dc conversion equipment has been applied in Europe as the source of adjustable-voltage power, replacing the m-g set. Rapid strides are being made in this country in developing solid-state power devices; with the development of larger ratings, the m-g set will be supplanted here also.

AC Drives

These need no ac-to-dc conversion equipment and consequently are simpler and less expensive than dc drives. The ac system consisted initially of the most fundamental reversing drive under manual control (Fig. 3a). This was a constant-potential system in which the full ac voltage (220 to 4160 volts, depending on horsepower rating and available power supply) was applied to a wound-rotor motor. Motor speed and torque were controlled by adjusting the secondary resistance and by applying reverse excitation (Fig. 3b). Hoist performance with this drive depended entirely on the operator's adeptness in manipulating the brake and control. The system was simple, it was inexpensive, but it suffered from performance limitations. Speed control at subsynchronous speeds with overhauling loads required careful manipulation by the operator since reverse motor excitation was required to develop hold-back torque.

The first step in refinement of this drive is use of an eddy-current brake with regulated excitation, or a second ac motor, to control torque (Fig. 3a). (The simple ac-motor drive is unable to provide performance at less than synchronous speed, as required during approach to a dump or landing, without continued adjustment of the secondary resistance to compensate for supply-voltage fluctuations and varying load conditions.)

The field of the eddy-current brake is easily controlled to provide the "dummy" load torque needed to establish consistent net torque load on the motor and permit controlled operation at less than synchronous speeds without continual adjustment of the secondary resistance (Fig. 3c). This system found immediate acceptance in the smaller sizes (50 to 150 horsepower). It is easily adapted to existing manually controlled hoists and so is often used when those hoists are converted to automatic operation. Its main limitation is the need to dissipate energy absorbed by the brake, which at times requires liquid cooling.

The trend toward static systems in the late 1940's produced rapid strides in development of saturable reactors for controlling the primary voltage of wound-rotor motors. Such control gives construction and operation advantages because the ac power is used directly, with no additional main rotating devices. The reactor type of control system is based on the principle that the torque of an ac induction motor varies as the square of the motor voltage. Hence, by

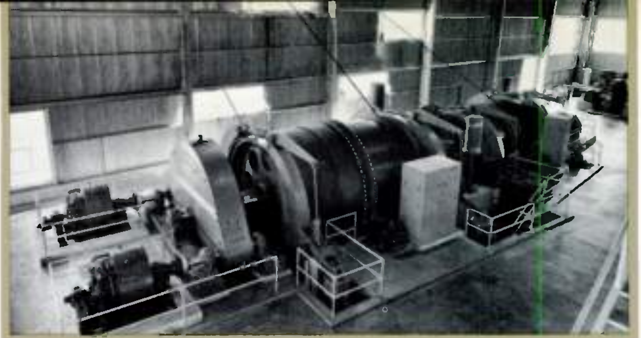


Fig. 1—Production hoist (left) and service hoist (right) at the Inspiration Consolidated Copper Company mine near Christmas, Arizona, have dc drive systems. Two 700-hp motors drive the automatically controlled production hoist, and one identical motor drives the semiautomatic service hoist. Advance Selector programmers are in the cabinets in front of the hoist drums.

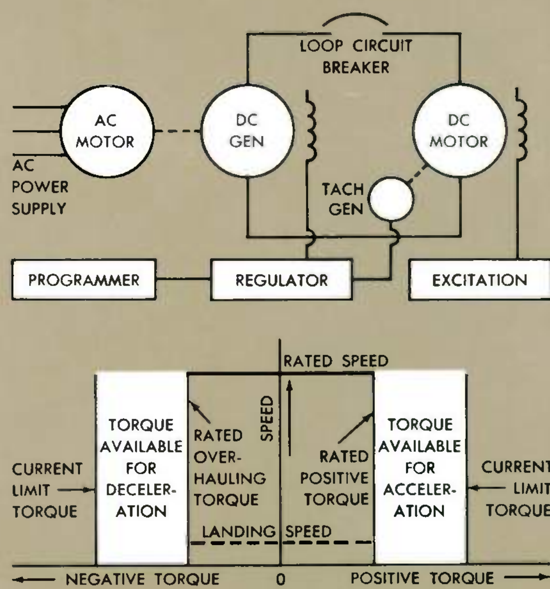


Fig. 2—Schematic arrangement and performance characteristics of a modern dc adjustable-voltage hoist drive. Hoist motor speed and torque are controlled by regulating generator output voltage. The regulator, in this example, includes current-limit circuits to protect electrical and mechanical parts of the system. A programmer supervises hoist functions for automatic operation.

regulating the applied voltage as a function of desired speed, motor torque can be adjusted to meet the requirements of the load and provide the desired speed. Saturable reactors in the motor primary leads control the motor voltage (Fig. 4).

The saturable reactors consist of a magnetic core with an ac winding and a dc winding. The ac winding carries line power to the motor. The dc winding is excited by adjustable dc control current from the regulator or programming system. The control circuits accurately adjust the saturation of the reactors and hence their impedance, and the impedance controls the voltage applied to the motor.

Besides speed and torque control, the reactors can reverse the phase rotation (sequence) of the ac power and thereby reverse the motor—all without primary contactors. This system has fewer secondary contactors than other ac systems because it requires less stepping of secondary resistance. Thus, it has a minimum of control components requiring maintenance yet provides performance close to that of the dc adjustable-voltage system.

This control is best suited to service-duty hoists (hoists for men and materials) and has been so applied at several mines in this country. It has also found application in other drives where performance is critical, including the passenger incline at Lookout Mountain in Tennessee, overhead cranes in nuclear power stations and manufacturing plants, and movable bridges.

Both investment and operating costs may be lower with ac hoists, especially in service duty. With a dc hoist, no-load losses, modest as they are, become a factor if the m-g set is kept running most of the time and the hoist is not used frequently. The ac hoist equipment is not energized unless the hoist is being used, so no-load losses do not exist. However, acceleration and deceleration of an ac drive is accompanied by greater power loss than with the dc system. In short, operating losses are greater with ac but no-load losses are lower; the economic choice can only be made for a specific application.

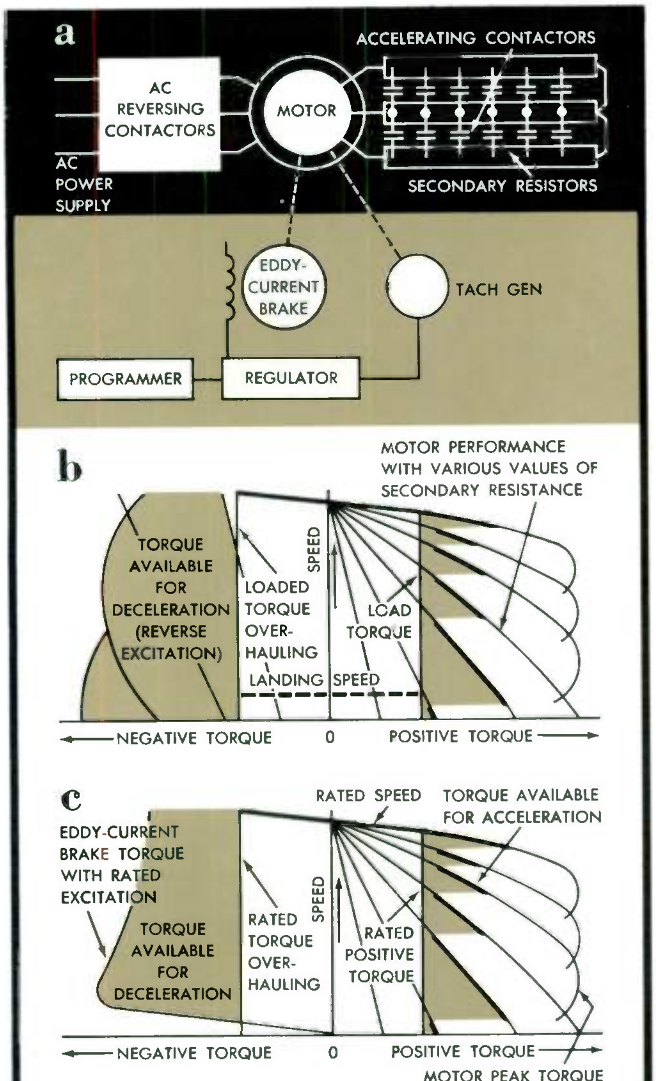


Fig. 3—(a) The fundamental ac drive is drawn in black; its evolution to an adjustable-speed ac drive by addition of an eddy-current brake with programmed excitation is shown in color. (b) Manual control with overhauling loads at subsynchronous speeds is difficult because it requires continuous adjustment of secondary resistance and reverse excitation. (c) The brake provides consistent net torque load during slow-speed operation and thus permits control without adjustment of secondary resistance.

Modes of Operation

Production hoists (hoists for bulk mine product) need continuous repetitive performance for maximum productive capacity, so they benefit from completely automatic operation. In such operation, every trip is initiated automatically when the skip has been loaded. Acceleration to full speed, after carefully leaving the loading and dumping mechanisms at reduced speed, is programmed by the electric control system. Deceleration when approaching the dump or other stopping location also is carefully programmed for safe consistent operation independent of skip load or direction of travel. Semiautomatic control differs from full automatic control only in that each trip is initiated manually by an attendant at the loading station.

The programming and regulating systems must duplicate all the functions of a hoist operator, who is quite a busy man. He starts the hoist in the proper direction and with the proper acceleration, detects overspeed by listening to the drive, detects overheating or mechanical difficulties by smell or noise, and even serves as a data logger. Duplicating these functions properly in automatic programmed control equipment has required considerable development, since safety and reliability are of prime importance in mine hoists.

Service hoists are used intensively during shift changes, but only occasionally the rest of the day. However, transportation is required for inspectors, fire bosses, and material—the hoist must be available at all times. Consequently, semiautomatic control is desirable. It gives riders immediate access to the hoist without having to wait for the hoistman's attention. Some systems permit the rider complete control of speed and direction.

Modern automatic and semiautomatic hoists also need manual speed control occasionally, as when making initial adjustments, handling special loads, and inspecting ropes and shafts. Vertical operating panels are convenient for this purpose. Only one operator control lever is needed, since the brake is actuated electrically through the hoist control system.

Mechanical Design Considerations

Mechanical design exerts considerable influence on the drive system. Fixed-rope hoists (rope attached to drum) were used exclusively for many years. These included clutched and unclutched varieties, and the drums were cylindrical, conical, or combinations thereof. Conical drums moderate the acceleration requirements, but they impose limitations on hoist travel and so are largely suited for installations where the life of the hoist is devoted to operation between two permanent levels. Clutched drums often have to operate unbalanced, with one drum unclutched and the other available, as when changing operation from one level to another or correcting for rope elongation. Also, emergency conditions may require operation of only one loaded conveyance. The drive system must be sized to meet such special requirements.

The more recent Koepe or friction-type hoists introduce additional considerations. Torque application to the friction wheel must be held within limits determined by the friction characteristics and basic design parameters of the wheel. Here, the torque-control feature that is available with today's sophisticated regulating systems is most advantageous.

Rope creep, inherent with a friction-wheel drive, requires the use of a recalibrating device to reestablish periodically the proper orientation between the skips or cage and the hoist-driven safety and programming devices. The recalibrator, or resynchronizer, is an electromechanical device inserted in the mechanical drive system between the hoist and the safety and programming equipment. During normal running, it transmits the motion from the hoist drive to the safety and programming equipment. When the skips or cage are stopped at a landing by direct-acting switches in the shaft, it senses any discrepancy between the position of the programming equipment and the actual position of the conveyance. A small motor in the recalibrator then corrects the position of the programming equipment.

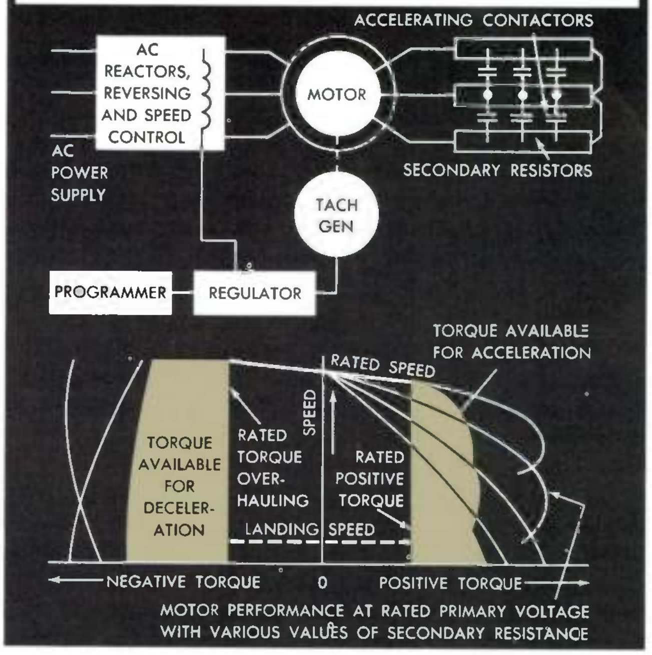
Regulation and Programming

Speed regulation is required in most hoist control systems, ac and dc, to optimize performance by providing consistent operation independent of loading variations and ambient temperature. A tachometer generator driven from the hoist machine supplies a signal to the hoist programming control in proportion to hoist speed. A speed regulator compares this feedback signal with the programmed speed signal and acts to produce the proper hoist speed.

Current-limit protection (which is torque-limit protection) is built into the drive systems to prevent overstressing of the electrical and mechanical equipment when handling extreme loads, as during maintenance or emergency. In a dc system, this feature is incorporated in the regulator as a separate control winding. In an ac system, the basic design of the motor plus the secondary resistor values and the stepping of this resistor establish a maximum envelope of speed-torque performance that inherently gives the required torque limit.

One of the operator's functions with a manually controlled hoist is to maintain desired rates of acceleration and deceleration. He senses whether the net load on the hoist is contributing to acceleration or deceleration and whether a contribution of positive or negative torque is required from the motor. With this information, he manipulates the controls in such a manner as to obtain the desired rate of speed change. Degree and type of experience, fatigue, natural caution, and other human factors affect the operator's performance at the controls.

Fig. 4—The ac adjustable-voltage system provides still further improvement in ac drive performance and simplicity. Saturable reactors adjust the value and phase sequence of the motor primary voltage. Fewer secondary contactors are required.



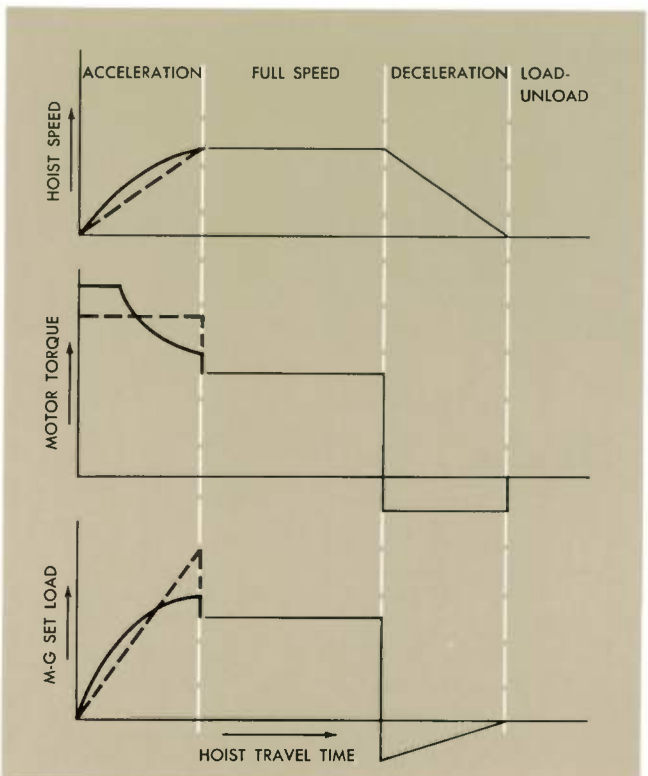


Fig. 5—Power peak limit control reduces the peak power drawn by a dc drive without diminishing productive capacity. Performance is compared here for a drive with constant accelerating rate control (dashed line) and one with power peak limit control (solid line).

With an automatic or semiautomatic hoist, the speed-change functions are performed by an acceleration and deceleration programmer. This is a static circuit, adjustable to permit separate rates of acceleration and deceleration. Many programming methods are available. Direct-actuated limit switches that indicate the conveyance positions for acceleration, deceleration, stop, and so on are the best from the standpoint of hoist performance. However, such devices located in the shaft are often difficult to adjust and maintain and are more vulnerable to mishap than are devices located in the hoist room; for this reason, programming equipment is often geared to the hoist machine. The equipment can be cam-operated switches or the more highly developed Advance Selector. (See Fig. 1.)

The Advance Selector was adapted from the elevator industry; it reproduces in mimic the travel of the conveyances in the mine shaft. The mock conveyance is advanced in shaft position with respect to the actual conveyance, with the "advance" in proportion to the hoist speed. The control system thus anticipates approach of the conveyance to a desired stopping position and initiates slowdown at the optimum shaft position.

For spotting accuracy, and to eliminate the effects of rope stretch and rope creep, all final stops must be initiated by a limit switch in the shaftway that detects the actual presence of the conveyance. The switch can be lever operated or a magnetic proximity type.

With the rapid development of digital measuring and indicating devices, it is certain that some or all of the programming decisions in complex applications will soon be performed by digital control devices. Pulse generators driven from the hoist will signal precisely the number of turns (or degrees of rotation) made by the hoist, and the control equipment will then determine the speed, position, and direction of travel of the conveyances. Simple numerical computers will interpret this intelligence to control the drive. The extent to which such equipment can supersede the electromechanical controllers presently used remains to be seen. These devices have provided reliable overspeed and overtravel protection for many years, and it may be some time before other equipment completely supersedes them.

Communication and Remote Control

With manually controlled service hoists, the rider signals the operator in the hoist house to deliver the cage to his landing. The rider then signals where he wishes to go and the hoistman delivers the cage to the destination. As a refinement, some hoists have cage telephones to give riders greater control by permitting communication with the hoist operator. The telephones are operated through trailing cable, through small wires embedded in the hoist rope, or through an electronic high-frequency carrier system. The carrier system uses the hoist rope to transport the signal, and an antenna-receiver system in the head frame transfers the signal to the hoist house.

For semiautomatic operation, riders should have direct control of the hoist from the cage. This permits them to withhold the start signal until the cage is properly loaded, and it facilitates shaft inspection and maintenance. Direct control requires trailing cable or the carrier system, both of which have been used successfully.

Trailing cable is a considerable problem in a deep shaft because it is subject to wear and abrasion. It also proves a handicap if special machinery loads are to be slung under the hoist cage. Carrier systems range from simple start-stop and directional control up to more advanced systems in which destination is selected with pushbuttons in the cage. The advanced systems use coded signals superimposed on the high-frequency carrier base. Reliable decoding equipment of the telephone type interprets the signals and forwards the intelligence to the hoist control.

Power System Considerations

Mining properties are usually located far from the large population centers where "stiff" power systems are found. Therefore, the nature of the power supply must be considered in the design of the hoist drive.

In the dc systems, use of a synchronous ac motor in the main m-g set provides reactive volt-amperes to the power system to correct power factor and stabilize system performance. Additional equipment can be provided to adjust the power factor compensation continuously. This equipment increases the field excitation of the synchronous motor when the load current drawn by the motor increases. It also can be arranged to reduce the motor field excitation when load current drops below normal. Increasing the leading volt-amperes when the heavier peak loads are drawn aids power system stability and has, on occasion, permitted the use of a synchronous m-g set with appreciable savings where otherwise a flywheel m-g set would have been required.

The compensator sometimes is used only to increase the field when operating above normal motor current, without reducing excitation when operating below rated current. This is advantageous when the m-g set drive motor is relatively large. The compensator permits maintaining the amount of corrective volt-amperes at a high level to compensate for the highly inductive load of a coal-cleaning or ore-processing plant that may be located nearby.

It is also possible, with dc drives, to include control circuits that reduce the peak power drawn by the hoist without decreasing productive capacity. This is accomplished by accelerating most rapidly at low speed and then progressively reducing the torque available for acceleration as speed increases (Fig. 5). A recent application of this power-peak-limiting control at a Midwest iron mine reduced the peak power loads drawn by the synchronous motor every trip from more than 4340 horsepower to 2855 horsepower.

Conclusion

As soon as new electrical devices have been proved adequate for the rigid requirements of mine hoist duty, they have been incorporated into hoist drive and control systems. The caution used in applying new ideas indicates the importance placed on safety and reliability. However, the unending development of new devices and new concepts in the electrical art assures constant improvement in drive performance. Much progress is being made in automation of beneficiating plants and in underground mining practices; as the vital connecting link, the completely programmed automatic mine hoist will be continually improved.

Thermoelectric Temperature Control

T. D. Merritts and J. C. Taylor, Semiconductor Division,
Westinghouse Electric Corporation, Youngwood, Pennsylvania.

This is often the most flexible, practical, and reliable method for regulating the operating temperature of electronic components.

Thermoelectric cooling and heating—the Peltier effect—has been known for 130 years, but practical applications have had to wait for the development of high-performance semiconductor materials. These materials are now available, so thermoelectric temperature control has become practical for a wide variety of uses.

This temperature control method is extremely flexible because it can be used in systems that have to operate in various ambient temperatures and deliver various controlled temperatures. It can provide temperature control requiring only cooling, only heating, or both cooling and heating. This article deals with devices that provide both heating and cooling because most applications require that ability and also because such devices most fully illustrate the principles involved.

One of the most important applications is in temperature stabilization of electronic reference components in industrial and military systems. Because many electronic components are temperature sensitive, their surrounding ambients must be regulated at some constant value to ensure proper stability and satisfactory system performance.

The most important advantages of thermoelectric elements are excellent temperature stability and ability to control the temperature surrounding an electronic component below, as well as above, the external ambient. (Controlling temperature well below the maximum external ambient retards aging of the electronic component.) Another advantage is the absence of moving parts, with consequent silent operation and inherent reliability. Compactness and design flexibility make it possible to design the devices to fit small irregular shapes and sizes. Finally, cooling and heating rates are controllable with present control systems and techniques.

Peltier Effect

The basic element of a thermoelectric heat-pumping device, the thermoelectric couple, is diagrammed in Fig. 1. It consists of two arms or pellets, one of n and the other of p type semiconductor material, joined at one end by a copper strap and connected at the other end by copper straps to an external current source. When current passes through the couple, the majority carriers (electrons in the n type and positive holes in the p type) experience a change in energies in crossing the contacts or "junctions." The reason for the change is that applying an electric field to the couple causes a difference in average energy levels of the moving carriers in the metal and in the semiconductor materials. The result is that the majority carriers absorb heat from one side of the couple and release this heat at the other side, so that the top copper strap (in Fig. 1) is cooled and the lower straps are heated. This is the Peltier effect. Reversing the polarity (direction) of input current reverses the positions of the hot and cold junctions.

The voltage across the couple is proportional to the sum of the IR drop and the developed Seebeck voltage (a voltage caused by the temperature difference):

$$V = IR + \alpha_{np}(T_h - T_c),$$

where α_{np} is the Seebeck coefficient (inherent voltage generating ability) of the n and p type materials in series, T_h is the hot-side temperature, and T_c is the cold-side temperature.

The thermoelectric couple pumps heat from its cold side at a net rate of heat energy (Q) expressed by the relationship:

$$Q_{total} = \Pi I - \tfrac{1}{2}I^2R - K\Delta T,$$

where I is the input current, ΔT is the temperature difference from hot to cold side ($T_h - T_c$), Π is the Peltier coefficient (inherent cooling ability) of the cold junction, R is the total resistance of the n and p arms in series, and K is the thermal conductance of the arms in parallel. The first term, ΠI, represents the heat absorbed at the cold junction by the Peltier effect. The second, $\tfrac{1}{2}I^2R$, represents the approximation that half of the Joule heat is conducted to the cold junction where it subtracts from the Peltier effect, the other half being rejected from the hot side. The last term approximates the thermal conductance by a constant and the temperature along the arms by a linear distribution.

The Peltier coefficient can be represented by:

$$\Pi = \alpha_{np} T_c, \text{ so}$$

$$Q_{total} = \alpha_{np} T_c I - \tfrac{1}{2}I^2R - K\Delta T.$$

The figure of merit (Z), a measure of quality used when evaluating potential thermoelectric materials, is represented by:

$$Z = \frac{\alpha^2}{\rho k},$$

where α is the material's Seebeck coefficient, ρ the electrical resistivity, and k the thermal conductivity. Figure of merit can be expressed in the heat pumping equation:

$$Q_m = \tfrac{1}{2}ZKT_c^2 - K\Delta T,$$

where Q_m is maximum heat-pumping rate.

It is desirable to use a thermoelectric material that has low electrical resistivity to minimize Joule heat loss and also low thermal conductivity to minimize thermal conduction loss. A large Seebeck coefficient is desired because it is pro-

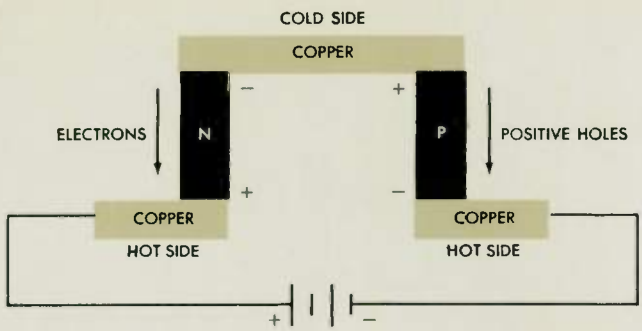


Fig. 1—The thermoelectric couple is the basic element in thermoelectric heat-pumping devices. Passing current through it causes majority carriers (electrons and holes) to absorb heat from one side and release it at the other side.

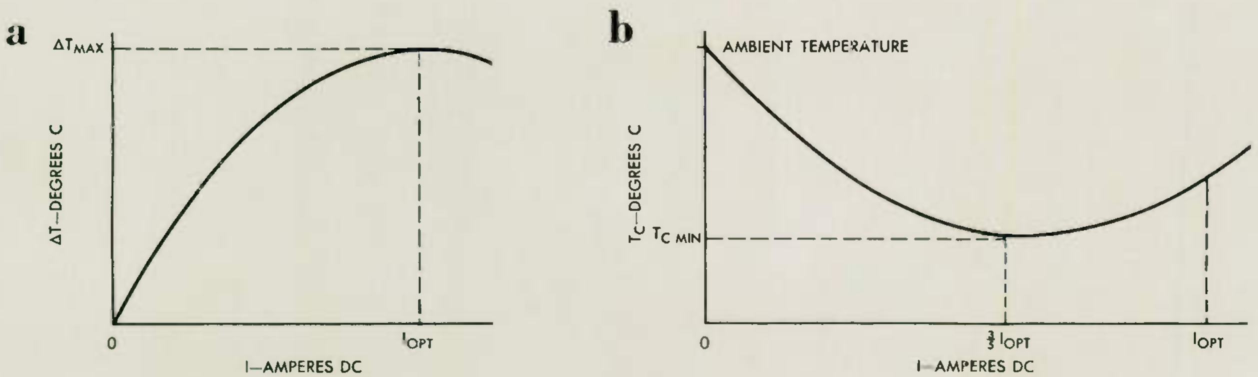


Fig. 2—(a) Increasing input current (I) up to an optimum point (I_{opt}) increases the temperature difference between hot and cold sides (ΔT). Then resistance heating and back heat leak overtake the cooling effect. (b) In practice, minimum cold-side temperature ($T_{c\ min}$) does not occur at optimum current because heat cannot be dissipated perfectly by the hot-side heat exchanger. The input current that produces minimum cold-side temperature with natural convection cooling of the heat exchanger is about $\frac{3}{5}$ I_{opt}.

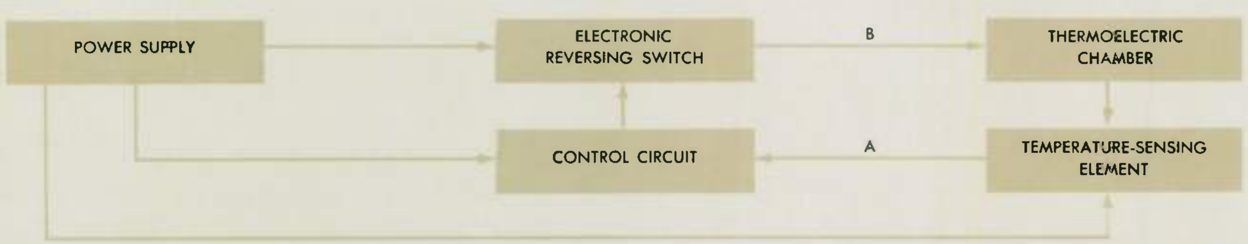


Fig. 3—The general relationships between the power supply, control elements, and thermoelectric chamber in a temperature-control system are diagrammed here.

Effects of Typical Thermoelectric Couple Area/Length Ratios on Optimum Current

AREA (cm^2)*	LENGTH (cm)*	AREA/LENGTH RATIO	OPTIMUM CURRENT (amps dc)
0.403	0.3175	1.270	60.0
0.403	0.635	0.635	30.0
0.1008	0.635	0.159	7.5
0.1008	1.270	0.0795	3.75

*Both arms of the couple have these dimensions.

portional to the gross cooling effect. It can be seen that the figure of merit (Z) is a function of temperature-dependent material parameters, which will be discussed shortly.

Optimum current (I_{opt}) is the current at which maximum temperature difference (ΔT_{max}) occurs between the hot and cold surfaces of a couple (Fig. 2a). Increasing the current flow above this value causes the I^2R heating and reverse heat leak to increase more rapidly than, and overtake, the useful Peltier cooling effect. This causes the temperature difference to decrease. Optimum current is a function of the geometrical and temperature-dependent material parameters but is independent of the number of couples used in a device.

Assuming for the moment that the mean temperature across a couple is held constant (say at 25 degrees C), the material parameters for a specific material can be assumed constant. Optimum current then will depend only on the geometrical parameter of area/length ratio (A/L), or arm ratio, of a couple, where A is the cross-section area in square centimeters and L the length in centimeters of each arm. Thus, as the value of the ratio A/L increases or decreases, the value of optimum current increases or decreases proportionately for a specific thermoelectric material. This effect is shown in the table for typical arm ratios that have been used in thermoelectric devices.

Increasing or decreasing the mean temperature also causes the optimum current values to decrease or increase.

From the preceding paragraphs, it would seem that thermoelectric couples should be operated at their optimum current values for maximum temperature difference. Unfortunately, this is not the case. A couple is a heat pump that pumps heat from the cold side to the hot side, and this heat must be transferred from the hot side to the surroundings by a heat exchanger. For minimum cold-side temperature to occur at optimum current, the temperature rise of the heat exchanger above ambient would have to be theoretically zero.

The heat-exchange mechanisms most often used are natural convection by air, forced convection by air, and forced convection by liquid. With a practical finned heat exchanger transferring heat by natural convection, the input current usually is approximately $\frac{3}{5} I_{opt}$ for minimum cold-side temperature. This effect is shown in Fig. 2b. If forced-air convection is used with the finned heat exchanger, the input current can be higher—approaching $\frac{4}{5} I_{opt}$—and thus provide a lower minimum temperature. When forced convection by water is used, the input current can be higher than $\frac{4}{5} I_{opt}$ for an even lower minimum temperature.

Thus, it is best to use water cooling or forced-air cooling whenever possible to minimize the temperature rise of the heat exchanger above ambient. This is not always possible or practical, however, so the designer must then design a fin that will transfer heat efficiently by natural convection. The upper size limit will be determined by the allowable dimensions of the fin and the lower limit by the allowable temperature rise of the fin above ambient.

Thermoelectric Temperature Control Systems

A general system is diagrammed in Fig. 3. The temperature inside the chamber is sensed by a thermostat or a thermistor. The control circuit can be a relay coil, mag-

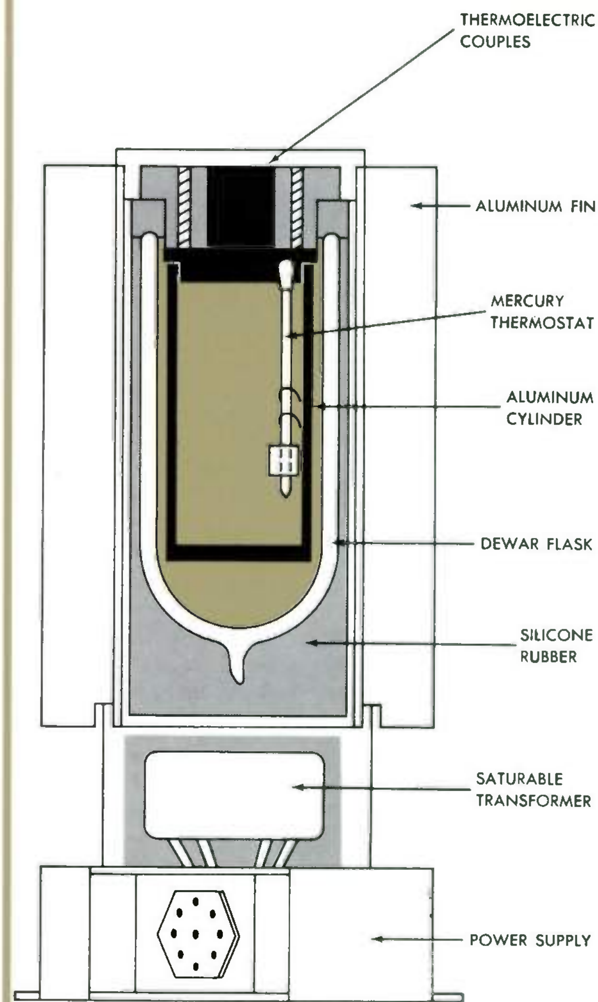


Fig. 4—A temperature-control chamber for a quartz crystal oscillator is shown here in section view. In use, the oscillator is housed in the inner aluminum cylinder.

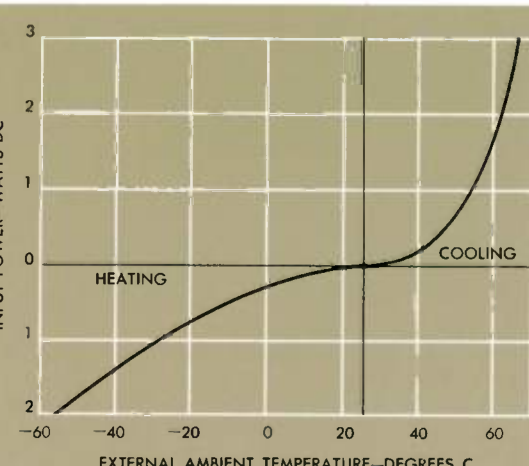


Fig. 5—This chart shows the input power required to keep the inner cylinder of the chamber illustrated in Fig. 4 at 25 (±1) degrees C through a wide ambient temperature range.

netic amplifier, transistor flip-flop, Schmidt trigger circuit, or similar device. The electronic reversing switch can be a double-pole double-throw relay, silicon controlled rectifiers, magnetic amplifiers, or high-power transistors. In the more sophisticated systems using a thermistor temperature-sensing element with a bridge, one or more error amplifiers can be provided at point A (Fig. 3) to increase the gain of the system. When the power supply consists of a full-wave center-tap stepdown transformer, a filter network must be placed at point B. The filtering is usually accomplished with high-current chokes.

The design considerations for a specific device, a chamber for thermoelectric temperature control of crystal oscillators, will serve to illustrate the basic principles that have been discussed.

This application was chosen for a feasibility demonstration because aging rate and frequency stability of quartz crystals are of prime importance when crystal oscillators are used as frequency references. The conventional method of controlling crystal temperature has been to house the unit in an oven that keeps the temperature surrounding the crystal at a constant value by resistance heaters. The disadvantage of this method is that the constant temperature must be higher than the maximum external ambient. Thermoelectric chambers provide both cooling and heating, so they can control the temperature surrounding the crystal well below the maximum external ambient. The aging rate of the crystal then is lower, and improved frequency stability and reduced power consumption can result under certain operating conditions.

Design objectives for the temperature-control chamber were: crystal oscillator heat load, 100 milliwatts; controlled temperature setpoint, 25 degrees C; temperature control tolerance, ± 1 degree C; ambient temperature limits, -40 to $+60$ degrees C; heat exchange by natural air convection; low power consumption.

The major heat load that has to be pumped for a crystal oscillator dissipating 100 milliwatts is heat leak entering through the chamber walls from the surroundings. Heat leaks in (at high external ambients) and out (at low external ambients) by conduction, convection, and radiation. The demonstration temperature-control chamber was designed to minimize heat leak by all three types of heat transfer (Fig. 4). A Pyrex dewar flask is the inner enclosure. It is a more effective heat barrier than insulating foams or powders, so fewer couples are required. This minimizes the input voltage and power, increases the useful temperature difference, and minimizes chamber size.

Most thermoelectric devices require more than one couple. The couples are connected electrically in series and thermally in parallel. The heat-pumping equation representing the cooling state is then:

$$Q_{hl}+Q_{pl}=n\ (\alpha_{np}T_cI-\tfrac{1}{2}I^2R-K\Delta T),$$

where n is the number of couples, $K\Delta T$ is heat leak flowing from the hot side through the couples to the cold side by conduction, Q_{pl} is the actual payload (100 milliwatts), and Q_{hl} is heat leak flowing through the chamber walls into the enclosure from the surroundings.

Since the Peltier effect is reversible, a chamber can be operated either as a cooler or a heater, depending on the direction of input current flow. During the heating cycle, the Joule heat generated in the couple (in the same way as in a conventional heater) adds to the heat pumped by the Peltier effect from the cold junction to the hot junction. This combined Joule and Peltier heating makes the couple more efficient as a heater than as a cooler, in terms of power utilization and temperature difference.

Minimizing heat leak improves heating performance as well as cooling performance. The heat-pumping equation representing the heating state is:

$$Q_{hl}=Q_{pl}+n\ (\alpha_{np}\ T_hI+\tfrac{1}{2}I^2R-K\Delta T),$$

where $K\Delta T$ is heat leak flowing from inside the enclosure (now the hot side) through the couples to the fin by conduction, $\alpha_{np}T_hI$ is the heat being pumped by the Peltier effect from the fin to the inside of the enclosure, T_h is the temperature of the fin base, and Q_{hl} is heat leak through the chamber walls to the outside surroundings. The $\frac{1}{2}I^2R$ and Q_{pl} terms now aid the heating cycle. (Although the fin is now the cold side, its temperature is still identified as T_h to prevent confusion.) Because the heating cycle is more efficient, it requires less design emphasis than the cooling cycle. The latter usually limits or determines the final chamber design.

The outside dimensions of the demonstration chamber are 3 inches by 3 inches by 4⅜ inches; overall height is increased to 6⁷⁄₁₆ inches with the addition of the power supply to the base of the chamber. The 12 thermoelectric couples each have ⅛-inch by ⅛-inch by ½-inch arms. Extruded vertical fins form the heat exchanger. The thin-wall dewar flask is evacuated to 10^{-7} mm of mercury and is potted in a silicone rubber compound as a shock absorber. An aluminum cylinder inside the chamber houses the crystal oscillator. The inside dimensions of this cylinder are 1 inch in diameter by 2 inches high.

The main reason for using an aluminum cylinder is to minimize the temperature gradient from top to bottom. However, some gradient is essential since heat cannot flow unless there are areas of lower temperatures to move into. Temperature changes occur continuously because of cooling and heating cycles, and these changes are not transmitted immediately throughout the system. As a result, there is always a temperature gradient between the heat source and the opposite edges of the system.

The highest external ambient at which this chamber is able to maintain the temperature inside the enclosure at 25 degrees C is 65 degrees C. At this ambient, the input power is 3.25 watts—2.50 amperes at 1.30 volts. The temperature of the fin base with natural convection is 73 degrees C, 8 degrees above ambient. Using average material parameters and experimental data in the heat-pumping equation, the calculated value of heat leak (Q_{hl}) for the chamber when operating at an ambient of 65 degrees C is approximately 0.80 watts.

Heat-pumping performance is illustrated in Fig. 5. This chart shows that input power is utilized most efficiently in the ambient temperature range from -40 to $+60$ degrees C, so this is the most practical operating range.

Power Supply and Control

The temperature difference in any thermoelectric device is influenced by the ripple of the dc input current. Any rms value of alternating components of the input current added to the average value produces Joule heating but does not pump heat. Thus, if the ripple factor is high, Joule heating tends to decrease the temperature difference.

The greatest temperature difference possible occurs when the percent ripple of the dc input current is zero. But designing a power supply that even approaches this value is impractical, especially when using high-current filter chokes. Therefore, a compromise must be made between obtaining a practical power-supply design (in space, weight, and cost) and losing a small percent of ΔT. The best compromise is a current ripple of approximately 10 percent. The temperature difference then is about four percent less than the greatest theoretical value.

In certain applications where direct current is the only available power source, or when high efficiency, small size, and minimum weight are important, static dc-dc power converters are used. Their basic function is conversion of a dc input voltage to a square-wave rectified dc output voltage lower than the source. Because of the square-wave output, no filtering is required to eliminate ripple. The power converter and temperature control for the demonstration chamber is diagrammed in Fig. 6.

A mercury thermostat, inside the chamber's enclosure and firmly attached to the cold-side plate, is the temperature-sensing element. A thin layer of a paste made of silicone oil and zinc oxide is included between the mercury bulb and the aluminum enclosure to minimize thermal lag between the controller and the thermoelectric couples. The paste also is used at joints between the enclosure and the couples and between the couples and fins.

Thermal lag is the enemy of accurate control because it withholds from the controller, for a certain interval, information about temperature changes in the system. The lag can prevent the thermostat from sensing cooling or heating demands in time to deliver the cooling or heating when needed. It also can delay the arrival of cooling or heating at the thermostat so long that the couples deliver more cooling or heating than the system needs. The results are temperature overshoot and undershoot. Thermal lag can never be entirely eliminated, but it can be minimized by placing the thermostat where it can sense important temperature changes quickly.

A miniature relay is used to switch the direction of the input current to the thermoelectric couples. The thermostat, which closes on temperature rise, is in series with the relay coil and controls the power (either on or off) that is supplied to the coil. This in turn controls the switching of the relay contacts for either cooling or heating power. This method supplies full power to the thermoelectric load, since there is no intermediate position. Thus, full heating or full cooling is supplied regardless of the external ambient value. The result is that the temperature surrounding the crystal oscillates continuously above and below the average temperature setpoint. The amplitude of these oscillations over the total external ambient range is within the design objective of ± 1 degree C, with the average temperature setpoint at 25 degrees C. A two-position controller is one of the simplest methods for temperature control in a system that provides both cooling and heating.

With this control system, the temperature inside the enclosure is controlled at 25 (± 1) degrees C from -40 to $+60$ degrees C external ambient temperature with an input power level of 1.94 watts dc—2.1 amperes at 0.925 volts. The overall system efficiency of the dc-dc power converter operating from a 12-volt dc source is 40 percent.

Conclusions

Thermoelectric elements are practical for temperature-control systems, and their inherent characteristics adapt them to a wide variety of applications. Practical heat loads have been as low as microwatts and as high as several hundreds of watts. Practical controlled-temperature setpoints have been as low as -50 degrees C and as high as 100 degrees C.

Thermoelectric temperature-control devices are now performing many tasks in industrial and military applications that could not be practically or reliably done in any other way. Applications include parametric amplifiers, portable refrigerators, photomultiplier tubes, infrared detectors, ferrite memory cores, constant-temperature laboratory chambers and baths, precision humidistats for air-sampling systems, and temperature-sensitive electronic reference components. Many home and institutional appliance uses also are possible.

Westinghouse ENGINEER July 1963

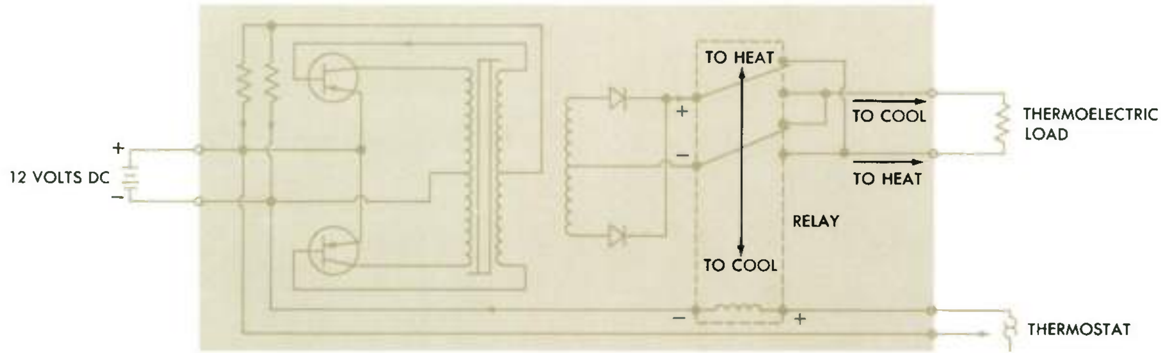


Fig. 6—The dc-dc power converter and control equipment for the chamber illustrated in Fig. 4 is diagrammed here. The 700-cps square-wave output has little current ripple, so no filtering is required.

Survey Vessels Are First U. S. Ships With Central Engine-Room Control

Two ships being built for the U. S. Coast and Geodetic Survey will have central engine-room control systems for improved speed and efficiency in hydrographic and oceanographic surveying. The Class I oceanographic survey ships are being built by Gibbs Shipyards, Inc., Jacksonville, Florida. They will be the first vessels constructed in the United States with central engine-room control (CERC) that includes automatic data logging, wired sequences, and complete pushbutton control.

Two single-armature propulsion motors, each rated 2500 shaft horsepower, 150 rpm, 900 volts dc, will drive each vessel's two propellers. Each motor will be energized by two generators rated 1000 kw, 850 rpm, 450 volts dc. Three 400-kw ac generators will supply ship's service power. Propulsion and ship's service generators will be driven by diesel engines. The bow thruster will be powered by a 450-horsepower dc motor energized with adjustable-voltage power from one of the propulsion generators.

The CERC system enables one man to see and operate all vital engine-room controls, indicators, and alarms. To achieve this, all important instruments and controls are brought together in the CERC compartment overlooking the engine room. These are augmented by a number of additional remote operating and monitoring devices to minimize the operator's need to move around the engine room to perform routine tasks.

For example, a mimic board for the main engines displays cylinder and exhaust temperatures and the status of lubrication, fuel, and cooling systems in terms of normal and alarm conditions. A logic system carries out the proper engine startup and shutdown procedures automatically and in the correct sequence at the touch of a button.

Other engine-room systems treated in similar manner include the ship's service diesel generators, distilling plant, fuel system, and ballast and tank pumping system.

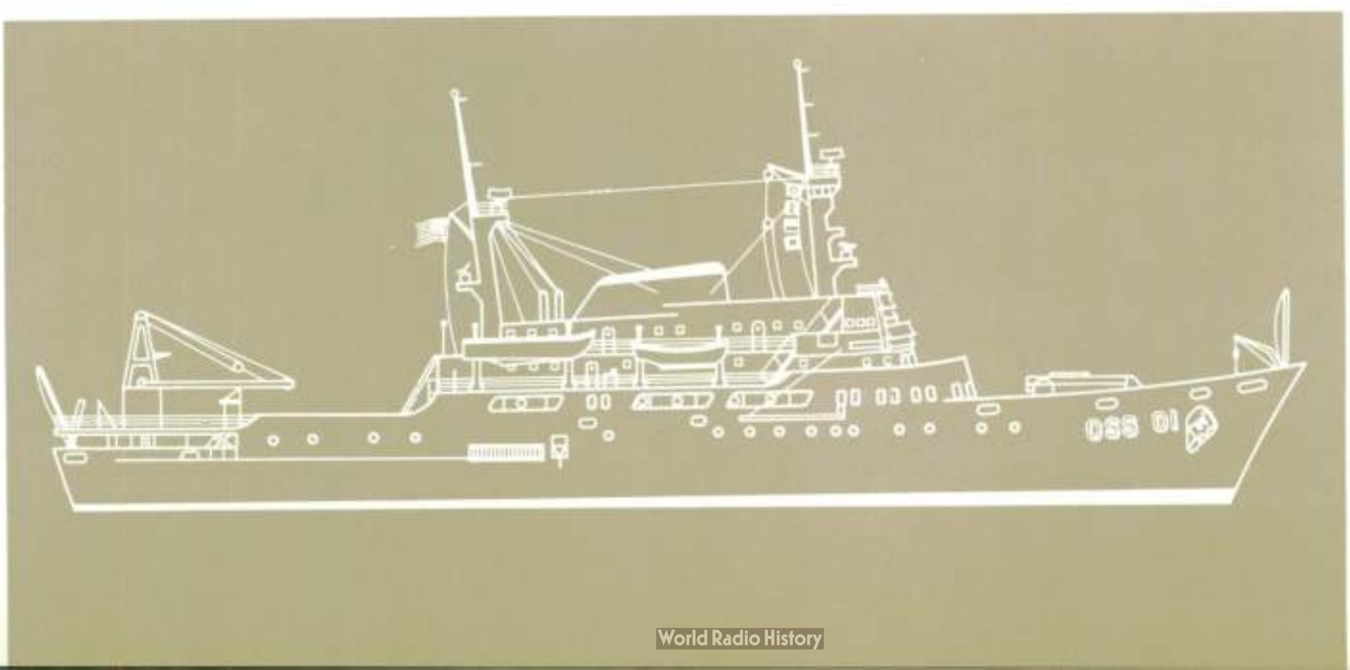
Another aid to the operator is a data-logging system that makes an hourly log of about 200 readings. These readings include bearing and exhaust temperatures, oil temperatures and pressures, cooling water temperatures and pressures, and cumulative readings of such quantities as kilowatthours and shaft revolutions. An alarm-condition trend recorder monitors the trend of any off-limit conditions. If an exhaust temperature, for example, exceeds a predetermined limit, an alarm circuit is energized and the temperature is printed out on the trend recorder every few seconds until it returns to normal. More than 100 alarm lights will give early warning of off-limit conditions.

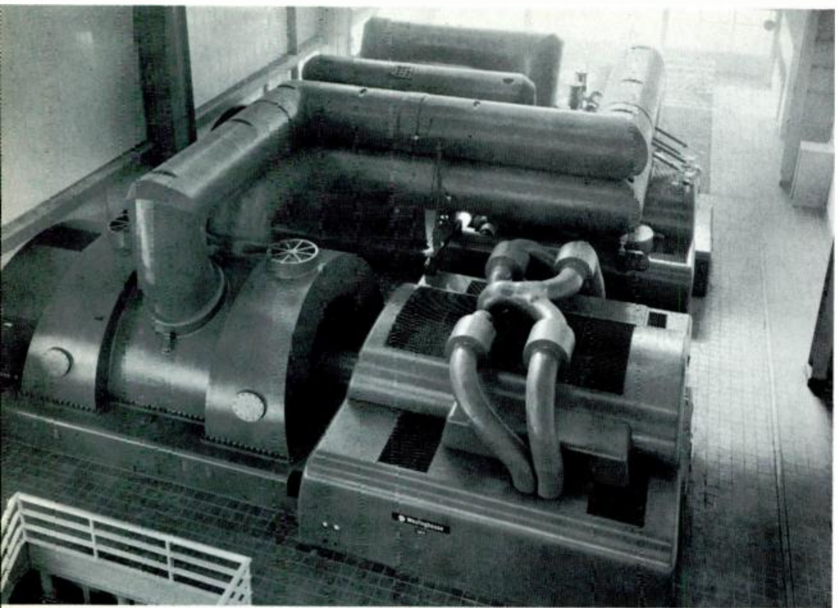
Closed-circuit television enables the operator to view remote engine-room areas, and a sound monitor permits him to listen to selected machinery. Pilot-house engine controls enable the ship's officers to control speed and direction of the ship directly.

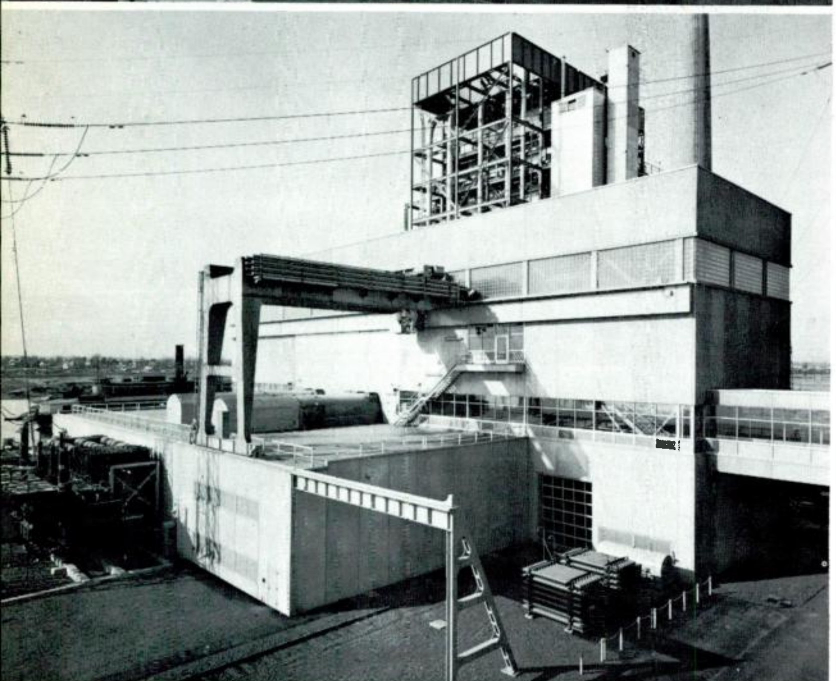
The new oceanographic ships will carry 116 crewmen and scientists. They will have the latest equipment for observing and measuring physical phenomena. Automatic data-processing equipment will speed the recording and processing of the data collected while at the same time improving accuracy and decreasing cost.

Until recently, Coast and Geodetic Survey vessels engaged primarily in mapping the shallower ocean areas to locate shore lines and obstacles to navigation. Because of the present emphasis on ocean studies, however, the new ships will be equipped to perform additional scientific work in chemistry, biology, meteorology, and geophysics. These investigations will supplement those of other agencies in collecting vital information for navigation, defense, public health, and exploitation of the ocean's food, mineral, and fuel resources. ■ ■ ■

This artist's concept illustrates one of the two oceanographic survey vessels being built with central engine-room control for optimum performance and efficiency.







Sewaren No. 5 Generating Unit Goes on the Line

The No. 5 unit at Public Service Electric and Gas Company's Sewaren Generating Station was placed in commercial operation in the fall of 1962, and is currently rated at 350 000 kw. This new unit has raised the total station capacity to 830 000 kw, and makes Sewaren the largest of the eight generating stations on the Public Service electric power system.

The turbine, shown in the top photo, is a cross-compound 3600/3600-rpm unit with a name-plate rating of 342 000 kw at throttle steam conditions of 2400 psig and 1100 degrees F, with reheating to 1050 degrees F and 1.25 inches Hg absolute exhaust pressure. The turbine consists of a high-pressure element, a double-flow reheat element, and two double-flow low-pressure elements. The low-pressure elements are duplicates.

The two identical 18-kv hydrogen inner-cooled generators (center photo) are rated 208 000 kva at 85 percent power factor with 45 psig hydrogen pressure. At 60 psig hydrogen pressure, the capability is 228 800 kva. A half-capacity boiler feed pump is driven from the outboard end of each generator. Each generator and its associated boiler feed pump are located outdoors on the generator deck. The turbine is enclosed in the turbine room.

Designed for Computer Control

The new unit will be operated by a digital computer that supervises and adjusts the conventional control system for optimum operation. The operating experience gained from use of this digital computer will be used to aid in the design of automatic control for future units.

Under operator control, the unit is controlled from the operator's console in the main control room, where the conventional indicators and controls necessary to manually start, stop, and operate all of the equipment associated with the unit are located (as shown in the bottom photo). Console control switches permit the operator to relinquish control to the computer, or to retain control on an individual circuit basis.

The computer system is superimposed over the conventional controls and sensing devices. The heart of the computer control system is a Prodac IV computer that can measure over 1400 plant conditions, decide on proper courses of action, and send out signals to operate plant equipment. The computer has been programmed to recognize abnormal plant conditions and quickly initiate corrective action.

The computer can also start the unit, initiate automatic synchronizing, and shut the unit down in either a normal or emergency mode. As an operating aid, it can monitor plant operation, calculate performance efficiency, calculate and display deviations from optimum conditions, and adjust combustion controls for optimum operation.

The computer system is inherently self-checking to insure proper operation. In case of computer malfunction, a

Top—Turbine room of Sewaren No. 5 unit.

Center—Exterior view of the new unit.

Bottom—Control room.

diagnostic program is automatically executed. If the trouble cannot be self-corrected by the computer, all controls are left in their current position and operation of the plant is returned to the operator; the computer takes itself out of service and an auxiliary scan system is turned on. This auxiliary scan system measures 600 key plant conditions and annunciates and prints an alarm message whenever abnormal operating values exist. The scan system can also be used to log or trend any of the important operating quantities.

The computer is presently being phased in to do plant monitoring operations. Following this will be a complete checkout of the control operations, which include the steam turbine unit startup and shutdown. The final phase will be the checkout of the computer report and optimization functions. ■ ■ ■

Ultrasonic Instrument Measures Ocean Temperature

Ultrasonic energy has been applied in a simple but accurate marine thermometer for measuring the ocean's temperature at various levels and locations. Laboratory models of the device have measured underwater temperatures to an accuracy of ±0.02 degree F.

The device is being developed to meet a need for better means for measuring underwater temperatures. Such measurement is basic to improved understanding of the ocean depths, since temperature governs many of the phenomena of oceanography. For example, even small differences in water temperature affect the performance of sonar systems.

The heart of the new system is a transducer containing an aluminum disk about an inch in diameter. This disk is set in vibration by a transistorized electronic circuit. The vibrating disk precisely fixes the frequency at which the circuit oscillates because it has a natural frequency of vibration (about 40 000 cycles per second). This natural frequency changes with temperature, so the temperature of the water surrounding the disk is measured simply by measuring the frequency of the electrical oscillations. The aluminum transducer disk is a good heat conductor, so it responds quickly to temperature changes.

Only two lead wires are required. They conduct dc power to the transducer and also carry the high-frequency oscillations up to the frequency-counting equipment that translates them into temperature information. Because the information is digital, the leads can be long without introducing errors into the readings. Accurate measurements at depths of several miles appear to be attainable in future models. Another advantage of producing temperature information in digital form is that the information can be fed directly into a digital computer if desired. ■ ■ ■

Big Motors Will Serve New Colonial Pipeline

The "backbone" section of the new Colonial Pipeline now nearing completion consists of 1047 miles of 36-inch pipe running from Houston, Texas, to Greensboro, North Carolina. It will have 13 electrically powered main-line pump stations.

A typical station will consist of one 2000-horsepower and two 5000-horsepower pump units. Connected in series, these pumps will deliver a total pressure boost of about 560 pounds per square inch to the stream of petroleum products flowing through the station at rates exceeding 600 000 barrels a day.

The 5000-horsepower pumps for this giant artery will be driven by 26 of the largest motors ever applied to pumping refined petroleum products. The motors are of outdoor weather-protected construction, which eliminates the need for a building to house the pump equipment. They are designed to minimize entrance of rain or snow in the ventilation air stream and have screens to exclude small animals, insects, and airborne matter. The windings are insulated with Thermalastic epoxy material for the high electrical and mechanical strength and moisture resistance required.

The pumps will operate 24 hours a day, 7 days a week, so the drive motors must perform at safe operating temperature and with minimum power consumption. Engineering tests performed on the first motors have confirmed the guaranteed efficiency, starting characteristics, and temperature rise at rated load.

For temperature testing, one unit operating as a motor was loaded by coupling it to the second unit operating as an induction generator feeding into the manufacturing plant load through conversion equipment. Temperatures in various parts of the motor and in the inlet and discharge air were measured by thermocouples temporarily placed at many points.

Other tests measured the motor's torque capability under starting and maximum load conditions. Efficiency determination by precise measurement of motor losses showed that the motor at full load will deliver to the pump shaft approximately 97 percent of the power it draws from the electric supply. ■ ■ ■

Test Facility for Space Power Components

A new liquid-metal loop system provides heat-transfer facilities for operational testing of space power components. Its primary purpose is to supply liquid metal for cooling rotating electric generators. These generators will have power outputs up to a megawatt and will operate at temperatures of 600 degrees F or higher. They are being developed to provide power for future space vehicles in long flights.

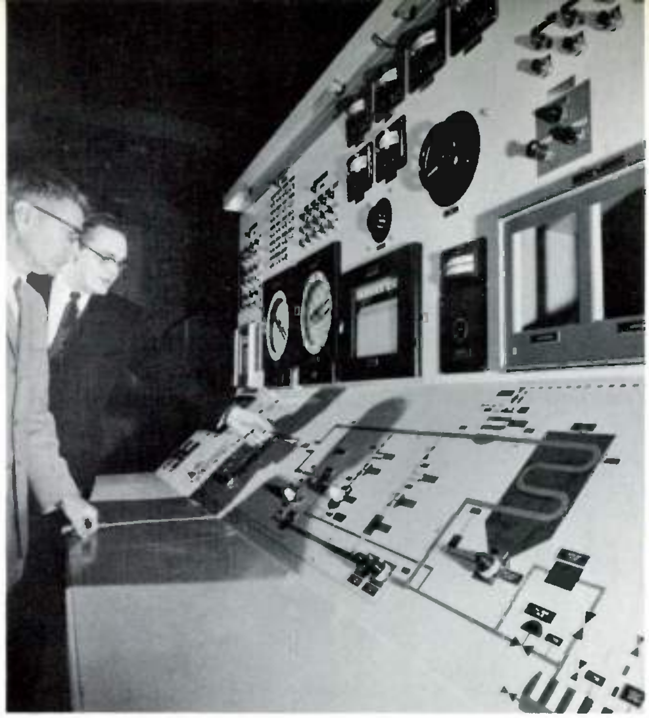
Other uses of the system are in testing static seals, seals for high-speed rotating shafts, potassium-lubricated bearings, and thermoelectric generating devices. The thermoelectric devices are tested in a part of the loop where the flow of liquid metal divides; one side of the thermoelectric junctions is cooled by metal coming from the system heat exchanger while the other side is heated by metal that has passed over heaters.

The test loop was built by MSA Research Corporation. It can be operated with potassium, sodium, or NaK (a eutectic alloy of sodium and potassium). The present testing programs are being conducted with a potassium charge in the loop.

The potassium-filled loop can provide cooling at the rate of 225 000 Btu an hour. Heating is supplied by two banks of immersion-type heaters in sealed cases. The main bank of heaters is rated at 15 kilowatts (51 000 Btu an hour); the other, in the hot side of the thermoelectric test circuit, is rated at 5 kilowatts (17 000 Btu an hour). Temperatures in parts of the test loop range up to 1600 degrees F.

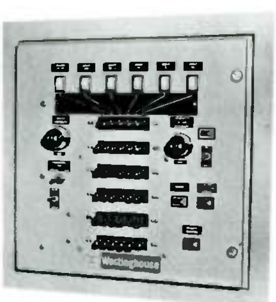
Two electromagnetic pumps with no moving parts circulate the potassium at 12 500 pounds an hour (36 gallons a minute). In these pumps, the liquid metal flows through a flattened tube. A magnetic field is passed through the broader walls of the tube, and ac current is conducted through the liquid metal perpendicularly to the magnetic field. The current and field interact, as in a motor, to produce force on the liquid metal. The magnetic field reverses at the same time the ac current does, so the force is always in one direction. This force moves the liquid metal through the system.

Previous experience has shown that potassium oxide in a system of this sort causes corrosion of the system's metal parts. To keep oxide content low, the metal is circulated through a hot trap filled with titanium chips and maintained at 1200 degrees F. Potassium oxide reacts with the titanium to form titanium oxide and potassium metal. The liquid metal can also be circulated through a device that indicates the remaining potassium-oxide content of the metal in the test loop. ■ ■ ■



The control and monitoring panel for the space power test facility includes a schematic representation of the main components of the liquid-metal loop.

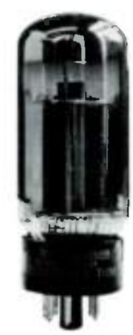
Products for Industry



TYPE SLS LOAD-SAVING RELAY UNIT for industrial and electric-utility systems that use more than one source of power guards against complete shutdown when one power source is lost. It also helps prevent load pickup problems. The unit adjusts the load to the available capacity, dropping only as many loads as necessary to retain the remainder of the system. *Westinghouse Electric Corporation, P. O. Box 868, Pittsburgh 30, Pennsylvania*

FILTER-SEAL WATTHOUR METER type D3S is sealed against contamination, yet its cover can be removed easily should it be necessary to do so. A continuous gasket seals the cover. Ceramic filters keep out dust, insects, and other foreign materials but permit the meter to "breathe." The filters also remove condensed moisture by capillarity. External lightning arresters protect the meter. *Westinghouse Meter Division, Raleigh, North Carolina*

DAR SERIES OF AC-DC INDUSTRIAL WELDERS is available in 200-, 300-, and 500-ampere ratings. The units combine ac transformer and dc rectifier welding equipment in one compact package, and they can perform all kinds of arc welding. A panel switch enables the operator to select either straight or reverse-polarity direct current or alternating current. *Westinghouse Westing-Arc Division, P. O. Box 2025, Buffalo 5, New York*



BEAM POWER PENTODE TUBE type 8417 is capable of power outputs up to 100 watts in push-pull circuits. Recent advances in high-conductivity materials and techniques are incorporated in the tube. Its linear response minimizes distortion. High power sensitivity permits use of low drive voltage, and this permits conservative operation of the preceding stages. *Westinghouse Electronic Tube Division, Elmira, New York*

About the Authors

R. A. Mintz received his BSEE degree at California State Polytechnic College in 1958 and has completed the course work for an MSEE from the University of Pittsburgh. He joined the Westinghouse Aircraft Equipment Department (now the Aerospace Electrical Division) in 1958 and has worked on various aircraft power systems. He is now a systems engineer, designing ground, aircraft, and spacecraft electric power systems.

R. D. Jessee graduated from the University of Kentucky in 1943 with a BSEE degree. He joined Westinghouse on the Graduate Student Course and then served in the U. S. Army Signal Corps from 1944 to 1945. He returned to Westinghouse in the aircraft equipment department after his discharge from the Army. Now a senior engineer in the Aerospace Electrical Division, he has contributed to the design of aircraft power control and protection systems, power conversion systems, and spacecraft electric power systems. His present responsibility is in power systems for space stations.

T. F. Saffold came to Westinghouse on the Graduate Student Course after graduation from Georgia Tech with a BSEE in 1941. Following his student assignments, he joined the transformer division, where he became a design engineer in the distribution department.

He transferred to the newly organized specialty transformer department in 1946, and was made section engineering manager in 1951. In 1957, he was selected to attend the Harvard Graduate Business School's Middle Management Program. Upon completion of the course, Saffold was named assistant to the department manager of the large rotating apparatus department.

Saffold returned to the specialty transformer department, when he was appointed department manager in 1959. From 1960 until 1962, Saffold served as director of engineering, apparatus products group. In 1962, he was made Engineering Manager of the Assembled Switchgear and Devices Division, his present position.

Joseph T. Laing is manager of the ocean survey systems engineering section of the Westinghouse Ordnance Division. Here, he is responsible for the development of instruments and instrument systems for oceanography and antisubmarine warfare, in addition to management of the mine countermeasure program.

Laing obtained his BSEE from Bucknell University in 1946, followed by an MSEE from Carnegie Institute of Technology in 1948. He came to Westinghouse on the Graduate Student Course, and was first assigned to the Research Laboratories where he worked on development of homing systems for torpedoes. He moved to the Ordnance Division to follow this same line of work, and progressed from project engineer, to supervisory engineer, to his present position.

Clark B. Risler and Walter E. Thomas write about mine hoist drives from a background of design and application experience in mining and material-handling equipment.

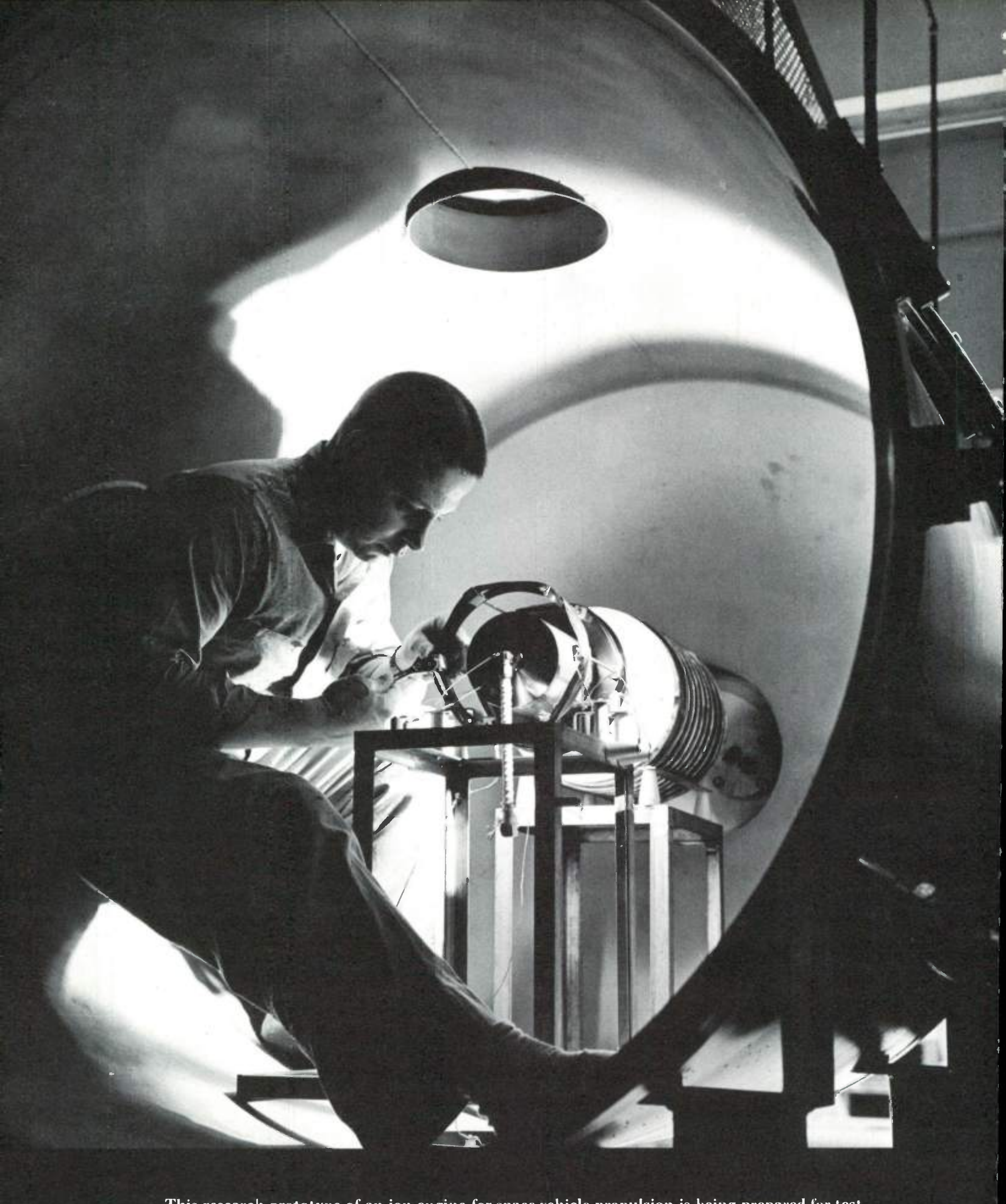
Risler received his AB degree from Columbia University in 1935 and his BS and MS in electrical engineering in the two succeeding years. He has since taken graduate work at the University of Pittsburgh. He joined Westinghouse at East Pittsburgh in 1937, serving first in central-station engineering and then in material-handling engineering. Since 1955 he has worked primarily with power and drive systems for the mining industry. Risler is now engineer in charge of the mining and preparation section, Manufacturing Province, Industrial Systems. His contributions in this field include application of adjustable-voltage drive systems to ore bridges and unloading towers and development of automatic mine-hoist drive systems. He received the Honor Award of the American Material Handling Society in 1958.

Thomas graduated from the University of Minnesota in 1946 with a BEE degree and is now working on his master's degree in business administration at the University of Pittsburgh. He joined Westinghouse on the Graduate Student Course in 1946 and then went to work with the former industrial control engineering department in East Pittsburgh. He moved with this department to Buffalo in 1948 and there designed industrial and marine control systems. He transferred to the industry engineering department (now Industrial Systems) in East Pittsburgh in 1955 and has served since then as a mining-industry engineer. Some of his recent contributions in this field are in utilization of computer techniques for mine-hoist duty cycle calculations and development of automatic control systems for mine hoists.

Both **T. D. Merritts** and **J. C. Taylor** were contributors to the *Westinghouse Thermoelectric Handbook* published last year, and they collaborated again in writing the article on thermoelectric temperature control for this issue.

Merritts served in the U. S. Army Signal Corps from 1948 to 1952 as a high-speed radio operator. He earned his BS in electrical engineering at the University of Pittsburgh in 1956 and has since taken a number of graduate courses. He joined Westinghouse on the Graduate Student Course and was assigned to design of magnetic amplifiers at the director systems department. In 1960 he moved to the Semiconductor Division, where he has worked on the design, evaluation, rating, and application of thermoelectric devices and their control and power-supply circuitry.

Taylor graduated from Pennsylvania State University in 1950 with a BSEE. He has also taken graduate work there and at the University of Pittsburgh and New York University. He served in the U. S. Army from 1950 to 1952, assigned to research projects at the Signal Corps Laboratories, Fort Monmouth, New Jersey. He then worked for the Pennsylvania Railroad Company until 1955 as an application engineer in power apparatus. Taylor joined the Westinghouse Semiconductor Division in 1955, where he has worked on application, testing, and evaluation of semiconductor products, including thermoelectric devices and complex components.



This research prototype of an ion engine for space vehicle propulsion is being prepared for test firing in a vacuum space simulation chamber at the Westinghouse Astronuclear Laboratory.