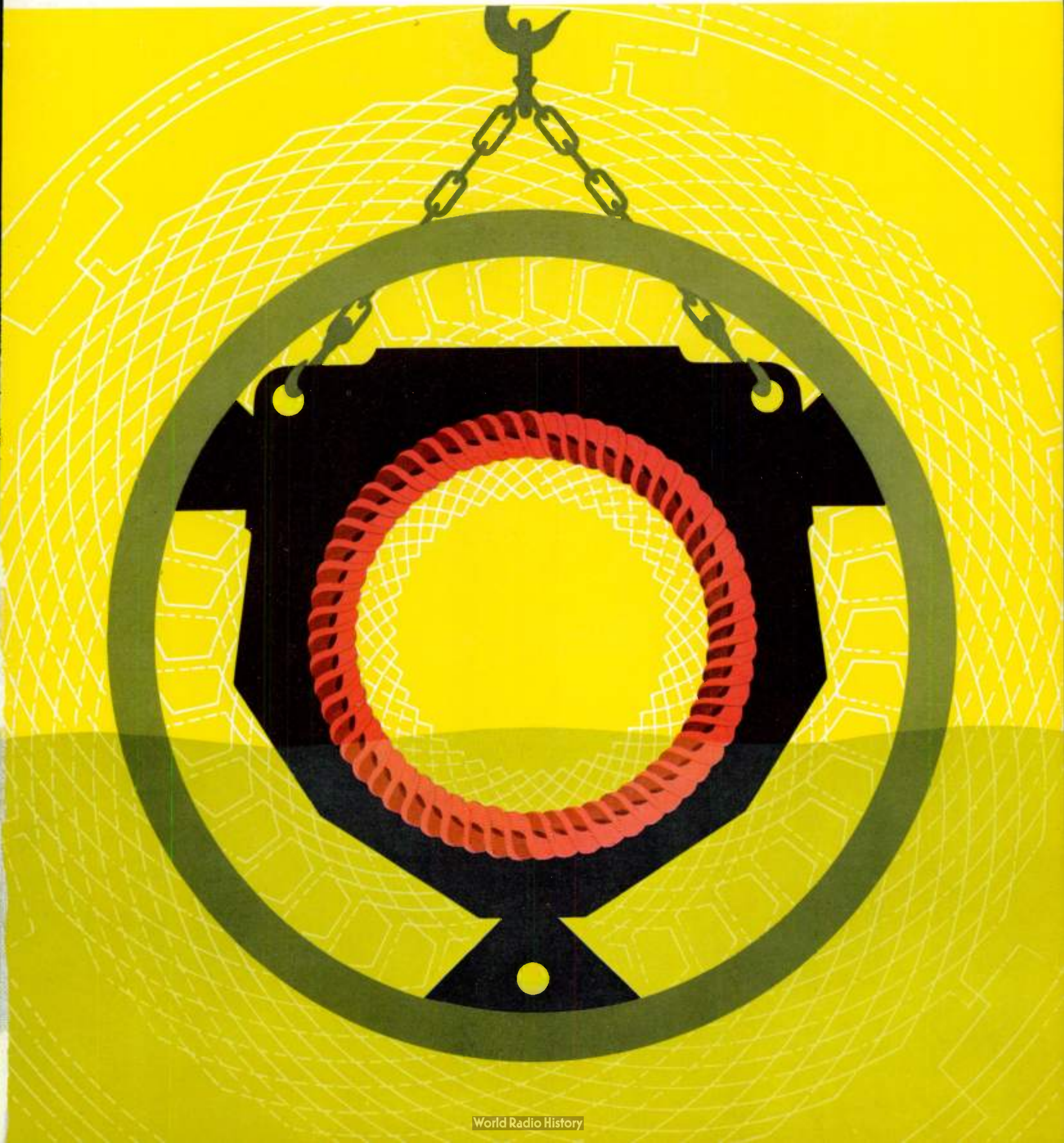
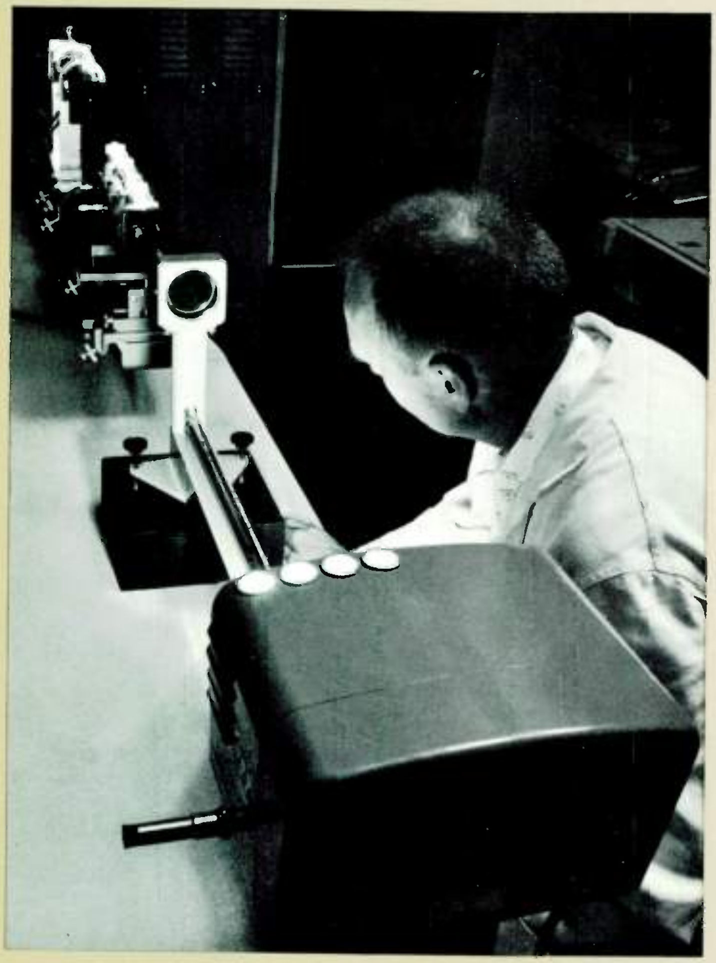
Westinghouse ENGINEER

March 1965





Complex patterns in the light beam from a laser are viewed with this optical device, which makes even the infrared part of the pattern visible for study. The heart of the viewer is a thin film of liquid-crystal material held in the round vacuum cell near the center of the picture. When the beam from the laser (rear) strikes the film, its heat alters the molecular arrangement of the liquid crystals. This effect causes color changes in the film that reveal the pattern of the beam. (For more information, see page 60.)

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Cover Design: The complete wound stator is vacuum-pressure impregnated as a unit in the Thermalastic epoxy insulation system for large motors. Artist Thomas Ruddy symbolizes the submersion of the stator windings in the impregnating resin on this month's cover.

Thermalastic Epoxy Insulation for Large AC Motors

Epoxy resin has replaced polyester resin in the Thermalastic insulation system for large motors, and has provided improved resistance to contaminants.

A quiet evolution in the design and construction of industrial and power plants has been under way during the past 10 or 15 years. In an effort to make such plants as functional as possible and at the same time minimize construction costs, the structure—walls and roof—that formerly housed much of the plant equipment has been eliminated. The chemical industry was perhaps the first to realize that with the product under manufacture adequately contained and protected in a maze of piping, tanks, and vats, further protection with a building was superfluous. This trend has spread to many industries with the result that most of the equipment involved, including large ac motors, must now be designed to be self-protected against the elements.

The introduction of Thermalastic insulation on large ac motors in 1953 did much to accelerate the trend. This was the first insulation system to offer a high degree of moisture and contaminant resistance, and it enabled users to place motors in outdoor locations where other insulation systems would have failed in a prohibitively short period.

Thermalastic insulation is a system consisting of large mica splittings, preplaced on the coil being insulated in either tape or wrapper form, and subsequently vacuum-pressure impregnated in a solventless resin. The tape or wrapper requires a backing material, which can be of either woven or nonwoven fibers, and a bonding resin which must be capable of coreacting with the impregnant. Upon completion of the vacuum-pressure impregnation, the coil with its insulation is subjected to heat and pressure, which initiates the polymerization of the resin, changing it from the liquid to the solid state. In its final condition, Thermalastic insulation consists of a series of overlapped mica splittings locked and held in place with tough, impervious films of thermosetting resin.[1,2]

The original Thermalastic insulation for large motors made use of polyester resins as the impregnant and tape bond. This insulation system has achieved an enviable record of success in many industrial and power plant applications and continues to establish new records in operating reliability. However, there were some instances, particularly in the chemical industry, where tests indicated the polyester resin was somewhat degraded by the presence of the product being manufactured. Typical instances involved acrylonitrile, soda ash, perchlorethylene, and other chlorinated solvents. In each case where an indication of attack on the polyester resin was discovered, an attempt was made to find a material that would resist attack, and in every case, the material that showed best resistance to these chemicals was an epoxy resin.

This article was prepared from information supplied by J. C. Botts, L. P. Connors, L. P. Petrich, D. A. Rogers, R. M. Sexton, and S. J. Stabile, Westinghouse Large Rotating Apparatus Division, East Pittsburgh, Pennsylvania.

Epoxy resins differ in their basic chemical composition from the polyester resins, and when cured the molecular structure provides an extremely high degree of inertness and consequent resistance to contaminants. Epoxy resins are also noted for their excellent bonding ability and are widely used today in bonding metals, ceramics, and other materials in critical applications where other agents have been unsatisfactory. In developing the epoxy resin insulation system, the approach taken was to substitute resins while maintaining the basic processing techniques that had proved so successful over the years.

About ten years ago, the Westinghouse Research Laboratories started screening available epoxy resins and catalytic agents to find a combination that could meet all the requirements of the Thermalastic process. After many tests, a blend of resins was developed that offered sufficient promise to warrant pilot plant operation. It then became necessary to decide upon the exact method of operation to be used in such a plant. With polyester resin, it had been the practice to impregnate individual coils and polymerize the resin in a heated press that also sized the slot portion of the coil. This produced a coil of high quality, but it left the problem of insulating the joints between coils and the connections between pole groups and main leads. All of the Thermalastic materials had been used on those areas, but resin had been applied by brushing between layers of tape during application instead of by impregnation. Although this is a satisfactory process, it is entirely dependent on operator performance; a preferable method would be to impregnate those portions of the winding as well as the coils.

Fortunately, another ac motor innovation that had preceded these developments by a few months fitted ideally into a new insulation concept. In the F/A (for Fully Accessible)[3] motor design, the stator core, which consists only of punchings and restraining end plates, is built as a separate component and is thus available for installation of the stator coils without the restricting influence of associated structural parts (Fig. 1). This construction made it possible to vacuum-pressure impregnate the *complete* wound stator and provided maximum exposure of the coils and connections to the impregnating resin.[4]

A pilot plant capable of processing motors with ratings up to 1000 horsepower was started early in 1960. At first, development stators were wound with "dry" (unimpregnated) coils, then impregnated, cured, and subjected to an exhaustive evaluation and test program. The results were so promising that it was decided to process a limited number of production orders in the pilot plant. Some 70 motors were manufactured in this manner starting in the summer of 1960. These motors are now entering their fifth year of service.

More elaborate and permanent facilities were completed in November 1962 and have been in continuous use since. The

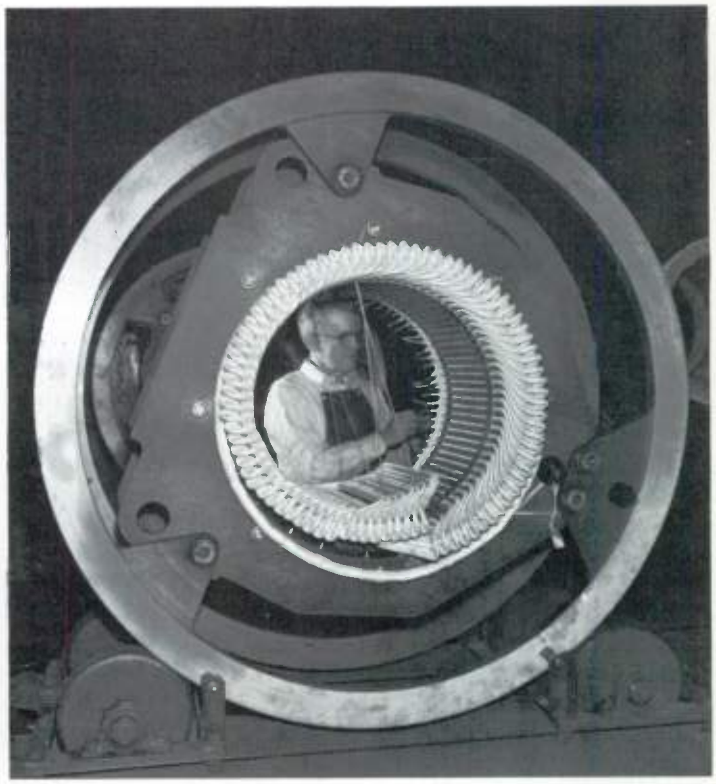
1—**Wound stator assembly** is shown in a typical F/A motor.

2—**Stator is mounted** on winding fixture for coil assembly.

3—**Wound stator** is being removed from impregnation vessel.

4—**Stator is placed** in rotational device during curing process.

1



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size of the facilities is such that nearly all motor ratings can be accommodated: the present range is about 300 to 15,000 horsepower at voltage ratings up to a maximum of 7000 volts.

The initial step in preparing a stator for impregnation is shown in Fig. 2. The stator core is mounted on a pair of rings, which are in turn supported by adjustable rubber wheels, thus providing complete operator control of stator position. The coils are pretested electrically, both between turns and to ground, but are unimpregnated during the assembly process. The coils are easier to handle while unimpregnated, and this, along with the ease of stator positioning, simplifies coil installation and assures an exceptionally high level of quality control. After all coils are installed, wedged, and braced, a second series of electrical tests is made to assure that both ground and turn insulation are adequate.

Following these tests, the connections are brazed and insulated. The basic steps of the impregnation process are exactly the same as they always have been for Thermalastic insulation —the stator is placed in a pressure vessel, the air in the vessel is evacuated to a very low absolute pressure, and the impregnating resin is introduced to completely submerse all parts of the winding. The vacuum is then released and replaced by a positive pressure of several atmospheres over the liquid resin. Following these steps, the surplus resin is drained away. An impregnated but still uncured stator is shown in Fig. 3.

The final step in the impregnation process can be seen in Fig. 4. The stator, still mounted on the ring fixtures, is placed in an oven. The resin cures while the stator is slowly rotated. This rotational cure minimizes resin runout and provides a smooth surface on the coil end turns.

Test and Evaluation Program

The use of an epoxy resin with the Thermalastic insulation concept is not a radical change but, rather, a development in an evolutionary process. Nevertheless, an intensive evaluation program was undertaken to assure both manufacturer and user that the new product was satisfactory for service. (To distinguish the new system from its predecessor, it is called "Thermalastic Epoxy".)

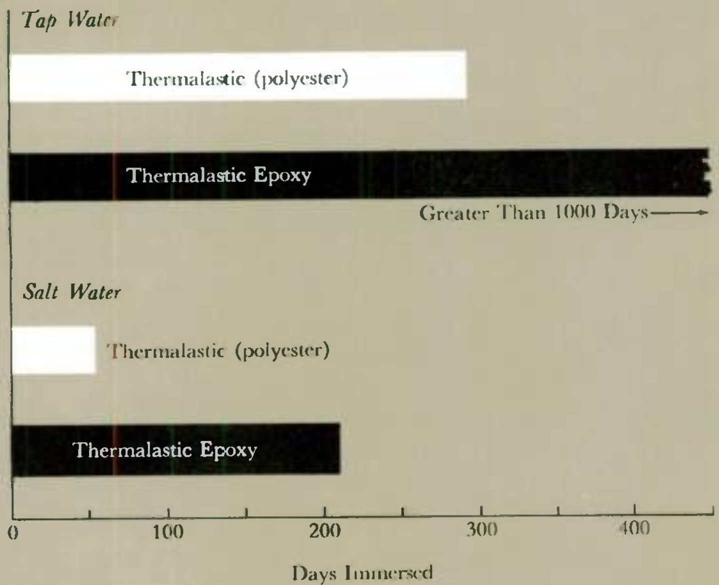
Complete evaluation of an insulation system for machines with an expected operating life in the order of 20 years is a complex process, and it would not be feasible here to go into detail regarding all the phases of testing. However, the basic requirements of any insulation system for large motors are: (1) adequate voltage endurance, or the ability to withstand continuous electric stress for the life of the motor; and (2) adequate thermal endurance. Both of these properties were thoroughly investigated, and Thermalastic Epoxy was found to be equal to or slightly better than earlier versions of service-proven Thermalastic insulation in these important characteristics. In other properties, Thermalastic Epoxy insulation has shown distinct advantages.

Moisture Resistance—Perhaps the most outstanding advantage of the Thermalastic Epoxy insulation system is moisture resistance. Of all the contaminants motors encounter in service, moisture is by far the most predominant. Therefore, tests of moisture resistance were conducted on a broad scale. The first screening test consisted of placing insulated coils designed for 2300-volt motors in tanks of water, applying 1300 volts to the coils, grounding the tank, and measuring total hours to failure. This was done in both salt and tap water, with the results shown in Fig. 5. The outstanding moisture resistance of epoxy resin was apparent.

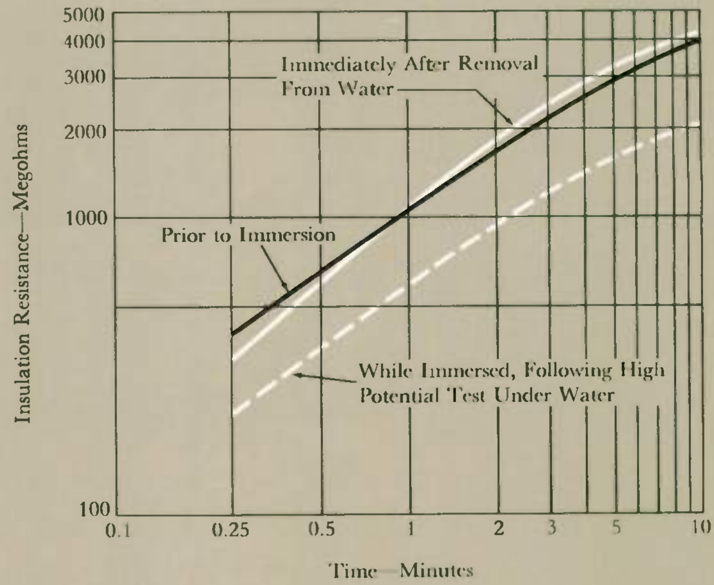
Complete stator windings were tested also. In one test, complete wound stators were submersed in water and insulation resistance was measured over a ten-minute period. This test has been made with great frequency on motors with many different ratings and always with outstanding results; those shown in

Table 1—Resistance to Chemicals

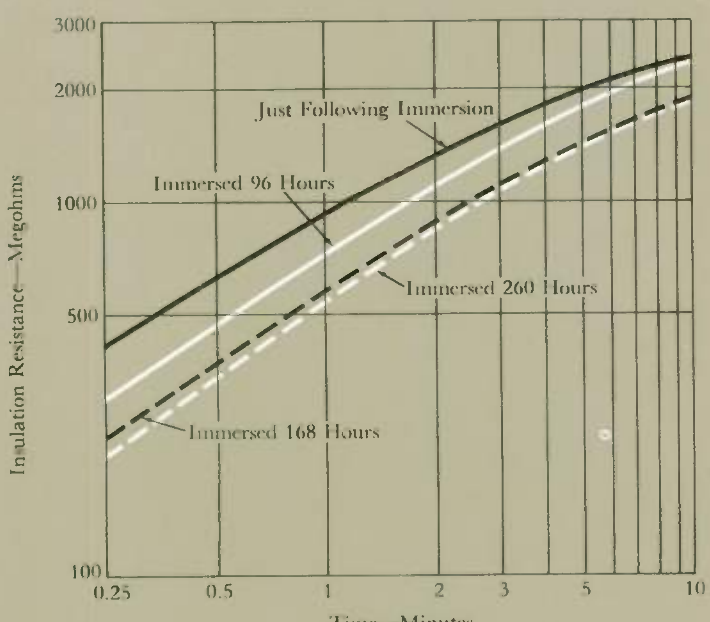
	Resin System	*Weight Change, Percent*	*Thickness Change, Percent*	*Rating*
Acids (hydrochloric, acetic, etc.)	Thermalastic Epoxy	None	None	Excellent
	Thermalastic (Poly)	None	None	Excellent
	Silicone Rubber	+5	+8	Good
Bases (sodium hydroxide, etc.)	Thermalastic Epoxy	None	None	Excellent
	Thermalastic (Poly)	+21	+4	Fair
	Silicone Rubber	None	+8	Good
Ketones (acetone, methyethyl ketone, etc.)	Thermalastic Epoxy	+12	+5	Good
	Thermalastic (Poly)	Decomposes		Poor
	Silicone Rubber	+3	+31	Poor
Aromatics (toluene, xylene, benzene, etc.)	Thermalastic Epoxy	None	None	Excellent
	Thermalastic (Poly)	Decomposes		Poor
	Silicone Rubber	−4	+58	Poor
Chlorinated Hydrocarbons (trichlorethylene, methyl chloroform, etc.)	Thermalastic Epoxy	+7	+1	Excellent
	Thermalastic (Poly)	Decomposes		Poor
	Silicone Rubber	−2	+46	Poor



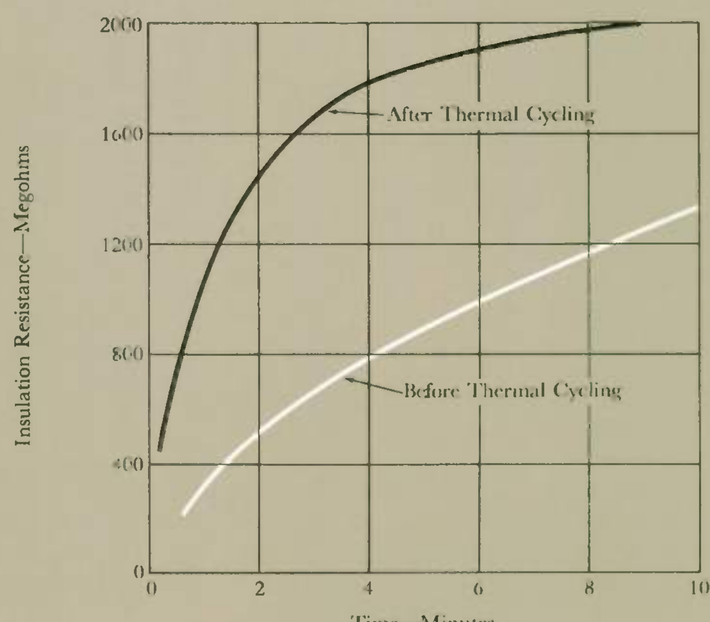
5—Average life of insulation systems, immersed, with 1300 volts applied continuously.



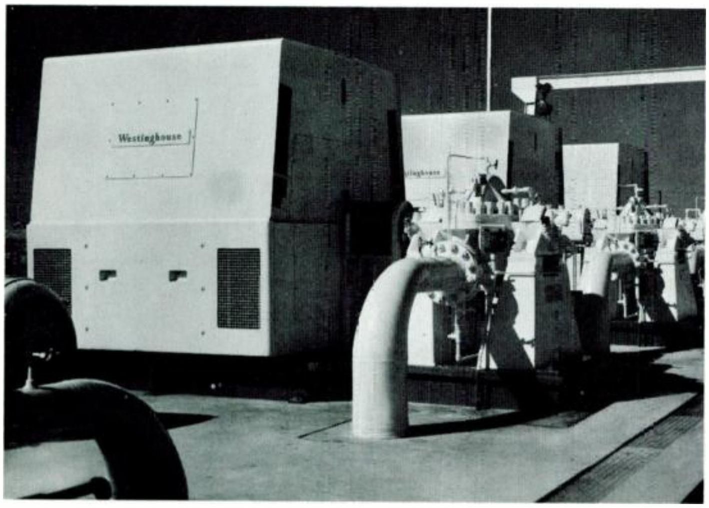
6—Insulation resistance characteristics of submerged Thermalastic Epoxy stator winding (600 horsepower, 3800 volts).

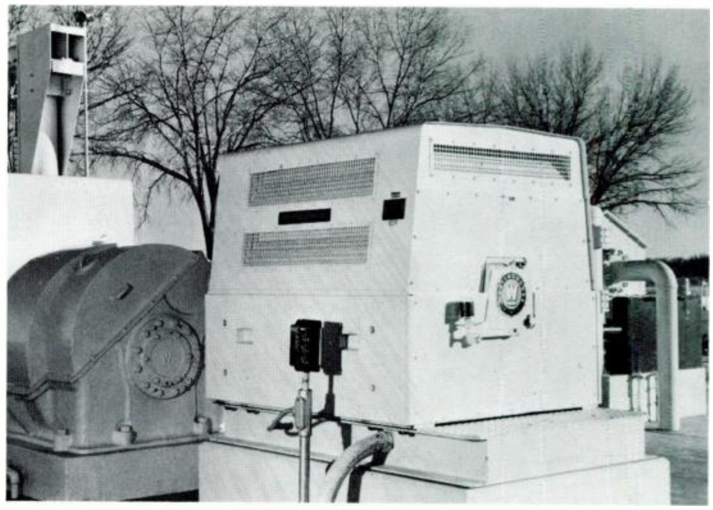


7—Insulation resistance characteristics of a Thermalastic Epoxy stator winding, disassembled from the motor and submerged in water. The motor (300 horsepower, 4000 volts) had been previously subjected to 1000 full-voltage starts.



8—Effect of thermal cycling on Thermalastic Epoxy insulation between temperatures of −40 degrees C and 125 degrees C. Insulation resistance measurements were made with stator completely immersed in water, using 500-volt megger.





Pipeline pumping stations are typical applications for Thermalastic Epoxy insulated motors.

Fig. 6 are typical. Also, a long-time test has been made on a wound stator exposed to 100-percent relative humidity at 50 degrees C. All of these tests demonstrate consistently the unequalled moisture-resistant properties of epoxy resins as used in the new insulation system.

Mechanical Properties—An insulation system in a motor must withstand many types of mechanical forces. It must have some flexibility to withstand deformations caused by across-the-line starts and thermal cycling, yet it must be rigid enough so that it can be adequately wedged and braced to withstand the rigors of service.

In devising tests to measure these two diametrically opposite characteristics (flexibility and rigidity), service simulation was the predominant objective. Two tests were developed to check these properties on the standard production motor design:

1) The wound stator of one motor was completely immersed in a tank of water and its insulation resistance measured. Following this the stator was assembled in the motor and subjected to 1000 across-the-line starts at its rated voltage of 4000 volts. The motor was then disassembled and the wound stator again immersed for 260 hours. Insulation resistance measurements were made just following immersion and after 96, 168, and 260 hours under water. Test results are shown in Fig. 7.

2) The wound stator of a second motor was subjected to severe thermal cycling. The winding was packed first with dry ice until the winding temperature, as measured by detector, reached −40 degrees C; then the dry ice was removed and the stator placed in an oven preheated to 125 degrees C. This cycle was repeated several times. Then the stator was immersed in a tank of water, and insulation resistance was compared to a similar test made before the start of the cycling. The results are shown in Fig. 8. (The higher value after cycling is due to a combination of temperature variation in the water bath and some further curing of the resin.)

Resistance to Chemical Contaminants—A third outstanding property of Thermalastic Epoxy insulation is its resistance to many commonly encountered chemicals. Thermalastic Epoxy insulation has been tested with enough industrial chemicals to demonstrate that it has the best resistance to a broad range of chemicals of any of the commercially available insulations for large motors (Table I).

Service Experience

In the five years that Thermalastic Epoxy insulated motors have been in service, they have established an outstanding reputation for reliability. About 1500 of these motors are now in service in a wide variety of applications. Of these, perhaps the most outstanding from the standpoint of total service and range of climatic conditions are those on the Mid-America Pipeline. On a line that reaches from Texas to Wisconsin, 30 motors, all mounted outdoors, have served since installation four years ago without a single winding difficulty.

Many other pipelines, including the Colonial, also have installed Thermalastic Epoxy insulated motors, as have many power houses and other industrial plants. In all cases, service experience with the epoxy system has been excellent.

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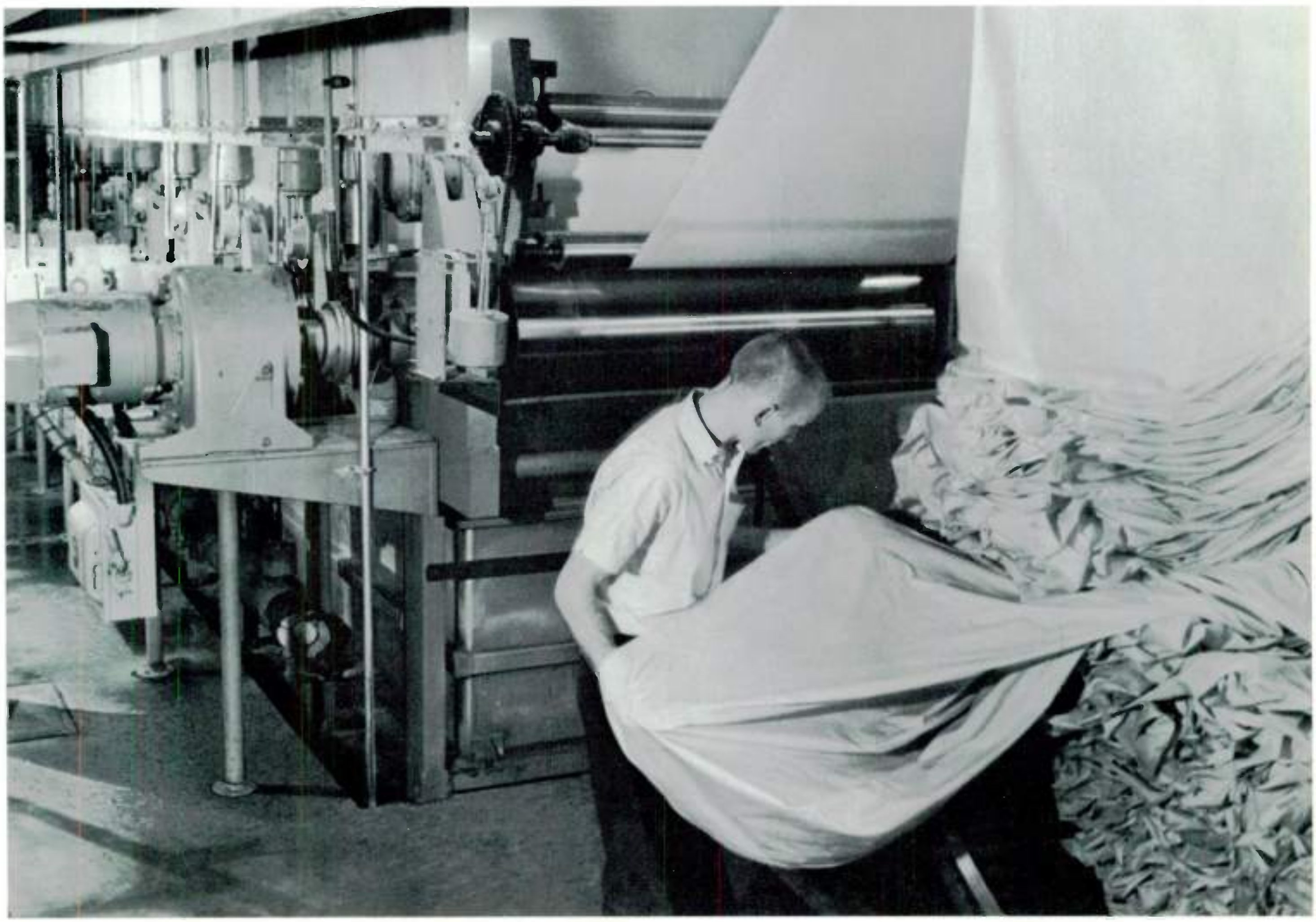
Static Drive Systems Serve Textile Processing Lines

As the cost of semiconductor diodes, thyristors, and transistors decreases with greater production volume and better manufacturing techniques, static drive systems become less expensive. This decrease in system cost (along with the advantages of static operation) makes the systems more competitive with older drive systems, which increases their use. Increased use raises the production volume of the static semiconductor devices, which tends to lower the cost of those devices to continue the cycle.

The static range drive systems on textile finishing lines at The Springs Cotton Mills Grace Bleachery near Lancaster, South Carolina, illustrated here, exemplify the modern static drive. The systems have been in successful operation for more than a year. They were designed by the Westinghouse General Industries Systems Department, which has chosen this type of packaged drive system as its standard for textile industry applications.

Textile finishing lines (or "ranges"), such as those used for bleaching, calendering, dyeing, printing, and tenting, consist of successive sections of machinery. The sections have to be driven in unison at varying speeds. This requirement has made adjustable-voltage dc drives the favored type, with the adjustable dc voltage traditionally supplied by m-g sets. In the new static drive, however, static power-conversion modules replace the m-g sets. Regulator and exciter modules also are static units that use semiconductor devices.

The systems have 10 to 15 percent better efficiency, require less space and maintenance, and need no special mounting. The static power equipment is supplied as near-standard func-



Textile finishing line at The Springs Cotton Mills Grace Bleachery is driven at various speeds by an accurate and trouble-free thyristor static drive system. Cloth is shown being delivered from a washer to an accumulating device called a scray.

tional packages in ratings from 5 to 150 horsepower, and units can be operated in tandem for higher horsepower ratings. The equipment is enclosed in a cabinet of NEMA 1 construction.

The packaged power unit converts incoming 60-cycle ac power to dc power for the drive motors. A power transformer reduces line voltage to the proper level for a three-phase thyristor bridge and isolates the bridge from the line. This bridge rectifies the output of the transformer and supplies adjustable-voltage dc power to the drive-motor armatures.

In operation, the range operator sets a speed-setting potentiometer to the desired product speed. This establishes a reference signal for an operational controller that controls gating amplifiers and functions as a counter-emf regulator to hold the selected speed within plus or minus two percent of the top value. The gating amplifiers turn on the thyristors at the proper phase angle to produce the dc voltage at the drive motor armatures that provides the desired product speed.

The Springs Cotton Mills systems include dynamic braking contactors and resistors for group braking of motors. Individual thermal overload relays for each motor open the line contactor and close the dynamic braking circuit if they are tripped by an overload. Motor acceleration and deceleration times are adjustable from 2 through 120 seconds.

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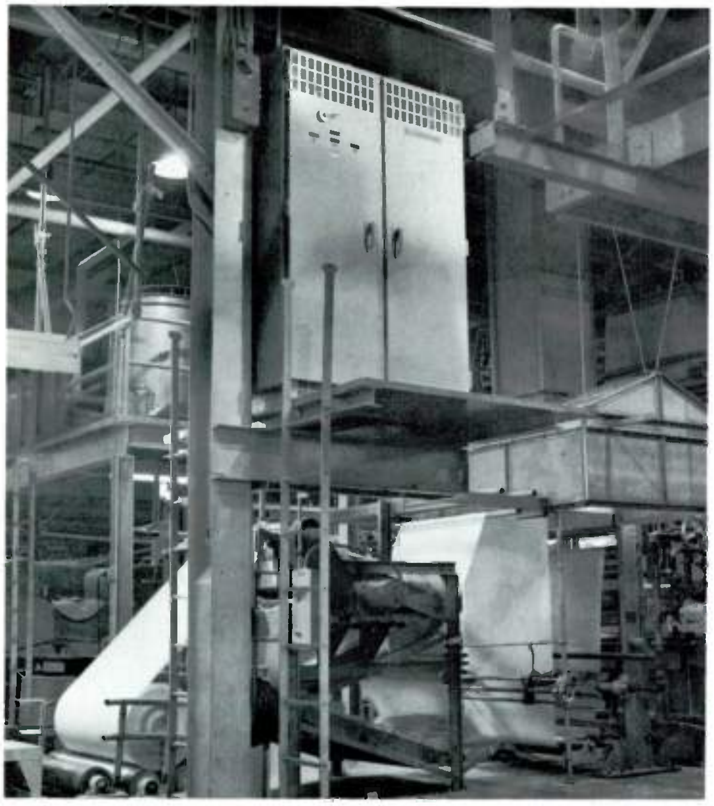

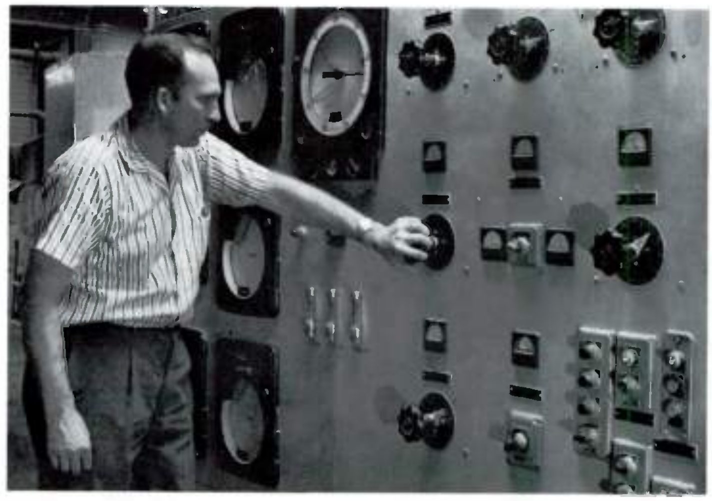

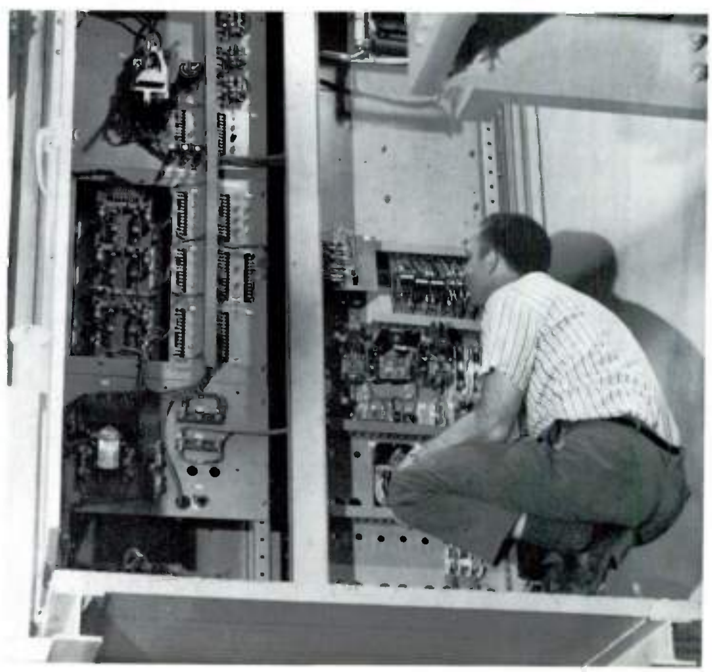

Small size and light weight of the packaged power supply and control equipment make it practical to mount the package near the process machinery (*above*). Since there is no rotating power conversion equipment, no special mounting base is needed.

Operator's control board (*right, above*) enables operator to control and monitor the equipment with speed-setting potentiometers, motor field trim rheostats, pushbuttons, selector switches, and indicators.

A NEMA 1 cabinet (*right*) houses all the power-conversion, regulator, and exciter circuitry. At upper left are the thyristor bridge and the control modules that turn on the thyristors at the proper phase angle. Dynamic braking equipment and overload relays are at upper right, and the power transformer is in the bottom of the cabinet.

A New Concept in Control Centers

by W. L. McKeithan

Even with time-tested equipment, occasionally it is worthwhile to "start from scratch" and design the particular element without regard to previous practices. This has been done with control centers, one of the most familiar pieces of equipment in industrial plants and commercial buildings. The result is a control center that is much more functional and useful from the user's standpoint.

Control centers are the "nerve center" of most industrial plants and commercial buildings, providing central control of motors or feeder circuits; main power is fed to a bus in the center, then distributed to the local circuits. A control center consists of a structure, which contains a number of control units; each control unit, in turn, contains the necessary equipment—such as a motor starter, circuit breaker, and relays—to perform its specific function. These units vary in size, depending upon their function, so that a particular structure contains two or more units. In many instances, units in one structure must be interconnected with units in one or more other structures, to provide necessary control.

With few exceptions, control centers have changed but little in many years. Recently, however, engineers have developed an entirely new control center based on a new approach; the new design is not only safer and simpler, but importantly is more flexible and more accessible.

The new control center also has a redesigned line of control components, for improved reliability. Among these components are motor starters (A-200) which are smaller, interchangeable in different capacity ranges, and have up to eight independent interlock contacts. Other new components include circuit breakers (A series), pushbuttons, and relays.

The new control center (Type W) houses standard assemblies of controls for individual control of three-phase loads. It can serve typical loads up to 100 hp, 220 volts, or up to 200 hp, at a maximum of 600 volts. Feeder circuits can also be controlled.

Flexibility

Control centers traditionally are assembled by bolting together twenty-inch-wide modular compartments. If additional space is needed, a full twenty-inch-wide compartment must be added, or a special compartment fabricated to provide the space required.

The new Type W design uses an integral frame structure with single top and bottom frames. Individual vertical frames separate the vertical compartments and wireways. The top and bottom frames are punched to receive the vertical frames at 4½-inch incremental spacings.

Thus, the vertical compartments can vary in width in 4½ inch increments. The standard vertical compartment is 13½ inches wide, and the standard wireway is 4½ inches wide.

Compartments can be wider or narrower than the standard where special applications require; and the wireway can be expanded to 9 inches or more where necessary.

Control units are available in vertical increments of 6 inches. The smallest unit housing is 12 inches high. The vertical compartment provides 72 inches of unit space to accommodate up to six control units (total control center height is 90 inches). This permits a maximum of six 12-inch units in one compartment. Any unit can be mounted at any elevation in any compartment.

Two depth dimensions are available—15 and 20 inches. The standard depth is 15 inches; it provides compartments for units mounted in the front only. The 20-inch depth is used when units are mounted back to back. The back-to-back units use a common vertical bus. The common wireway extends the full depth of the compartment, providing increased wireway cross section.

This incremental-spacing approach provides the user with unusual flexibility in specifying a wide variety of arrangements in his control center. The design also permits future changes and additions to be made with maximum ease. A cutaway sketch of the control center is shown on the next page.

Accessibility

Perhaps the most significant feature of the new Type W control center is its improved accessibility.

Elimination of the double-wall partitions between vertical compartments in the new design simplifies installation, maintenance, and future wiring changes.

Wireways are common to two compartments and permit jumper connections between adjacent compartments. This is possible because the unit terminal blocks are mounted horizontally in the front, and are accessible from either side. Wires enter the wireway through the side of the unit housing.

A wireway shared by two compartments also allows larger actual wireway area without reducing space efficiency. Additional area is picked up by making the wireway the full depth of the control center. The full-depth feature also permits access to the wireway from both front and back of the control center. Thus, two men can work simultaneously.

The full extent of this access advantage is realized in the back to back option. Jumper wiring can be run directly between any of 24 units in four compartments, so there is easy access to all wiring between unit terminal blocks.

The wireway provides ample space, ready and available for any wiring arrangement called for. In effect, the control center is designed around the wireway, for maximum convenience of user.

Another advantage of eliminating the double-wall partitions between vertical compartments is the resulting free

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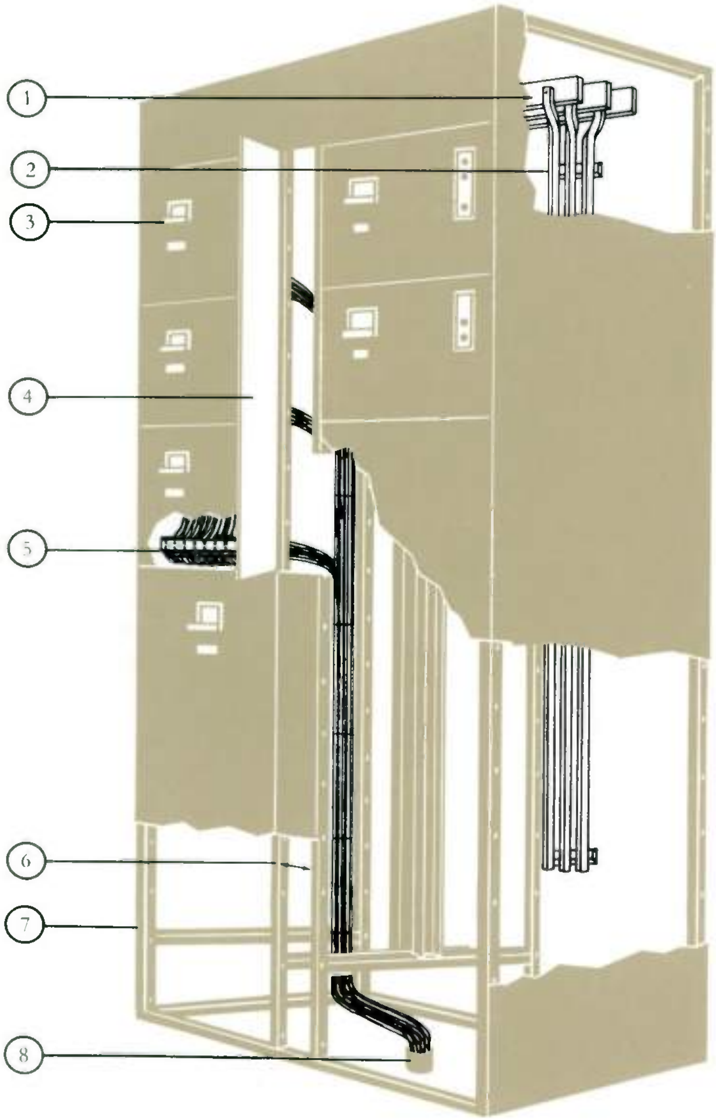


1. Main Horizontal Bus
2. Vertical Bus
3. Circuit Breaker
4. Wireway Door
5. Terminal Blocks
6. Wireway
7. Frame
8. Conduit

space throughout the entire base of the control center. This makes the location of all conduit terminations less critical. For example, the conduit terminations can be brought up anywhere within the outline floor dimensions, Fig. 1. This makes installation simpler and faster.

Removable end sheets allow access to the interior, impossible with conventional cubicle-type construction. This again could simplify installation. Headroom over the horizontal bus has been increased to provide easier cable connections to the terminals. The top of the individual control unit enclosure has been opened up to give ready access to interlock terminals with the unit in the "tilt-out" position, or completely removed from the structure.

Safety

Isolation of the power-distributing bus is a primary safety consideration. Wireways are isolated from the bus structure and it is impossible to make contact with the bus after a unit housing is slid into its cubicle. The back plate of the unit housing separates the control components from the bus.

Power connections are made directly to the bus through insulated stab connectors that project through the unit housing; no power cables extend into the bus compartment.

There are four primary safety measures "built-in" to the control center to provide positive operator safety:

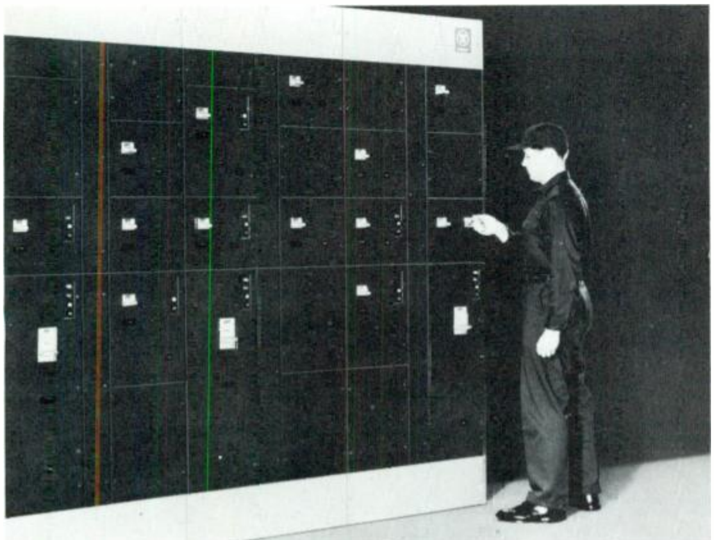
1) The control center has a "dead-front" design. This means there is no possibility of touching a hot line or terminal from outside the control center.

2) The unit door cannot be opened while the unit is energized. This is accomplished by a door interlock lever mounted on the operating mechanism of the disconnect device. This lever engages a bracket on the inside surface of the door when the door is closed, and prevents movement of the door until the disconnect is opened, Fig. 3. A simple mechanism is provided so skilled personnel can override this interlock.

3) When the door is open, the disconnect cannot be closed inadvertently. The spring-loaded door interlock lever slides forward into a notch when the door is opened, preventing movement of the device operating handle.

Also, since the operating handle of the disconnect device is mounted directly on the device, accidental closing of the disconnect can be prevented whether the door is open or closed, Fig. 4. A spring-loaded pawl is pulled from the operating handle and padlocked. With the pawl extended, the handle cannot be moved.

1—This cutaway sketch shows some of the details of the new control center. Note that the construction allows wiring to be brought up through the conduit anywhere within the frame. Note also that the common wireway for the two units shown greatly simplifies wiring of each control unit at their terminal blocks; the common wireway also simplifies interconnecting any two control units, regardless of their relative locations. Individual control units have stab connectors that plug directly into the vertical bus; no power cables extend into the bus compartment.



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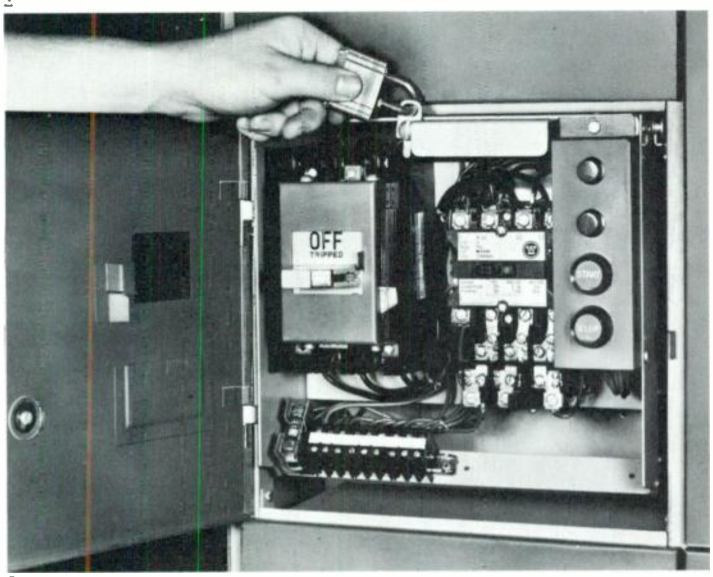

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4) The unit can be disconnected from the bus simply by sliding the unit forward on its tracks after disengaging a latch. Once the unit is forward and de-energized, an additional latch prevents further movement of the unit. The unit can be padlocked in this position, Fig. 3.

Simplicity

Probably the greatest simplifying influence has been the use of incremental spacing. Units can be installed in any desired arrangement within any compartment, and the common wireway simplifies installation and service.

The operating mechanism for the disconnect device is mounted directly on the device, and its design has been greatly simplified. Traditionally, the operating handle has converted the reciprocating mode of operation of the device to rotary motion. The new design eliminates this conversion step, provides a straight reciprocating action of the handle (up and down), and simplifies both the mechanism and its operation; reliability is also improved because this is a direct operating mechanism and has fewer parts.

All the control unit components—including starters, breakers, terminal blocks, and auxiliary devices—have been redesigned, making them smaller. This results in control units having reduced size and weight, permitting easier handling and removal from the control center. Also, with this reduction in size, more starters can be delivered in a given-sized shipping section, minimizing installation cost. In addition, this reduction in control center size reduces floor space required.

The new control center is based on preferred features requested by users. In fact, typical customers were asked to examine the prototype and point out weaknesses they could see from either the standpoint of installation or use. Thus, the final design was heavily influenced by users' preferences.

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2—Control center is designed for service to 600 volts. Each door provides access to a removable unit that contains control components for one load, including main disconnect device and motor starter. Each vertical stack of unit housings forms one compartment; up to six compartments can be shipped as a single structure.

3—Open door shows operating handle mounted directly on main disconnect device. When unit is energized, the door cannot be opened. A lever on the disconnect engages the bracket on the door. Also, when door is open, unit cannot be energized. The spring-loaded lever slides forward into notch when door opens, preventing movement of the operating handle. Note the terminal block, located at the front for simpler connection. Wiring from the wireway, although not shown here, would enter the space below the terminal block and then be connected to the block. The unit is shown here in a forward, de-energized position. Rotation of the screw and finger (see padlock) into the position shown simultaneously rotates a second steel finger farther back on the shaft into a position that maintains the forward, de-energized position. The padlock is a safety device to prevent rotation of the shaft.

4—With pawl on operating handle extended and padlocked, handle cannot be moved to energize the centol unit. Pawl accepts up to three padlocks.

A Modular SF_6 Circuit Breaker Design for EHV

by R. C. Van Sickle
R. N. Yeckley
C. F. Sonnenberg
J. J. Brado

A new live-tank circuit breaker, an assembly of series-connected interrupter modules, utilizes the excellent arc-interrupting ability of sulpur-hexafluoride gas.

Power circuit breakers for 500-kv and 35,000-mva interrupting capacity are being installed for service on the Virginia Electric and Power Company EHV system. These breakers will be the first of this voltage and interrupting rating to go into service in the United States. They use SF_6 as the interrupting medium, but unlike previous SF_6 breakers, are of modular design so that the same basic live-tank module can be used in combinations to make up breakers for 345-, 500-, and 700-kv service.

Modular Design

The new SF_6 live-tank module utilizes a modification of the interrupting element now in service in 230- and 138-kv dead-tank designs. A breaker pole is made up of two, three, or four of these modules connected in series, depending upon the voltage for which the breaker is to be used. Each module is mounted on its own insulated vertical column, the length of the column being commensurate with system voltage. The first breaker of this type, being 500 kv, uses three series-connected modules per pole, as shown in the photograph. Two modules are used for a 345-kv pole, and four modules for 700 kv.

A three-phase breaker consists of three parallel poles with the controls connected electrically, and with one compressor serving the SF_6 gas system and one compressor serving the pneumatic system. The poles are not otherwise interconnected mechanically. Each pole unit has its own operating mechanism, which mechanically links together all moving contacts and blast valves of the pole.

All columns of each pole are mounted on a single base. Each base for the three poles is identical except for minor details; for example, a central control housing containing the gas and air compressors is mounted on the middle pole. The air compressor supplies air to reservoirs mounted on the bases of each of the poles in close proximity to the pneumatic operating mechanisms. The gas compressor supplies SF_6 gas to high-pressure reservoirs located on each of the base frames, and through them to the smaller high-pressure reservoirs in the modules. The mechanically interconnected moving contacts and blast valves of each pole are opened by stored energy of torsion springs in the modules, all released by a single trip coil. All contacts for each pole are closed by a single pneumatic mechanism located at ground potential.

Interrupter Modules

Each module contains two breaks in series, with each break good for the maximum voltage that can be impressed on any one break when the module is part of a breaker operating at the maximum rated voltages of 362 kv, 550 kv, or 765 kv. The essential elements of the module are identified in the schematic cross sections shown in Fig. 1. The tank forming the central section of the module is a part of the low-pressure system.

The high-pressure reservoir, which provides SF_6 gas storage close to the interrupters, is located on the inside wall of the tank opposite the access door. A blast valve is mounted on the high-pressure reservoir and supports the bearings for the rotating contact arm that surrounds it. When the blast valve is opened, gas is discharged radially outward, through the hollow crossarm to the contacts and interrupter chambers.

The moving contacts, which rotate through arcs of approximately 40 degrees, engage stationary contacts mounted on the inner ends of two insulating bushings. These bushings are gas filled and extend horizontally from the ends of the tank along the longitudinal axis of the pole unit. The inner ends of the bushings also support resistor assemblies, which are connected in the circuit only during closing operations to minimize switching surges.

The mechanical linkage system within the module, which operates the contact crossarm and blast valve, is connected through an insulating operating rod to the mechanical linkage at ground potential. A tension force exerted by the insulating operating rod closes the contacts. A torque bar located in the module linkage system provides a high-force, low-inertia energy source for high initial acceleration of the crossarm and blast valve toward the open position. The blast valve opens rapidly and remains open until the contacts approach the full-open position. The blast valve does not operate during the closing operation.

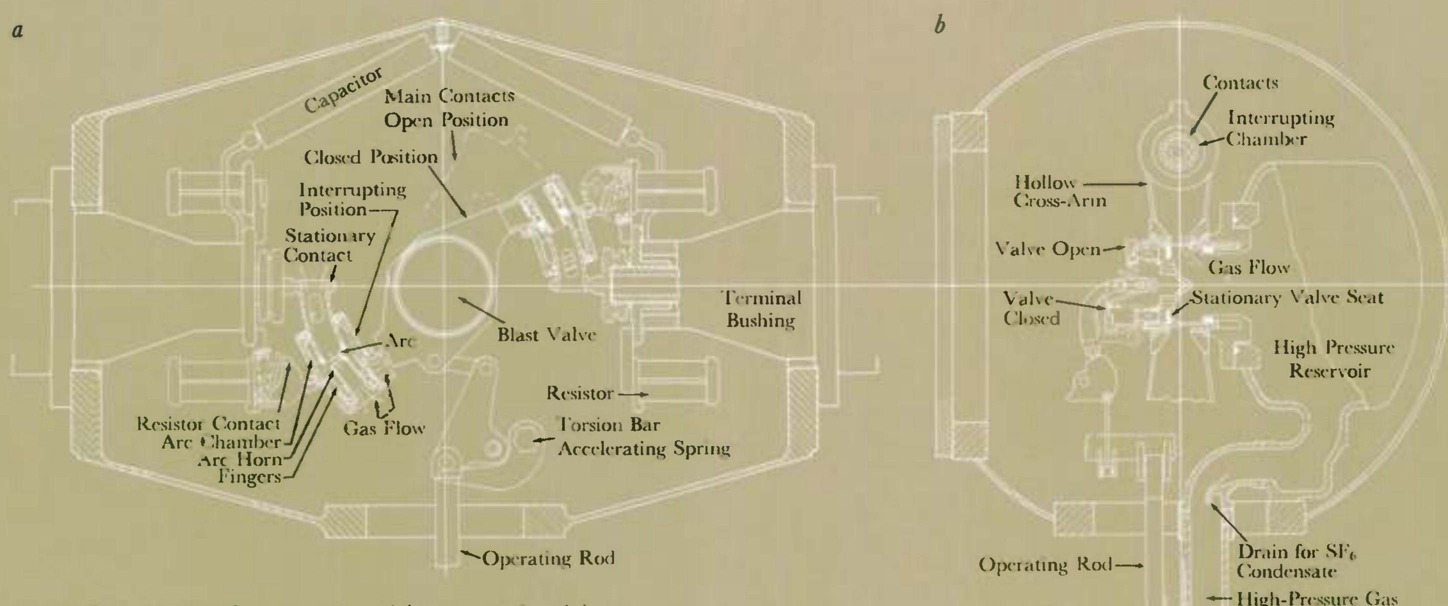
Insulating Columns

The insulating column that supports each module is made of several insulators, the number and length depending on the rated BIL of the breaker. The insulators and the sealing gaskets at their ends are held in compression by four spring-loaded insulating tie-rods extending the length of the column. These tie-rods also give the column sufficient stability to withstand high winds and earthquake shocks.

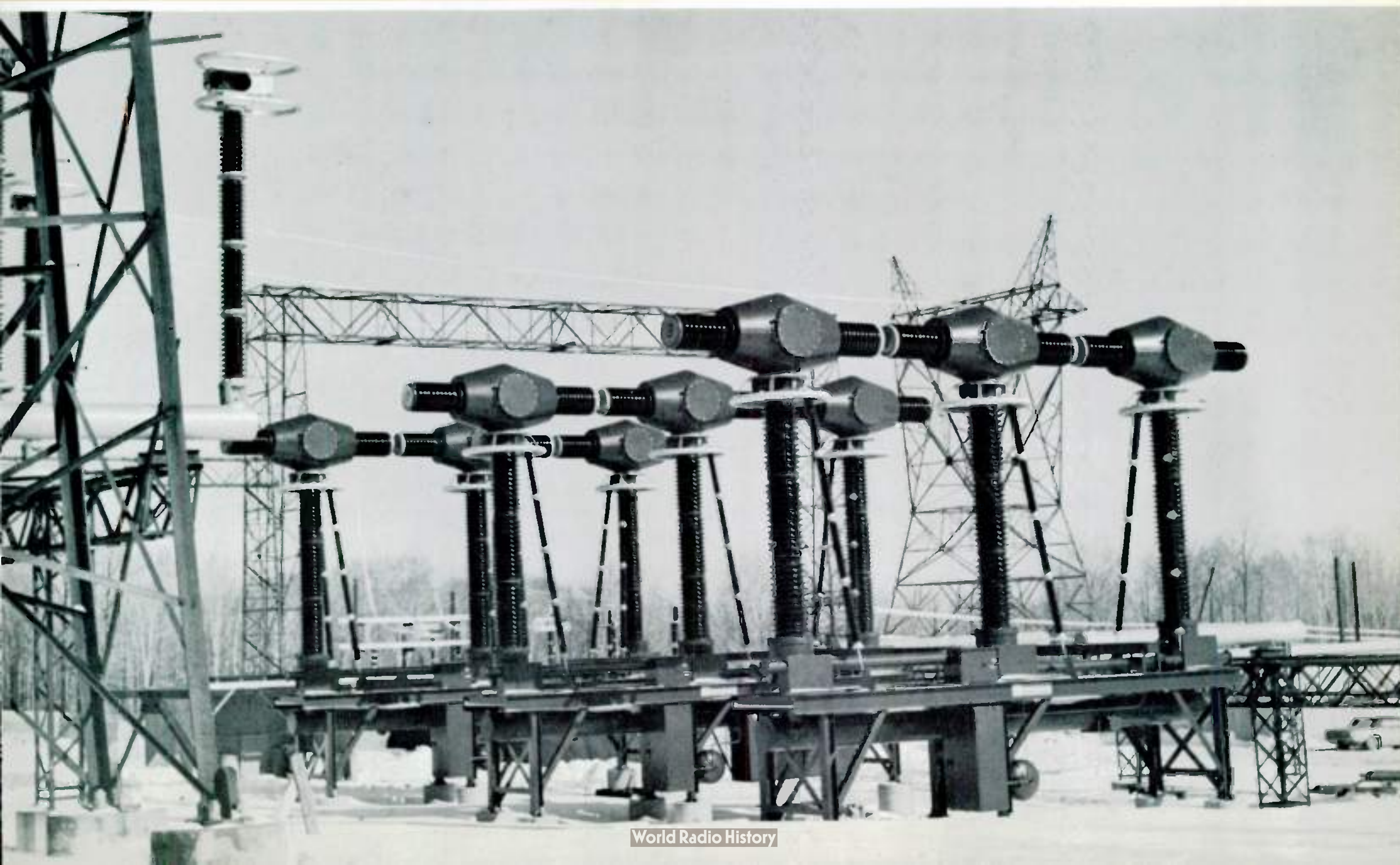
The column is filled with low-pressure SF_6 and forms part of the low-pressure reservoir, providing a channel through which low-pressure SF_6 can return to ground potential. The hollow column also houses the vertical operating rod and an insulating tube that conducts high-pressure SF_6 gas from the large reservoir at ground potential to the high-pressure reservoir in each module. The columns are mounted on a steel chamber, which is a low-pressure, gas-filled part of the base-frame assembly. A low-pressure gas line connects the base chamber to the low-pressure manifold in the central control housing. A shaft, passing through a gas-tight seal in the wall, connects the vertical operating rod to the horizontal linkage of the pole unit. The high-pressure gas line passes directly downward through the base to the high-pressure reservoir.

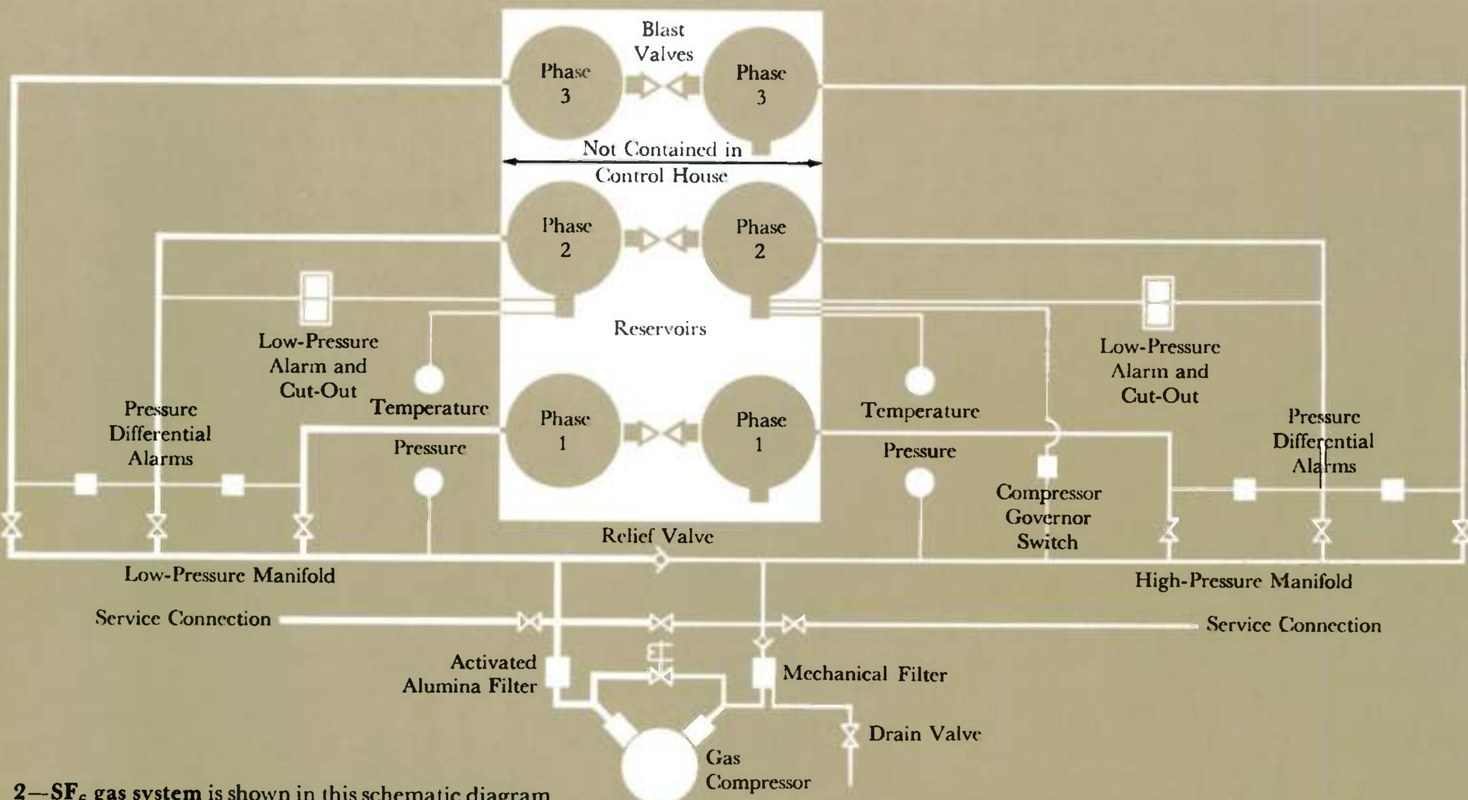
The authors are with the Power Circuit Breaker Division, Westinghouse Electric Corporation, Trafford, Pennsylvania.

Fully-assembled 500-kv SF_6 breaker ready for hookup at the Mt. Storm station of the Virginia Electric and Power Company.

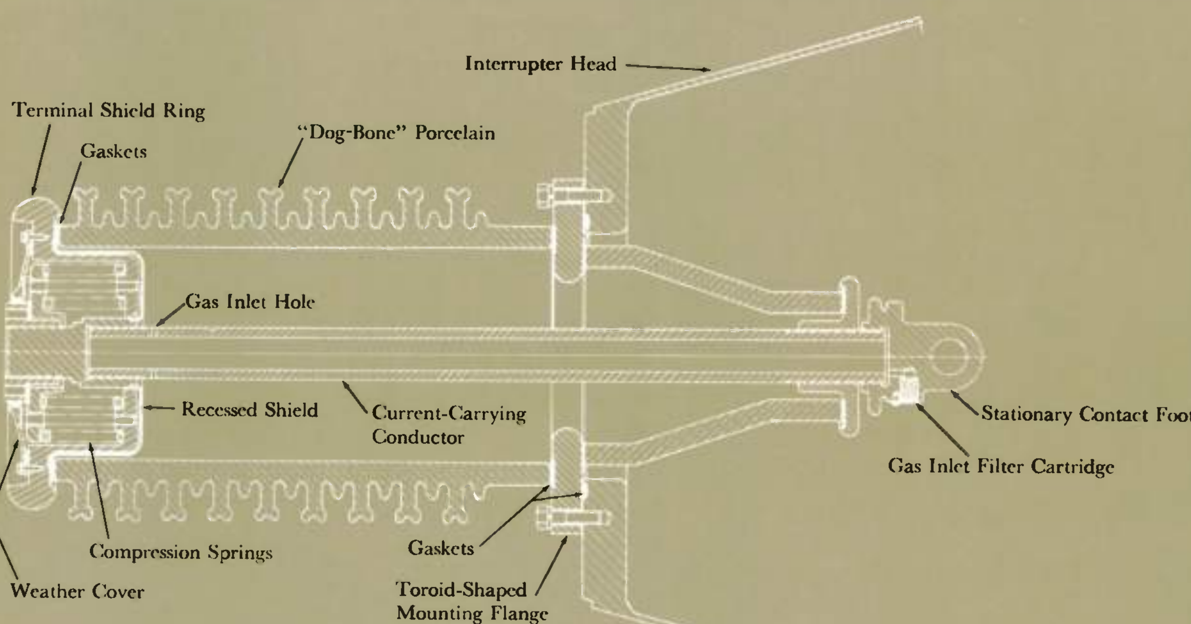


1—Module cross section, front view (a) and end view (b).





2—SF_6 gas system is shown in this schematic diagram.



3—Dog-bone bushing cross section, mounted on interrupter module.

Gas System

The SF_6 gas used in this breaker is contained in a sealed system, part of it operating at about 240 psig and part at about 45 psig. Gas from the low-pressure system is pumped by a simple, maintenance-free gas compressor to the high-pressure system. High-pressure gas is returned to the low-pressure system when the breaker opens and a short blast of high-pressure gas is discharged through the interrupters.

A schematic diagram of the gas system is shown in Fig. 2. The compressor control switch and the low-pressure alarms and cutouts are temperature compensated and therefore operate as a function of the gas densities. When gas density in the high-pressure system is reduced by discharge through the blast valves or by slow leakage from the high-pressure system to the low-pressure system, the compressor governor switch is actuated, and starts the gas compressor. Valves at the high-pressure and low-pressure manifolds permit the isolation and servicing of the individual pole units. Differential-pressure alarms are actuated if the breaker is operated while any reservoir remains shut off from its manifold.

To satisfy ASA C37, breakers should be designed for normal ambient temperatures down to −22 degrees F, and since even lower temperatures may be encountered in specific cases, the high-pressure SF_6 tanks are equipped with heaters and covered with thermal insulation. The heaters are controlled by thermostats located at the bottom of each tank.

When temperatures are low enough to cause condensation, the SF_6 system functions as a vapor-heating system. The heater vaporizes any condensate in the large lower high-pressure reservoir. The warm gas flows upward to the high-pressure reservoirs in the modules to replace gas that has cooled and condensed. Condensate in the upper reservoirs drains into special elbow connections at the tops of the high-pressure tubes, and is returned to the lower tank. The lower tank is tilted slightly so condensate from all modules will collect at one end, where it is detected by the thermostats.

Pneumatic Operating Mechanisms

The SF_6 EHV breakers can be supplied with rated interrupting times of two or three cycles, depending upon the pneumatic operating mechanism used. The operating mechanism is located between the columns of a pole unit so that differences in the lengths of the operating linkages to the moving contacts can be made as small as possible.

The first EHV SF_6 breakers have an interrupting time of three cycles, and use an operating mechanism that is also used in other breakers. The pole units of these breakers have a lever box in line with the horizontal rods between two columns. It adapts the approximately constant force of the pneumatic operating mechanism to the module load, which increases rapidly as the closed position is approached. The operating mechanism is located directly beneath the lever box and contains the tripping coil and holding latch.

A new operating mechanism has been developed to give the rated interrupting time of two cycles. It contains a lever system that adapts the input of the pneumatic cylinder to the output needed for the operation of the horizontal rods. Consequently, it is located in line with the horizontal operating rods between columns. The latch is arranged to reduce the inertia of the parts that must be moved during high-speed tripping.

Module Bushings

The horizontal entrance bushings for the modules are a departure from conventional bushing designs (Fig. 3) in that a single top plate replaces the spring bowl. By nesting the complete spring cluster and flexible diaphragm cylinder within the porcelain weather casing, the outer end of the porcelain is electrostatically shielded from high-voltage gradients in air. The toroid-shaped top plate further adds to this shielding complex, thus producing a bushing not only free of corona at maximum line-to-ground voltage, but also capable of effectively shielding most line terminals.

Low-pressure SF_6 is admitted to each bushing from the interrupter module through a filter that prohibits the passage of interruption by-products.

The industry's concern for the possible vulnerability of horizontal bushings to flashover when moist and contaminated prompted an extensive laboratory investigation into the mechanism underlying such flashovers. A significant result was a new "dog-bone" porcelain design, so named because of the appearance of its cross-section, as shown in Fig. 3.

This new design has been proved most effective. Droplets of moisture, made conductive by surface contamination, are forced to run around the insulator circumference in grooves at the crest or base of each shed and drop to earth without any axial migration. Those droplets that do roll over the edge of a shed drop off the sharp undercorner and fall to the root groove without wetting the protected undersurface. Actually 46 percent of the total creepage is protected by the overhanging skirt —a most significant statistic on an insulator whose creepage-to-striking distance ratio of 2.8 approaches the practical maximum of 3.0.

Insulation Coordination

Three fundamentals of insulation coordination must be observed in designing a live-tank circuit breaker:

1) The breaker must not flash over internally under any normal or expected abnormal condition;

2) External flashovers must go to ground without shunting the open breaker contacts;

3) The weakest internal breakdown path should be across the open or partially open contacts to prevent internal shunting of the interrupter.

To achieve the required withstand voltage when circuit-breaker contacts are closed, the support insulation must be high enough above ground to prevent flashover at voltages less than one per-unit, where one per-unit is the required withstand voltage, such as rated BIL. Consequently, when circuit breaker contacts are open, the insulation strength of the lead bushing is added to the one per-unit strength of the support column. Thus, if one per-unit were also the external insulation strength across the six horizontal bushings (of a 500-kv breaker pole) and if 0.22 per-unit will appear across the lead bushing, the open-circuit external withstand of the circuit breaker will be 1.22 per-unit to ground down the support column, but only 1.0 per-unit across the contacts. Obviously, this situation would violate the second stated fundamental of insulation coordination because flashover could occur across the bushings, thus shunting the open contacts.

However, if the external withstand voltage across the bushings is at least 1.3 pu, then the external withstand from an open circuit breaker's energized terminal to ground over the lead bushing and support column becomes:

$$(1.3\text{ pu})\ (0.22) + 1.0\text{ pu} = 1.29\text{ pu}.$$

Now the breaker will flash to ground down the column rather than across the bushings. The first term in the above equation indicates that the external withstand of a single bushing must be 0.29 pu, corrected for atmospheric conditions; and it follows, in line with the first stated coordination fundamental, that the internal withstand of a single interrupter and bushing must exceed 0.29 pu, uncorrected.

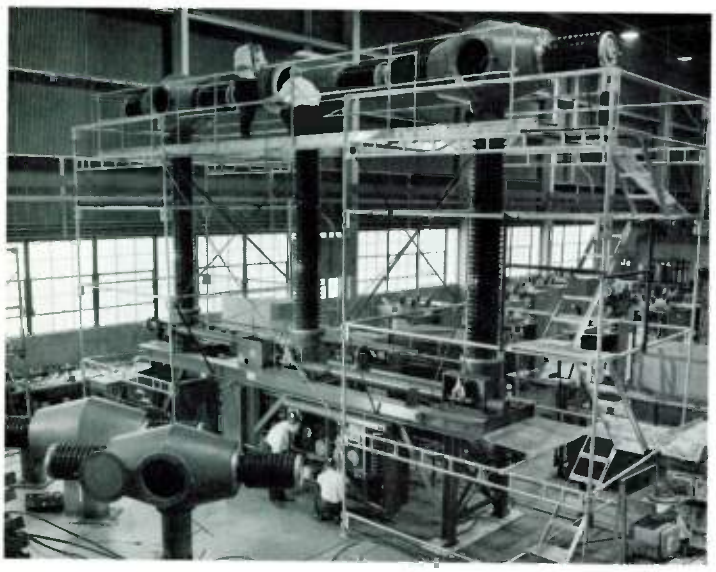
Parallel Protective Gaps—When a current transformer is placed on the line side of a live-tank circuit breaker, its line-to-ground insulation normally will be chosen to coordinate with the system and breaker by also being one per-unit. The current transformer insulation always is subjected to the full line-to-ground voltage regardless of whether the circuit breaker is open or closed. It will, therefore, act as a parallel protective gap in conjunction with the circuit-breaker support columns if the contacts are closed, or singularly if the contacts are open. This is not a desirable situation because:

1) A porcelain surface that is designed to adequately coordinate when wet and contaminated must, of necessity, have excessive voltage withstand strength if clean and dry. Such variation makes any porcelain insulator or bushing unreliable as a coordinating gap.

2) A coordinating gap also may carry a power-follow arc, which should not be drawn near the surface of a porcelain column.

Coupling the above facts with the realization that many variables will be encountered that can upset the coordination calculations of the previous section, such as heavily contaminated bushings, parallel protective gaps should be installed on the system ahead of current transformers. Such gaps should be set to coordinate within the spectrum of lightning arrester characteristics and line design factors—but never greater than either the circuit breaker impulse or switching surge requirements. Thus, if circuit-breaker and current transformer support insulation has a voltage withstand in excess of one per-unit under the most severe requirement, safe and effective insulation coordination is insured through the use of a parallel protective gap. A schematic of an ideally gapped and coordinated circuit breaker-current transformer combination is shown in Fig. 4.

First pole of a 500-kv SF_6 circuit breaker during assembly.



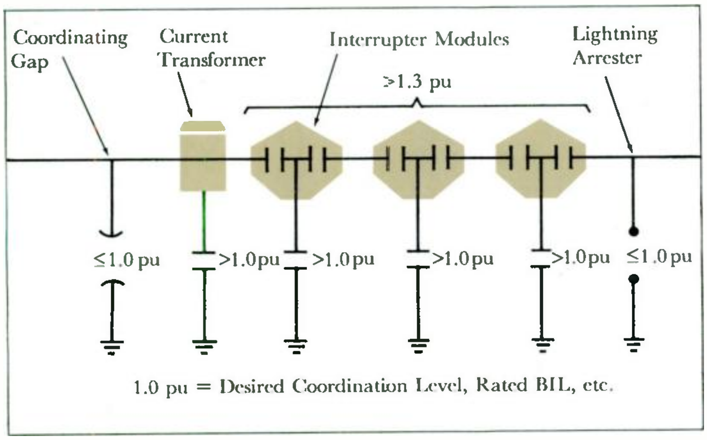
Breaker Performance

The design features originally selected for the new modular breaker were initially built in two prototype modules, from which necessary additional experimental data was obtained. One prototype was tested in the High Voltage Laboratory, and contributed to the development of insulation details, current-carrying ability, and mechanical strength; the second prototype was tested at the High Power Laboratory, and contributed to the development of the mechanical operation and switching performance with various types of currents.

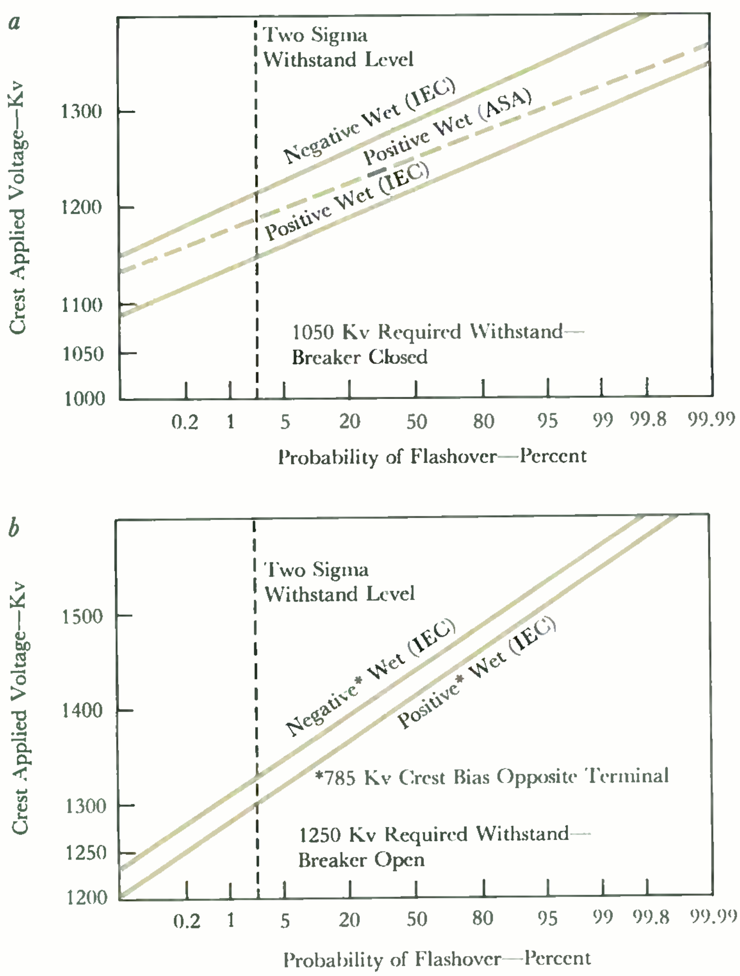
The first 500-kv breakers built were given tests as single-pole units. This expedited testing by permitting one pole to undergo mechanical tests while the second was in the High Voltage Laboratory and the third in the High Power Laboratory. At the conclusion of these single-pole tests, two poles were assembled with normal pole spacing to undergo mechanical operation and voltage distribution tests.

Mechanical Test Results—The 500-kv pole unit assigned to the High Power Laboratory was operated over 2000 times; the pole undergoing mechanical tests also made about 2000 operations, including a life test of 1100 operations without change of parts, and with only one inspection after 270 operations.

To verify the structural strength of the breaker, 100 operations were made with parts subjected to higher stresses than they could possibly encounter in service. For example, the pneumatic mechanism was operated at abnormally high pressures to raise speeds and stresses on the operating parts during closing. The biasing springs were overloaded 25 percent to increase loads on closing and to increase speeds and stresses on opening. In addition, some individual parts, such as insulating tie-rods, operating rods, porcelains, gas reservoirs, and gas tubes were subjected to stresses greater than they could encounter in service. Similar tests were established for components of production line breakers.



4—Ideally coordinated live-tank circuit breaker installation is shown in this schematic diagram.



5—Wet switching surge probability curve for 1550-kv BIL circuit breaker in the closed position (a) and in the open position (b).

The ability of the breakers to withstand high winds and earthquakes was checked by applying, at the top of the porcelain columns, horizontal tension forces that correspond to the calculated loading of winds up to 185 mph. The forces were applied at various angles with respect to the columns because bracing is not the same in all directions. The applied forces corresponded to horizontal accelerations up to 0.6 gravitational acceleration, giving assurance that earthquake loading, usually assumed to be not over 0.2 g's, can be withstood.

Since contact speeds and decelerations are controlled in part by hydraulic cylinders, cylinder operation was tested over a temperature range that went as low as —40 degrees C.

Electrical Test Results—High Voltage Laboratory developmental tests on individual interrupter modules, and verification tests on one pole of a 1550-kv BIL circuit breaker, have demonstrated that a live-tank circuit breaker will coordinate effectively not only at 1550-kv BIL, but equally well at 1800-kv BIL. It has been shown that the breaker can be designed to withstand switching surges in excess of 2.8 per-unit, while remaining within the coordination spectrum dictated by existing 60-cycle and impulse standards. (In discussions of switching-surge voltages, one per-unit equals the maximum rated line-to-neutral, or 450 kv for 500-kv systems.)

Even with all gas pressure lost, the modular circuit breaker design retains considerable dielectric strength. In the open position, the breaker will withstand 60-cycle voltage in excess of twice line-to-neutral, and retain moderate impulse and switching surge strength. In the closed position at zero gauge pressure, the full rated impulse and 60-cycle test values can still be withstood to ground.

The new horizontal circuit breaker bushing has been shown to be much more capable of withstanding atmospheric contamination than a conventional saw-tooth bushing. For example, the dog-bone bushing's flashover voltage, when contaminated and subjected to fog, was always at least 33 percent higher than the conventional saw-tooth bushing; the *wet* withstand of the dog-bone bushing was 15 percent higher than the saw-tooth bushing.

SF_6 for 345 and 500 Kv

The new EHV breaker is now in production for 345- and 500-kv application. These breakers have been subjected to extensive development and design tests to verify their performance. By imposing on the initial components conditions that are much more severe than will be encountered in service, assurance has been gained that breakers made within the tolerances inherent in production line units will provide excellent performance in service.

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Seven Years Experience With Taut-Band-Suspension Instruments

by L. J. Lunas

The frictionless, shock-proof, taut-band instrument suspension system has demonstrated superiority over pivot-and-jewel mechanisms in all types of ac and dc instruments.

Until ten years ago, American instrument manufacturers traditionally had supplied instruments for general industrial and laboratory service with conventional pivot and V-jewel bearing systems and spiral control springs. However, experience with pivot-and-jewel instruments in electric utility and industrial applications had already demonstrated a real need for improvements in sustained accuracy, reduced maintenance requirements, and immunity to environmental influences. Therefore, when several basic European taut-band switchboard instruments[1] were demonstrated in 1954 to be practically immune to repetitive shock tests, genuine interest was generated in this new taut-band suspension system.

Westinghouse immediately initiated a development program to explore the taut-band suspension principle for use in American instruments. The European instrument design had to be further developed for American use for two reasons:

First, the scale-deflection angle was limited to 90 degrees, in contrast with the U.S. switchboard instrument standard of 250 degrees. Since this desired 250-degree deflection required almost three times the twist on the taut bands, basic analysis and development of band proportions and metallurgy were necessary to produce bands and suspension assemblies capable of providing the desired performance.

Second, the European designs were relatively complex and required extensive hand adjustment and alignment. For example, in the European version, the tension spring and anchor subassembly consisted of six detail parts that required careful adjustment in final assembly to center the parts for proper clearance; in the Westinghouse design, this subassembly has been reduced to two detail parts, which are produced on precision tools so that the parts are self-aligning in assembly and require no further adjustment.

By 1958, Westinghouse had completed the development and introduced the first taut-band-suspension, 250-degree-scale instrument.[2] The circular-scale, dc switchboard instruments had been selected for this initial development because of their wide use, particularly in electric utility and industrial applications where shock and vibration problems are often encountered. The taut-band development had made it possible to build electrical measuring instruments that could withstand these severe vibration and shock conditions. Thus, a rugged, trouble-free mechanism had been combined with the inherent accuracy of frictionless taut-band suspension.

The immediate success of these 250-degree dc instruments led to a rapid extension of the taut-band principle to the complete line of Westinghouse instruments, including moving-iron ac instruments[3], wattmeters, varmeters, and frequency meters. The complete line went into production early in 1961. Corresponding pivot-and-jewel instruments were discontinued as the taut-band designs demonstrated their superiority—more reliable instruments with better accuracy due to improved repeatability, lower temperature influences, and reduced operation influence (both short-term and sustained).

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Friction Versus Bearing Life

Pivot-and-jewel bearings and the control spring have always been major sources of instrument trouble requiring maintenance or repair; an estimated 90 percent of instrument repairs involve these components. This problem persists even though the manufacture and processing of the detail parts have been refined and perfected to provide very hard, highly polished pivots that have an extremely low friction coefficient with the polished contact surface of the sapphire V-jewel. Also, the design and processing of spiral springs now provides what appears to be an irreducible minimum in the temporary and permanent zero set, and in reading repeatability as influenced by hysteresis. However, material limitations still require a design compromise between an acceptable amount of bearing friction and longevity of the bearing system.

For a mechanism to deflect to the true reading with the desired repeatability, bearing friction must be minimized by reducing the pivot radius to the minimum possible. However, as pivot radius is reduced, load on the pivot bearing surface increases.[4] This loading will ultimately exceed the elastic limit of available materials, causing the pivot to deform and wear away, particularly under vibration or shock conditions. Thus, from the standpoint of bearing life, it is desirable to provide as large a pivot radius as possible.

The compromise generally followed in instrument design results in a normal static pivot loading of about 60 tons per square inch. Since, under impact conditions, the increase in loading exceeds the ultimate strength of available materials, the pivot surface in contact with the jewel must flatten or deform to provide a contact area sufficient to support the load. The resulting pivot proportions are greater than desirable from the standpoint of friction, but smaller than desirable from the standpoint of bearing life. Consequently, it is necessary to develop a level of operating torque in the pivot-and-jewel mechanism to reduce the influence of bearing friction to an acceptable value.

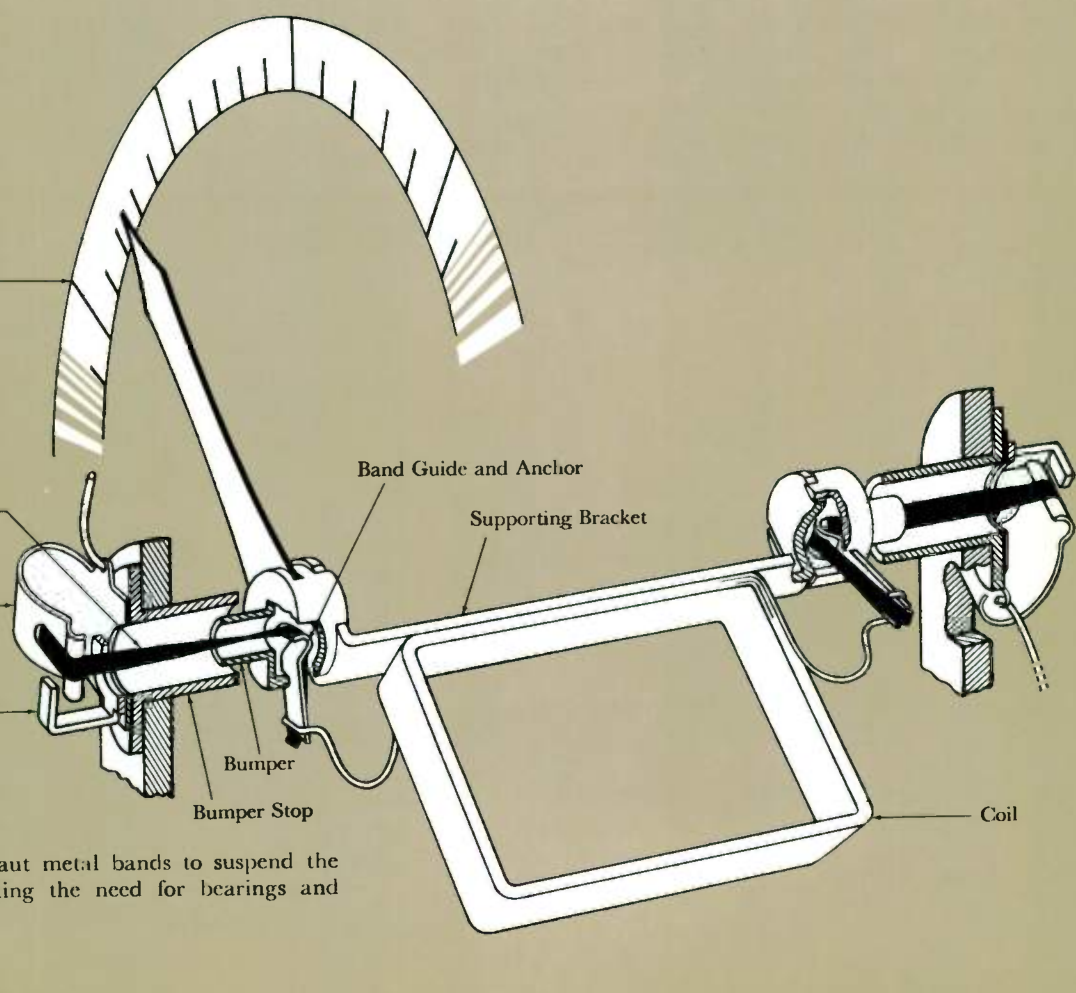
Frictionless Taut-Band Suspension

With the taut-band suspension system, bearings and control springs as such have been eliminated. Instead, the moving element is supported at each end by a short hair-like band of special high-strength alloy, drawn to rectangular cross section (see Fig. 1). The bands are approximately 0.005 inch wide and 0.0005 inch thick, and they are dimensionally controlled to less than five millionths of an inch. The bands are permanently anchored to the moving element of the instrument and to U-shaped springs that maintain proper band tension and contribute immunity to shock and vibration. Small stops prevent excessive axial and radial movement as a further measure of shock-proofing. The rectangular taut bands provide restoring torque and also carry current to the moving coil.

Successful design of taut-band suspension instruments requires a "clean-sheet-of-paper" approach. Any attempt to adapt taut-band bearings to existing designs of pivot-and-jewel mechanisms would severely limit the potential performance of taut-band systems. Thus, moving-element weight and inertia must be re-evaluated to minimize inertia and to provide minimum weight with maximum strength and stability. By reducing inertia, mass, and operating torque, critical damping with little overshoot and optimum response time can be more easily achieved. The allotment of relative space for torque-producing components and bearing systems requires reapportionment. The complete redesign of the moving element obviously requires redesign of the stationary parts of the mechanism. Some of the more difficult design and manufacturing problems that had to be solved during instrument design were: optimize material characteristics, proportions, and processing of the suspension band; develop means for producing proper band tension; design limit stops to confine the travel of the element in vibration and shock to safe values to prevent breakage or failure; design methods for centering the mechanism with proper clearance; and design termination anchors for the bands. The successful solution of these problems resulted in a mechanism free of the inherent friction-versus-life limitations of pivot-and-jewel bearings.

Torque and Temperature

The production of instrument operating torque requires power input, which must ultimately be dissipated as heat. The magnitude of power input determines the limit of such performance factors as sensitivity, overload capacity (momentary and sustained), loss (power consumption), operation influence (short-time and sustained), effect of extreme ambient temperatures, wave-form influence (in rms-responding instruments), terminal



1—TBS suspension system uses taut metal bands to suspend the moving element, thereby eliminating the need for bearings and control springs.

resistance, frequency influence, shunt lead resistance, and operating temperature range.[5]

The major temperature influences on instrument accuracy are:

1) Change in resistance of the copper wire of the activating coil (approximately 0.393 percent per degree C);

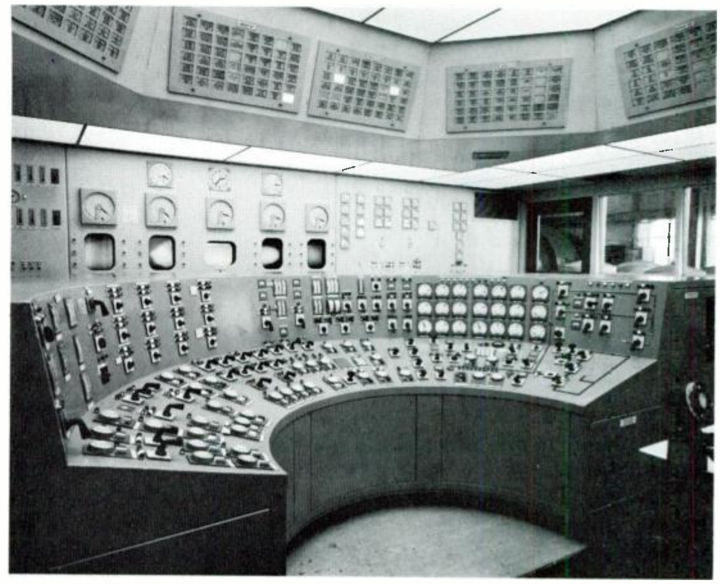
2) Change in the strength of the magnetic field in permanent-magnet, moving-coil instruments (magnet weakens 0.02 percent per degree C rise);

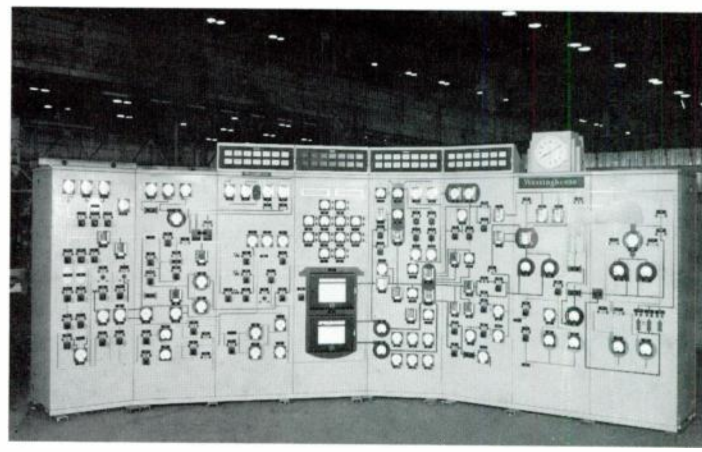
3) Change in spring strength (0.04 percent per degree C).

The weakening of the spring with temperature rise is partially offset by a weakening of the magnetic field, leaving a net difference of 0.02 percent per degree C, or one percent for a 50-degree change.

Voltmeters and millivoltmeters, which ultilize external series resistance, can be designed to be theoretically free of temperature influence by proportioning the ratio of the zero temperature coefficient of the series resistance to that of the moving-coil resistance; thus, the overall effect of a temperature change on the instrument circuit can be made to compensate for the changes in spring strength and magnetic field. However, the perfect compensation needed in high-accuracy instruments is difficult to obtain. For example, the various components of the instrument have different thermal capacities, which result in a variation in the rate of temperature rise. The moving coil is most sensitive, heated by its own watt loss; next comes the temperature rise of the torque springs, which is mainly due to the current in the springs and to a lesser extent to heat radiated from the moving coil. The magnet, with relatively large thermal capacity, is not affected substantially by current but responds slowly to changes in ambient temperature. Thus, the surest way to reduce temperature influence is to *reduce power input*, i.e., reduce the required operating torque.

Since taut-band-suspension mechanisms have no friction to overcome, the lower limit of operating torque level is determined by the force required to overcome moving-element inertia and produce the desired damping and response time. A further consideration is the practical manufacturing limitation in maintaining stability of moving-element mechanical balance to minimize position influence. Therefore, the net result is a reduction in operating torque for taut-band systems to about one-third that required for pivot-and-jewel mechanisms. Reduced operating torque requirements mean fewer ampere turns: only one-third as many turns are needed on the moving coil. If full advantage is taken of the available winding space, the wire cross-sectional area can be tripled, thus reduc-





TBS instruments (*top*) monitor performance of the No. 5 Unit generators and 230-kv circuits at Public Service Electric and Gas Company's Sewaren Generating Station.

Centralized control board (*center*) for the BR-3 Belgian reactor is shown in shop after construction, prior to shipment overseas.

Automatic calibrator (*bottom*) and scale-marking machine is used to calibrate and mark each scale division of high-accuracy TBS portable instruments.

ing resistance (and therefore watt loss) to one-ninth. Thus, temperature rise and change in moving-coil resistance is much less for a taut-band system, and temperature influence is reduced significantly.

The increased cross-sectional area also makes possible a large increase in overload capability, both momentary and sustained. For example, a 250-degree, 0—1-ma milliammeter with taut-band construction can carry 150 ma continuously without damage.

Applications With Reduced Power Consumption

Reduced power consumption of taut-band instruments has made possible broadened or improved applications. A typical illustration is provided by the one-milliampere, dc, 250-degree instrument: a pivot-and-jewel design has a moving-element resistance of 180 ohms and requires 0.18 milliwatts for full-scale deflection; the equivalent taut-band instrument has only 13 ohms resistance and a power consumption of 0.013 milliwatts. Thus, the current loss for a shunt-operated ammeter with taut-band suspension is only one milliampere, but it is 10 to 20 milliamperes with pivot-and-jewel mechanisms. The reduced millivolt drop in the shunt leads makes it possible to use smaller wire for leads or permits much longer lead runs between the instrument and the shunt. An example illustrating the advantage of instruments with reduced power consumption is provided by a power station that needed an indication of megawatt and megavar loading of the power transformers, which were located 670 feet from the control room. Watt and var transducers having 100-mv output at full load were available at the transformers. It was first planned to use conventional millivoltmeters connected in parallel to indicate the loading, until tests showed that instrument power requirements were beyond the transducer capability. (The circuit resistance of a number 12 copper-wire pair for this distance is 2.3 ohms.) Milliammeters connected in series were then considered, but again the loading exceeded the transducer capacity. (The typical pivot-and-jewel milliammeter rated 0—1 ma has a resistance of 180 ohms, which causes a 180-mv drop; transducer output terminal rating is only 100 mv.) A taut-band instrument solved the problem. The 0—1-ma milliammeter, with a resistance of only 13 ohms to be added to the 2.3 ohms line lead resistance, caused a total drop of less than 16 millivolts. The only other solution would have been some form of self-balancing potentiometer system, which would have been more complex and more expensive.

Because of the extremely low power consumption of the taut-band suspension system, the permanent-magnet moving-coil instrument is no longer limited to the usual dc voltage and current measurement. Its low power requirement makes it feasible for use with suitable transducers to measure watts, vars, and frequency.[6]

Experience With TBS

The original taut-band-suspension models were exhaustively performance tested and life tested. In comparative life tests, no movement deterioration was encountered on the taut-band instruments after 50 million or more full-scale oscillations; in contrast, conventional pivot-and-jewel instruments required bearing replacement after less than one million oscillations. The new instruments also were found to be practically immune to damage from vibration and shock levels that made pivot-and-jewel instruments inoperable.

As part of the initial field-testing program, all taut-band instruments needing attention were returned to the factory. Over a one-year period, with several thousand instruments in use, fewer than a dozen were returned for repair.

Table 1—Comparison of Taut-Band Instruments versus Pivot-and-Jewel Instruments

Characteristic	*TBS*	*Pivot-and-Jewel*
1. Sensitivity	+	—
2. Vibration (effect of)	+	—
3. Shock (effect of)	+	—
4. Repeatability	+	—
5. Overload (momentary)	+	—
6. Overload (sustained)	+	—
7. Tracking	+	—
8. Effect of use (lifetime)	+	—
9. Loss (power consumption)	+	—
10. Operation influence (short-time and sustained)	+	—
11. External temperature influence	+	—
12. Effect of extreme temperatures	+	—
13. Wave-form influence (rms responding instruments)	+	—
14. Terminal resistance	+	—
15. Frequency influence	+	—
16. Shunt-lead resistance	+	—
17. Self-contained ranges	+	—
18. Operating temperature range	+	—
19. Damping factor	+	—
20. Response time	=	=
21. Rated accuracy	+	—
22. Dielectric test	=	=
23. Zero-set (temporary and permanent)	+	—
24. Position influence	=	=
25. External-field influence	+	—
26. Magnetic platform influence	+	—
27. Humidity (effect of)	=	=
28. Proximity influence	+	—
29. Pointer shift due to tapping	+	—

This analysis is based on the assumption that each instrument is designed for optimum performance. Absence of bearing friction in taut-band instruments permits significantly lower operating torque, which results in higher sensitivity. The tabulation compares the Westinghouse taut-band design with recognized standard performance of pivot-and-jewel instruments:

+ sign indicates superior performance
— sign indicates inferior performance
= sign indicates equal performance

TBS ac and dc ammeters and voltmeters are used as comparison standards in a ± 0.25 percent accuracy, direct-reading Instrument Calibration Standard for voltages from 0.25 millivolt to 2000 volts, and currents from 2 microamperes to 20 amperes.

Photo courtesy Radio Frequency Laboratories, Inc.

Sensitive video electronic voltmeter with logarithmic scale having ranges from 100 microvolts to 100 volts over a frequency span from 2 cps to 6 mc. All scale divisions of the taut-band suspension instrument are individually calibrated and marked making possible unusually high accuracy and repeatability.

Photo courtesy Ballantine Laboratories, Inc.

Resistance to shock damage was highlighted in a service report received from an instrument service man, who was sent to make repairs on switchgear shipped to an island in the Far East. The assembly apparently had been dropped during dockside or on-site loading or unloading, and damage was severe. Panels were bent, brackets and supports cracked and broken, and practically every type of component such as switches, relays, watt-hour meters, and instruments suffered damage and required repair and recalibration. Instrument pivots were broken, jewels cracked, dials bent, and screws loosened. But the final statement in the two-page report read: "The only bright spot in this whole situation is that, of the 21 taut-band instruments, all except one were undamaged and in calibration. The lone casualty suffered a broken band."

Particularly severe service conditions have demonstrated the stamina of the taut-band design. One of the railroads in the South reports that pivot-and-jewel ammeters on diesel locomotives required frequent repair with overhaul and recalibration on an average of every eight months; occasionally servicing was needed as frequently as every 30 days. Taut-band instruments in this same service for four years have required calibration adjustment only twice, with no parts replacement.

In another example, a paper mill had established a servicing routine in which all instruments were checked, repaired, and adjusted twice a year during regular shutdowns. It was always found necessary to replace a large percentage of pivots and jewels, rebalance the instruments, and adjust calibration. Taut-band instruments were installed and, after a year's service, they remained free of friction, were in balance, and were well within guaranteed accuracy.

Although the outstanding performance of taut-band instruments is most apparent in severe service conditions, the higher performance level has been just as impressive in other situations where vibration or shock may not be a problem but where sustained accuracy and repeatability are needed, or where high sensitivity and minimum possible loss are required. For example, high accuracy and repeatability are especially needed in certain electronic test equipment, such as vacuum tube voltmeters and decibel meters. These instruments frequently have logarithmic scales with accuracy specified on the basis of the reading rather than as a percentage of full scale. Low loss and absence of bearing friction make the taut-band suspension instrument ideally suited to this type of service.

Westinghouse ENGINEER
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Estimating Transmission Line Shielding Performance

by F. S. Young
J. M. Clayton
A. R. Hileman

A geometric analysis of the lightning stroke, ground wire, and phase conductor has provided a graphical method for estimating shielding performance.

Most investigations of the lightning performance of transmission lines have emphasized the stroke mechanism and the probability of insulator flashover when the stroke terminates on the tower or ground wire. However, the difficulty of making line performance estimates agree with actual performance records has prompted several investigators to take a closer look at the effectiveness of ground-wire shielding. Results of these investigations suggest that many outages previously attributed to strokes to ground wire or tower actually have been shielding failures, which have allowed strokes to terminate directly on the phase conductor. Common practice has been to shield transmission lines with ground wires that have shielding angles (with respect to phase conductors) of 20 to 45 degrees. New calculations now indicate[1, 2] that ground-wire shielding effectiveness is a function of both ground-wire height and shielding angle, and that shielding angles as low as 10 degrees are required to provide adequate protection for today's extra-high-voltage lines. As a result of one investigation, a simplified graphical method[2] has been developed for estimating ground-wire shielding effectiveness.

A Geometrical Approach

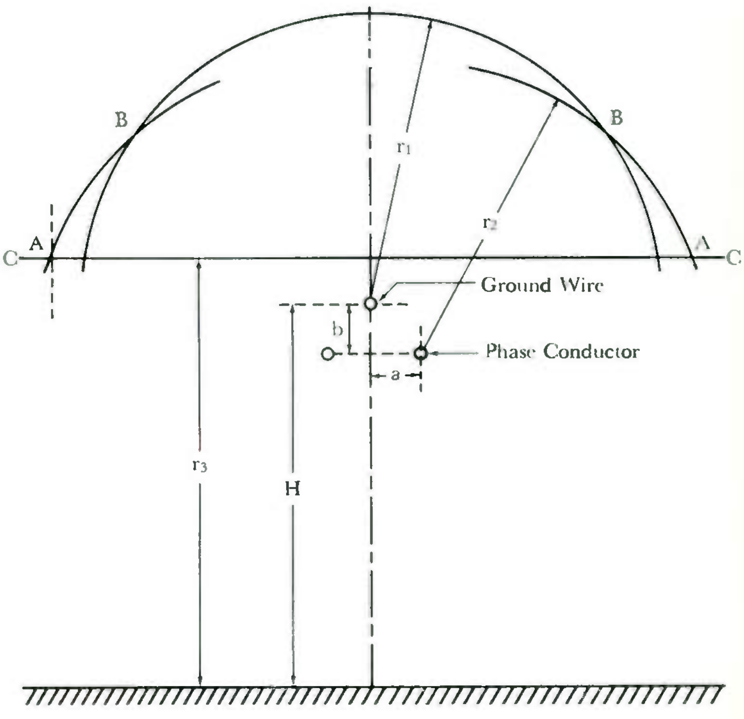
The approach used to derive the graphical estimating method is based on a geometric model of the lightning stroke, ground wire, phase conductors, and ground. Briefly, the stroke leader is assumed to be relatively unaffected by grounded objects until it is within approximately 140 to 480 feet of the terminating object. At some point, the voltage between the leader head and ground is sufficient to break down the remaining air gap, thereby completing the stroke channel and resulting in the lightning discharge. In this analysis, the stroke is assumed to select the ground wire, phase conductor, or ground depending on the distance, voltage, and voltage gradient between the leader head and ground-terminating object. A recently developed stroke model[3] has made possible a much more accurate calculation of these variables.

The geometry used to determine phase exposure is shown in Fig. 1. The striking distance calculated for the stroke appears in this diagram as radius r_1 for the ground wire, r_2 for phase conductors, and r_3 to ground. Thus, if the downward leader reaches a point between *B* and *B* along the arc of the circle, the stroke terminates on the ground wire; if the leader reaches the arcs between *A* and *B*, the stroke terminates on the phase conductor; leaders that reach the line between *A* and *C* terminate on ground.

From this geometrical model, the distribution of strokes between ground wire, phase conductor, and ground can be determined as a function of height. This data is then combined with the estimated exposure of the line to lightning strokes to obtain a complete family of shielding curves for locating ground wires with respect to phase conductors. Typical curves from this set are shown in Fig. 2. (The complete set of curves for ground-wire heights of 40 to 160 feet, in 10-foot increments, can be found in reference 2, along with a derivation of the method used to obtain them.)

The curves were developed assuming an isokeraunic level of 30 (storm days per year). For other storm levels, the number of shielding failures is assumed to vary directly with isokeraunic level. Using the isokeraunic level of 30, the number of strokes to lines of various ground-wire heights can be calculated. For example, a 90-foot ground wire should receive 96 strokes per 100 miles per year, as shown on Fig. 2a. The number of strokes is not given on the curve sets for 4 and 8 shielding failures (Figs. 2b and 2c) because the total number of strokes to the ground wire and phase conductors varies, and depends to some extent on conductor location. However, the total number of strokes will be greater than for the no-shielding-failure condition because a line with shielding failures will collect strokes over a wider swath.

These stroke values are based on single-ground-wire lines, ignoring line sag. However, on many lines it may not be practical to obtain essentially perfect shielding with one ground wire. Shielding requirements may be the most im-



1—Exposure of phase conductors was calculated from this geometric model of lightning stroke, ground wire, phase conductors, and ground.

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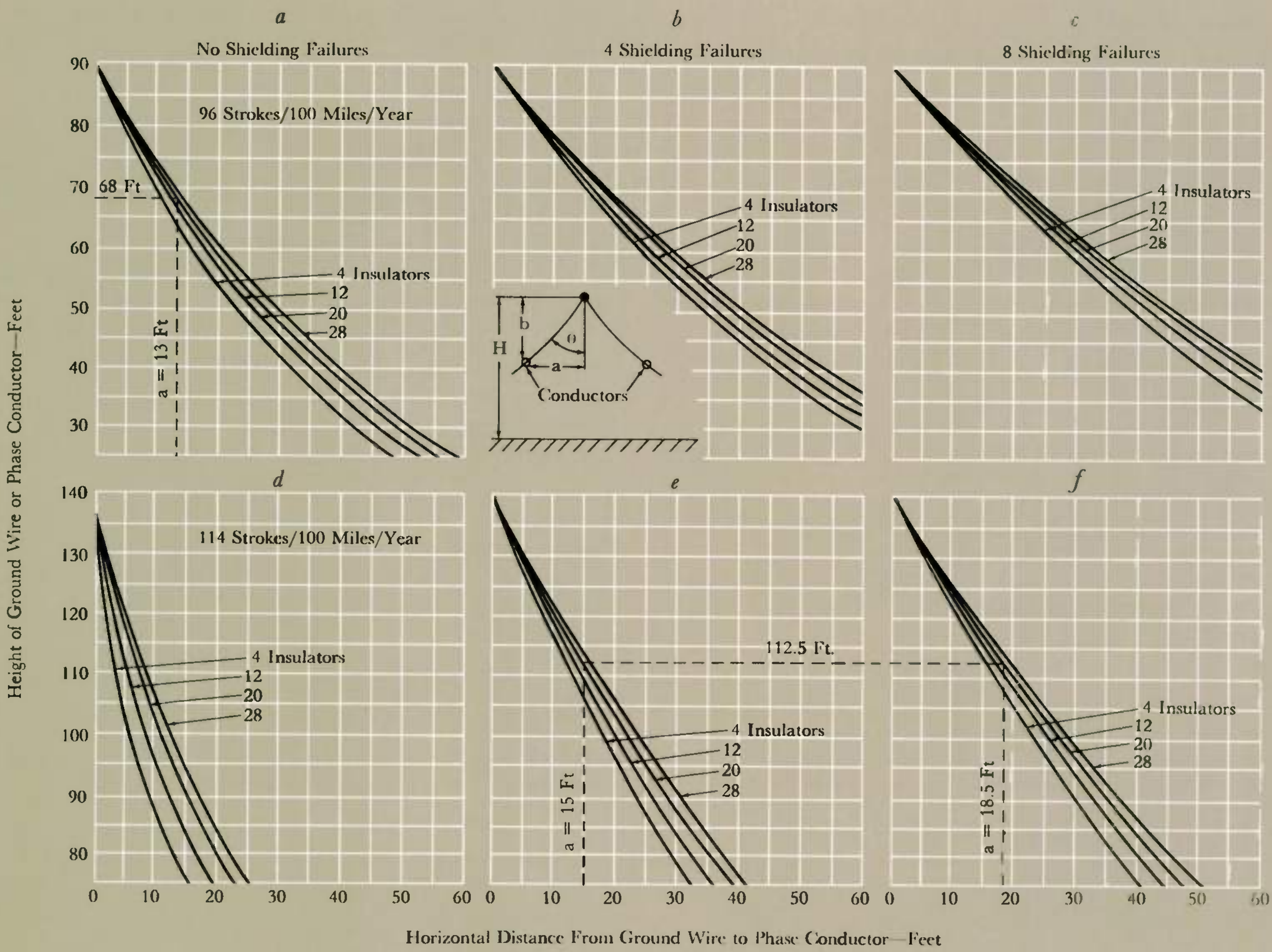

a
No Shielding Failures
96 Strokes/100 Miles/Year
68 Ft
a = 13 Ft
4 Insulators
12
20
28
b
4 Shielding Failures
4 Insulators
12
20
28
H
b
θ
a
Conductors
c
8 Shielding Failures
4 Insulators
12
20
28
d
114 Strokes/100 Miles/Year
4 Insulators
12
20
28
e
112.5 Ft.
a = 15 Ft
4 Insulators
12
20
28
f
a = 18.5 Ft
4 Insulators
12
20
28
Height of Ground Wire or Phase Conductor—Feet
Horizontal Distance From Ground Wire to Phase Conductor—Feet

portant consideration in choosing between one and two ground wires. The total number of strokes will be somewhat greater for lines with two ground wires because these lines will collect strokes over a wider swath. However, for the same shielding angle the number of shielding failures will not be affected by the second ground wire because shielding failures cannot result from strokes originating in the region above and between the two ground wires.

The shielding curves give the number of shielding failures that result in flashover of line insulation, but this does not include strokes to phase conductors of insufficient magnitude to cause flashover. Hence, the number of shielding failures resulting in flashover can be shown as a function of line insulation, as indicated in Fig. 2. Minimum current to cause flashover is determined from the relationship, $I = 2E/\mathcal{Z}$, where I is the minimum stroke current that will cause flashover, $\mathcal{Z}$ is surge impedance (450 ohms) of the phase conductor, and E is the critical flashover voltage of the standard suspension insulator string. The sensitivity of the shielding curves to the number of insulators is an indication of the number of strokes to phase conductors that do not cause flashover.

Application of Shielding Curves

Two general classes of problems can be solved using the shielding curves of the type shown in Fig. 2. In designing a line, ground wire and phase conductor configuration can be determined to provide some desired level of shielding performance; or where transmission line configuration is already established, the shielding effectiveness of the ground wire can be determined. Both problems will be illustrated with examples.

Line Design—Consider a typical line design for 345 kv, which uses 18 insulators, a ground wire height of 90 feet at the tower, top conductor height at the tower of 68 feet, and ground wire and conductor sag of 20 feet at midspan.

Referring to the insert in Fig. 2b, the vertical distance between ground wire and conductor (b) will be $90 - 68 = 22$ feet; the horizontal distance (a) is to be determined so that no shielding failures will occur.

The shielding curves for a 90-foot ground wire with no shielding failures are shown in Fig. 2a. For a phase conductor height of 68 feet and phase insulation of 18 insulators, horizontal distance (a) is found to be 13 feet (or less). This corresponds to a 30-degree shielding angle between the ground wire and phase conductor for essentially perfect shielding.

At midspan, where ground wire and phase conductor are 70 and 48 feet above ground, respectively, the horizontal distance would be similarly determined from the curves for a 70-foot ground wire[2]; horizontal distance would be found to be 17 feet, which corresponds to a shielding angle of about 38 degrees. Therefore, if a 30-degree shielding angle is adopted, a sufficient margin of safety will exist to allow for conductor swing between towers.

Performance of Existing Line—To illustrate the converse calculation of the above, consider the 345-kv, double-circuit line shown in Fig. 3. The line has 1000-foot spans, 18 insulators, and ground wire and conductor sags of 35 and 40 feet respectively. Ground wire height at the tower is 150 feet; the top phase conductors are spaced 26 feet below the ground wire, and 17.75 feet horizontally from the ground wire.

The required steps in calculation are summarized in Table I. The 35-foot ground-wire sag is first divided into 10-foot increments so that ground-wire heights will correspond to the heights used in the family of shielding curves[2]. From a catenary curve of the ground wire (Fig. 3b), span positions corresponding to these heights are located so that effective span length (ΔL) of the ground wire for each chosen height can be determined. Phase conductor height at these same span positions can be calculated[2], and vertical distance from ground wire to conductor can be determined. With this information (tabulated in the first four columns of Table I), shielding performance can be obtained by interpolation from the shielding curves.

To illustrate the graphical process, consider the ground-wire span at the 140-foot height, for which shielding curves in Figs. 2d, 2e, and 2f apply. Conductor height at this point is 112.5 feet; thus, for 18 insulators, the four-failure curve (Fig. 2e) gives a horizontal distance of 15 feet; the eight-failure curve (Fig. 2f) gives a horizontal distance of 18.5 feet. Therefore, a horizontal distance of 17.75 feet will have a failure rate between 4 and 8 and can be solved by linear interpolation to be 7.1 failures (per 100 miles per year). This same process is used to determine the failure rate at each ground-wire height. (Since the mid-position height is 115 feet, the curve for a 120-foot ground wire must be used if the curves from reference 2 are applied.)

The shielding failures thus determined are tabulated in the fifth column of Table I. However, since these failure rates only apply to the particular span section (ΔL) for the given height, each failure rate must be multiplied by the ratio, $\Delta L/500$, and the results added to obtain a weighted value of shielding failure for the line. The value obtained in this example, 3.9 failures per 100 miles per year, is the total number of shielding failures for both circuits. Single-circuit failures can be obtained by dividing by two.

Since the shielding curves apply for lines located in an area with an isokeraunic level of 30, shielding performance for a line located in an area with a different isokeraunic level can be obtained by direct ratio: thus, if the isokeraunic level is 45, shielding failure rate will be $3.9\ (45/30) = 5.85$.

2—These shielding curves, showing location of conductors shielded by ground wires at 90 and 140 feet, are typical of a complete set[2] calculated for ground-wire heights ranging from 40 to 160 feet, in 10-foot increments. The number of shielding failures is based on an isokeraunic level of 30 and conductors on both sides of ground wire.

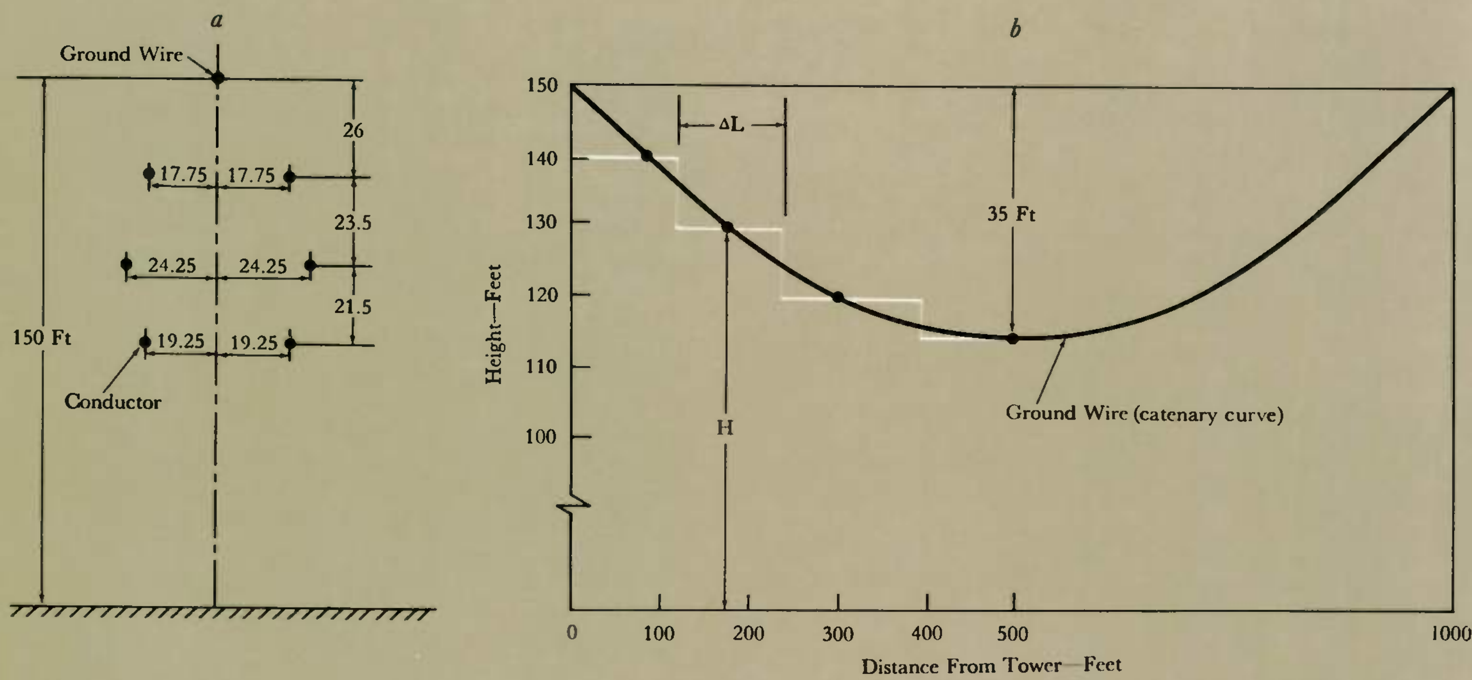
Insulators, Shielding Angle, and Tower Height

Using the shielding curves, sample calculations have been made to illustrate the effect of the number of insulators, shielding angle, and tower height on shielding failures.

Table 1—Summary of the calculation of shielding performance for the line illustrated in Fig. 3.

H (*ground wire height, feet*)	ΔL (*effective span for ground wire height, feet*)	*Conductor Height, Feet*	*b** (*ground wire height minus conductor height, feet*)	*Shielding Failures per 100 Miles per Year for* ΔL	*Shielding Failures per 100 Miles per Year* (*adjusted for span*)
150		124.0	26.0		
140	127.5	112.5	27.5	7.1	1.81
130	112.5	101.1	28.9	4.0	0.90
120	162.5	89.7	30.3	2.9	0.94
115	97.5	84.0	31.0	1.3	0.25
					3.90

**a* = 17.75 feet



3—**(a) Conductor and ground-wire** configuration of the AEP, OVEC 345-kv line. Span length is 1000 feet, number of insulators is 18, and the average sag of ground wire and phase conductor is 35 and 40 feet, respectively. **(b)** Catenary curve is used to divide ground-wire span into increments (ΔL) having constant heights (H).

Shielding failures that result in flashover of the line insulation as a function of standard suspension insulators are shown in Fig. 4. As indicated, the number of shielding failures is independent of the number of insulators until the number of insulators exceeds 5.5. This is because the minimum lightning stroke current considered is 2400 amperes, which will develop slightly more than enough voltage to flash over five insulators (when discharging into a conductor having a surge impedance of 450 ohms).

As the number of insulators increases above 5.5, the number of shielding failures decreases. Actually, it is the number of shielding failures that result in insulation flashover that decrease, because the number of shielding failures will be independent of line insulators. However, since shielding failures that do not result in line flashover are ignored in this analysis, the failures that cause flashover can be considered a function of the number of insulators. If it is desirable to position the ground wire to eliminate *all* shielding failures, rather than just those that cause flashover, the four-insulator shielding curve should be used. Likewise, the total number of shielding failures for an established ground wire position can be found using the four-insulator curve.

The relationship between shielding failures and shielding angle for two typical tower heights is shown in Fig. 5. These calculated curves demonstrate that shielding failures increase appreciably with increasing shielding angle. Also, the curves reflect the smaller shielding angles required for the higher towers used on EHV lines.

The required shielding angle for essentially perfect shielding, as a function of tower height, is shown in Fig. 6. This curve was developed using a typical ground wire and conductor arrangement, and number of insulators. The need for smaller shielding angles as tower height increases is clearly demonstrated. Thus, the shielding angles from 45 to 30 degrees commonly used at voltage levels up to 230-kv, have been satisfactory on conventional towers ranging from 50 to 90 feet high. However, towers used on EHV lines may be as high as 150 feet, and require shielding angles as low as 10 to 12 degrees.

In the practical situation, it is recognized that the electric fields associated with lightning strokes do not necessarily follow uniform patterns; and therefore, the final flash may not always be to the object indicated by a geometric analysis. However, the geometric model has provided a practical approach to the problem of locating ground wires with respect to phase conductors. And based on presently available information, the estimates obtained with this analytical approach agree substantially with observed line performance.

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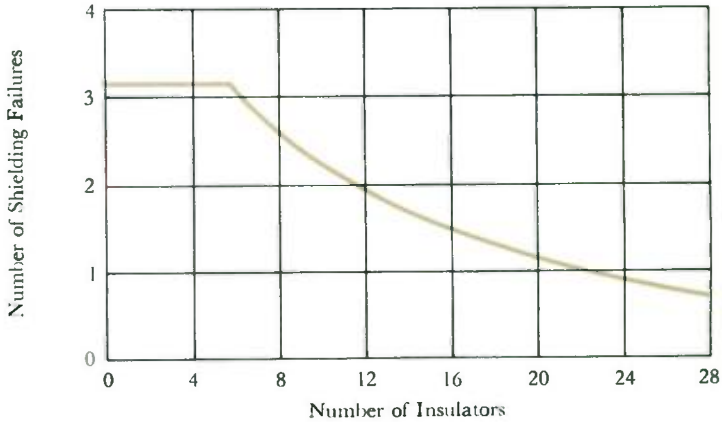
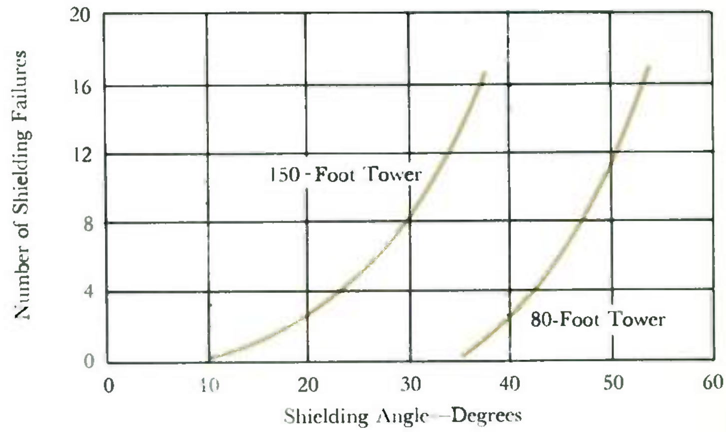
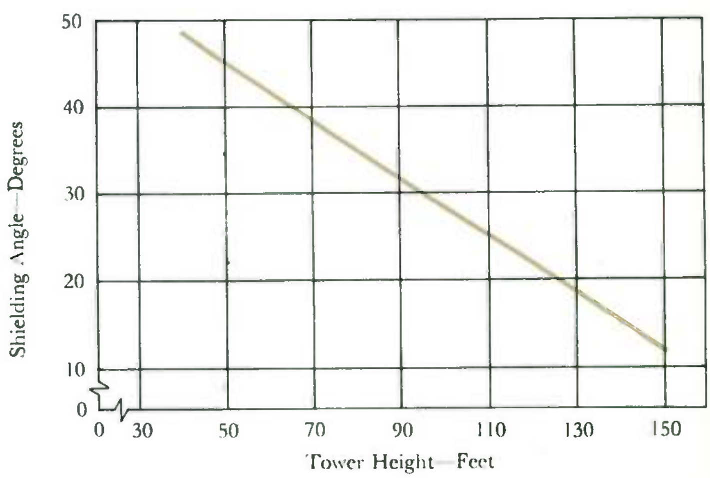


4—Number of shielding failures for 100 miles per year is shown as a function of number of insulators for a ground wire having a constant height of 80 feet ($a=8$, and $b=10$ feet).



5—Number of shielding failures per 100 miles per year is a function of shielding angle, as shown here for two ground-wire heights.



6—Shielding angle is a function of tower height, as shown here for essentially perfect shielding.

NMR Spectrometer Has Superconducting Magnet

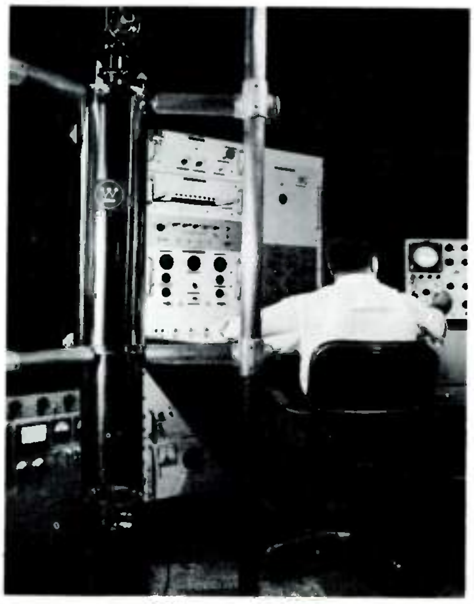
Nuclear magnetic resonance (NMR) spectrometry, though new, is a technique that has been growing rapidly in importance in the field of analytical chemistry. A sample to be analyzed is placed in a magnetic field and simultaneously irradiated with radio-frequency energy. The spectrogram of r-f transmitted energy versus magnetic field is characteristic for each chemical compound and is thus a means of identification. Equally important, the technique makes it possible to visualize the locations of the component atoms in the compound.

The first commercial NMR spectrometer with a superconducting magnet was supplied recently to the chemical engineering department at Rice University. The instrument is a Model PS-60A pulsed NMR spectrometer manufactured by NMR Specialties, Incorporated, New Kensington, Pennsylvania. Its Westinghouse superconducting magnet is rated 25 kilogauss and has a field uniformity of better than one part in 10^6.

Use of a superconducting magnet is the only means of getting very high field intensities combined with the high field uniformity required for NMR spectrometry. The combination increases the resolution of NMR spectra. Superconducting magnets also impart flexibility and versatility; for example, any desired field up to the limit of the system can be obtained with the turn of a dial. The magnet also is portable, weighing only 200 pounds instead of the approximately six tons of a comparable conventional electromagnet.

Many magnetic nuclei can be investigated with the instrument at one fixed frequency. Frequencies also can be varied to provide an even wider range.

Pulsed NMR spectrometry differs from continuous-wave techniques by applying a high-intensity short-lived rf signal to the sample. The decay signal of the nuclear relaxation process, after excitation by a single pulse or series of pulses, can be observed or recorded. The results lead to determination of either the longitudinal or the transverse relaxation times, depending on the mode of operation of the spectrometer. The data can be obtained from solid, liquid, or gas samples for studies in such areas as spin-spin interaction, diffusion coefficients, interatomic distances, motional spectra, and paramagnetic impurity effects.



Nuclear magnetic resonance spectrometer has a superconducting magnet to provide the high field intensity and uniformity required. The magnet is housed in the cylinder in the left foreground.

Beam Pattern Viewer Aids Study of Lasers

The beam of a laser includes infrared rays that form the so-called "far-field" patterns in the beam. This radiation is far too low in frequency to stimulate the eye or photographic film, yet it can tell the experimenter a great deal about the operating characteristics of a laser. To make the far-field radiation patterns visible for study, a new instrument called an infrared pattern viewer has been devised. Its sensing element is made from liquid-crystal materials, unusual compounds that have some of the properties of a liquid and some of the properties of a solid.

One of the more striking characteristics of these compounds is that they respond to temperature changes by sudden dramatic changes in color. The infrared pattern viewer makes use of this color change to display the laser's radiation pattern. Compounds of cholesterol have been found to be the most useful liquid crystals for showing small temperature differences. (A comprehensive research program at the Westinghouse Research Laboratories has shown that the cholesteric liquid crystals are delicate sensors of pressure, chemical vapors, and electrical fields as well as of temperature.)

The simple heat detector in the viewer consists essentially of a thin film of the liquid crystals supported on a blackened membrane and mounted in a small vacuum chamber. On one side, a mercury lamp and an adjustable heat lamp are aimed at the film. On the other side, the laser is mounted so that its beam strikes the surface of the film. The film is observed from the mercury-lamp side. (See photograph, inside front cover.)

The heat lamp is adjusted to raise the film to the desired temperature. Then the laser beam is shone on the opposite side of the film, where it is absorbed and causes a pattern of further temperature rise. The color shift in the light supplied by the mercury lamp and reflected by the liquid crystals forms a visible pattern that can be watched continuously as the laser shifts its mode of oscillation due to its own instability or because of changes made in its conditions of operation.

The usefulness of the pattern viewer is not limited to infrared radiation. Any optical radiation—including visible light and ultraviolet—that heats the liquid-crystal film is displayed with equal ease and clarity.

Molecular Electronics Enhances Machine-Tool Control Reliability

Molecular electronic devices incorporated in a new machine-tool numerical control enhance the control's reliability and also make it more compact. Initial applications of the two-axis digital control will be on drills, punches, small milling machines, and similar tools. It was developed jointly by the Westinghouse Systems Control Division's numerical control group and the Aerospace Division's advanced development group.

Molecular electronic devices combine, on a single chip of silicon, several diodes, transistors, resistors, and their circuit interconnections to form a complete logic function in a package the size of a conventional transistor. This configuration greatly reduces the number of solder joints and connectors in a system, thereby enhancing reliability. It also reduces power requirements and makes for compact yet accessible construction. The use of silicon semiconductors throughout, including the molecular electronic devices, permits the logic system to be housed in a nonventilated cabinet without air conditioning. Because of its small size, the control cabinet can be mounted on a wall, a column, or the machine.

The control system normally includes step-motor servos for axis positioning. However, it is also designed for use with dc servos, hydraulic servos, and multispeed clutched drives.

Positive and negative programming is a standard feature, as is relocatable zero and 0.001-inch minimum programmed increment. Positive and negative programming is a means for determining on which side of the zero reference point a programmed point lies. It is accomplished by prefixing the proper sign to the dimension number for each axis of the machine motion.

The combination of positive and negative programming with relocatable zero simplifies the programming of symmetrical patterns. By moving the zero reference point from its normal place near a corner of the table to the center of symmetry of the pattern—say a circle of boltholes—dimensions calculated for one quadrant of holes can be used for the other three quadrants, and only the signs need be changed in the program.

The control reads commands from perforated tape one line at a time in word-address format. As many as 20 auxiliary and machine functions can be programmed. Dimension commands are programmed in absolute coordinates from a reference location, and the servos position the machine in both axes simultaneously. Optional additional features have been developed to make the control flexible in application. These include manually controlled or programmed milling in one axis of machine motion at a time; selection of up to 20 feeds, spindle speeds, and tools; and manual command input through dial switches.

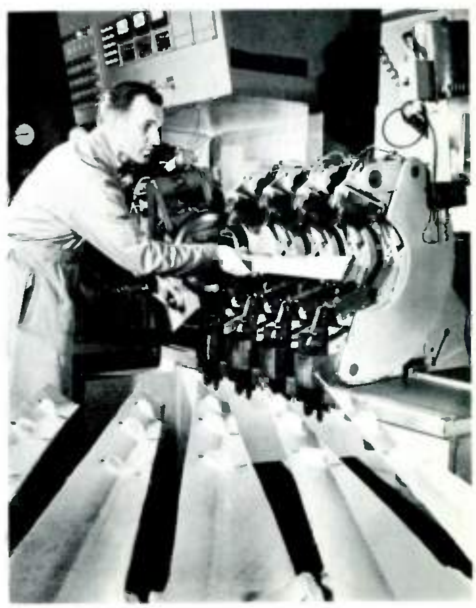
Numerically Controlled Machines Produce Uniform Turbine Blades

Blades for large steam turbines are precision forged and machined from high-quality material to assure proper contours and reliability. Since there may be several hundred blades in a single turbine wheel, manufacturing and checking the blades is an exacting production task.

A new blade production line at the Westinghouse Large Turbine Division includes tape-controlled machines for manufacturing flexibility and product reliability. Manufacturing flexibility is improved by reduction of lead time for new products, easier modification of designs, lower tool costs, reduction in the number of machines required, reduction of work in process, and reduction of inventory reserve. Product reliability is assured by elimination of human error, uniformity of operation, and automatic checking of each cycle of the operations.

Blade roots are machined by a rotary-index mill that can handle side-entry blades up to 10 inches wide and 50 inches long (see photograph). Machining is done at eight stations around the 32-foot circumference of the index table. The numerically controlled machine tool can machine 38 different blade styles.

Blade forgings or finished blades are straightened by another numerically controlled machine (see photograph). It accepts blades 16 to 50 inches long and 7 inches wide. The machine is tape-pro-



Steam-turbine blades are precision forged and machined to assure proper contours and reliability. The blade-root mill and blade straightening machines shown at right help assure the required quality and also improve manufacturing flexibility.

grammed to correct for twist only, for bow only, or for twist and bow together. A separate tape is provided for each blade type or series. Tapes can be made for any number of blade forms.

In operation, the blade-straightening machine gauges the blade, applies pressure where needed to correct it, and then gauges it again. The gauging and correction cycle repeats automatically, with the number of cycles desired (up to 20) dialed in by the operator. The blade can be clamped at up to five locations along its length. The machine can also be used as an inspection machine; in this mode, it checks forgings or finished blades without correcting them.

EHV Test Center Opened

An outdoor electrical testing laboratory built to meet and anticipate the fast-growing needs of extra-high-voltage (EHV) power transmission has been placed in operation by Westinghouse at Trafford, Pennsylvania. The new EHV Test Center is equipped initially to test electrical equipment with ratings up to 1000 kv. Test data from the center will be used with analytical studies in the development of more efficient and economical EHV products.

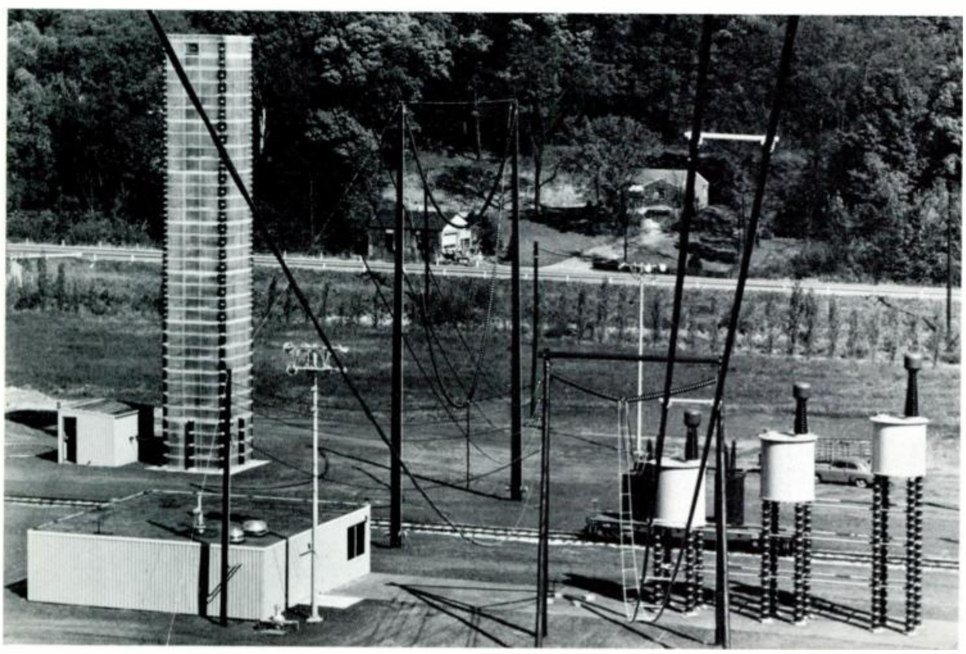
The test center is equipped for impulse, switching-surge, and 60-cycle tests under wet, dry, and contamination conditions and also for fundamental research. An area is provided for erection and testing of full-size transmission towers, transmission lines, and associated hardware.

The center consists essentially of a high-voltage 60-cycle source, an outdoor surge generator, circuitry for producing switching surges, and associated power supplies, controls, and measuring instruments. (See photograph.) The three cascade-connected transformers have a combined output of 1100 kv. A single-phase transmission line carries excitation and an initial 500 kv from the existing high-voltage laboratory nearby. This gives a total of 1600 kv, 60 cycles, at the new test center. In the future, the present transmission line will be replaced with two 500-kv transformers, increasing the capacity of the center to 2100 kv.

The transformers and the surge generator are supported on 32-foot concrete piles. The entire laboratory area has a buried copper grid tied into ground rods.

The outdoor surge generator is enclosed in plastic siding and stands 85 feet high on a 13-foot base. A 200-kv dc power supply charges the 32 stages for an output rating of 6400 kv. Each stage has two 1/8-mfd capacitors in parallel, with a total stored energy of 160 kw per second. The power supply is a full-wave bridge with silicon-diode rectifiers.

A railroad spur through the facility permits the testing of large units without unloading them from the rail car.



EHV Test Center is used to test power transmission equipment and also for fundamental research in EHV insulation. The surge generator at left has 32 stages and provides 6400-kv output. The three cascade-connected transformers supply 1100 kv initially.

Laser System Produces Spikeless Pulses of Adjustable Duration

A high-power narrow-beam laser system developed recently produces smooth rectangular-wave signals, with no spikes, that are variable in duration from 2 to 50 microseconds. The optimum rectangular-wave pulse is produced at the system's minimum power of 20 joules. Power output can be raised, however, to 44 joules, with slight degradation of the output pulse shape.

The system's output is a beam one inch in diameter, composed of six smaller parallel beams. Angular beam divergence of the total signal is 0.010 radian. At the 20-joule power level, signal wavelength is 6943 angstroms.

The system was made possible by two new techniques developed by the Westinghouse Defense and Space Center's Surface Division. The first was a new type of electro-optical oscillator that is more efficient over a wider range than previous types of laser signal generators. The oscillator operates at room temperature and produces a kind of pulse, called quasi-continuous, that has no "spike" but rather a smooth rectangular wave form. It is the first high-power laser energy source capable of producing a long-duration spikeless output pulse. The other new development that helped make the system possible was a significant improvement in laser amplification, the result of an improved laser head design that yields higher efficiencies than any previously available.

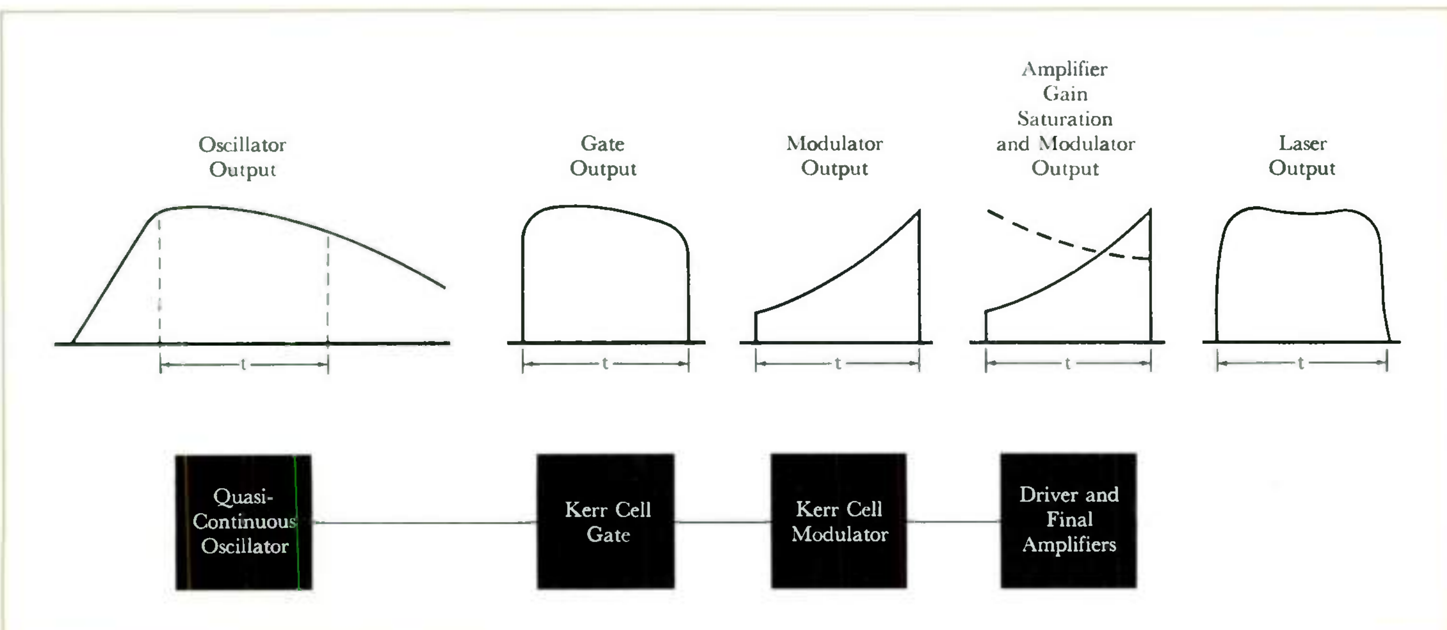
In operation, the system first generates a laser pulse in the quasi-continuous oscillator (see diagram). Part of the pulse is passed on by an electro-optical gate. This segment of the pulse is modulated and sent on to electro-optical amplifiers that successively raise the energy of the pulse to produce the final desired power and time-duration output.

The quasi-continuous oscillator is made up of a cylindrical ruby crystal, an optically resonant cavity, and a helical flash lamp. The ruby crystal is silver coated on one end, for high reflection, and dielectric coated on the other end for minimum reflection. The cavity is composed of a plane mirror at the silvered end of the ruby (the output end) and a high-reflection spherical mirror placed beyond the other end of the ruby.

Only a segment (time segment *t* in the diagram) of the signal generated by the oscillator is selected for amplification. This segment is in the early portion of the signal, near the point of maximum power, where ripples on the wave form have been damped and the curve is stable and relatively smooth. The segment is selected by a Kerr cell optical shutter or gate. Pulse duration is also determined by the Kerr cell over a range of 2 to 50 microseconds.

Another Kerr cell device modulates the pulse segment. Modulation determines the amplitude characteristics of the device's output. One important characteristic is exponentially rising power. This power rise compensates for declining gain in the succeeding amplifier stages due to amplifier saturation.

The modulated signal is amplified first in the driver amplifier and then in the final amplifier, both of which are of the high-efficiency design. The amplifier rubies are excited, or pumped, with linear flashlamps. The flashlamps are preionized before applying the excitation pulse to prolong their life.



High-power laser system produces spikeless pulses of light of controlled duration. The wave forms above the blocks of the schematic diagram represent the signal as it passes through the stages of the system to emerge as a smooth pulse of rectangular form.

Plant Uses Waste Heat From Utility's Gas Turbine

Trading fuel gas for exhaust gas may not seem a very good bargain, but it can be —for both parties. Southwestern Public Service Company of Amarillo, Texas, is installing a gas turbine-generator unit at Phillips Petroleum Company's Plains Butadiene Plant near Borger, Texas. The unit will be maintained and operated by the utility company and will run interconnected with its system; the hot exhaust gas will be used by Phillips as part of the combustion air requirements for a number of steam boilers. The waste heat in the gas will substantially reduce the amount of primary fuel gas required for the boilers, thus improving overall process efficiency. Phillips will sell the natural-gas turbine fuel to the utility company.

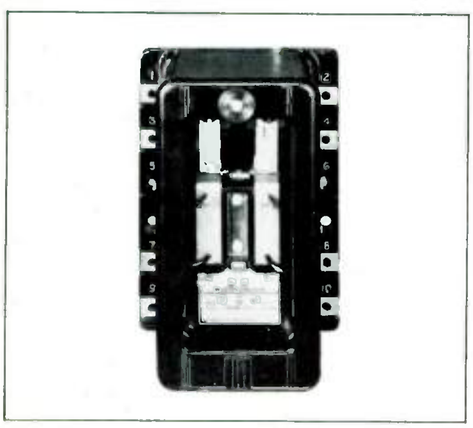
Southwestern Public Service supplies all of Phillips' electric power requirements from its integrated system. Since this unit will run interconnected with that system, it will not be necessary to provide separate standby for the unit.

The gas turbine-generator will have a capability of 30,400 kw at 100 degrees F, supercharged by a motor-driven fan. An auxiliary exhaust stack will permit the unit to operate independently of the steam generation requirements of the Phillips plant. The unit will be housed in an insulated fabricated steel building.

Products for Industry

Cathode-ray tubes with fiber-optic faceplates are especially adapted for making photographic reproductions of their outputs. They are about 20 times more efficient, for film exposure, than conventional tube-and-lens systems, and the fiber optics also save weight, size, and volume. Type WX-30038 tube has a fiber-optic faceplate four inches in diameter; usable screen diameter is 3.2 inches. Type WX-5321 tube, designed for line scanning, has overall face diameter of 5¼ inches and a band of optical fibers across faceplate center with a usable length of 4¼ inches and a width of ¼ inch. Spot size in both tubes is 0.0008 inch. Both have potted leads for high-voltage protection. *Westinghouse Electronic Tube Division, P.O. Box 284, Elmira, N.Y. 14902.*

Two-contact heavy-duty type SG auxiliary relay has been brought out in a front-connected version with a molded cover that can be either solid or with a glass window. Contacts can be make, break, or transfer. Operating coils for ac or dc current or voltage are available in a variety of ratings. Base is 5½ inches long and 3¾ inches wide; overall height is 5 inches. *Westinghouse Relay-Instrument Division, Plane and Orange Streets, Newark, N.J. 07101.*



Indoor dustproof capacitors for power factor improvement in industrial plants combine accessibility, flexibility, and protection. Single- and three-phase units are rated 240, 480, and 600 volts, 2 through 600 kvar. Type IDP (individual dustproof) units, shown at left in photo, provide small amounts of corrective capacity near the load. Type MDP (multiple dustproof) units (at right in photo) provide larger capacities needed at power centers. They consist of groups of capacitors completely assembled and wired. The dustproof design isolates live parts from accidental contact. *Westinghouse Distribution Apparatus Division, P.O. Box 341, Bloomington, Ind. 47402.*

Portable industrial x-ray machine has two focal spot sizes (4 × 4 mm and 1.5 × 1.5 mm), permitting use of both total power output and fine-focusing techniques. Rated 400-kv constant potential at ten milliamperes, the Baltomatic 400 can inspect metal products ranging from thin-walled aluminum castings to four-inch steel weldments. A single compact head unit contains the x-ray tube, generators, lead shielding, high-voltage transformer, selenium rectifiers, automatic thermal cut-off device, and receptacles for low-voltage connections. The control panel has a kilovoltage meter and selectors, milliampere control, automatic reset timer, and overcurrent and overvoltage protection devices. *Westinghouse X-Ray Division, 2519 Wilkins Avenue, Baltimore, Md. 21203.*

Rectomatic static constant-voltage battery charger performs continuous floating and equalizing-charge service. It maintains dc voltage within ± 1 percent of rated voltage, no load to full load, even under a ±10-percent variation in ac line voltage. Protective and control devices limit overload current, regulate equalizing charge through a timer, monitor voltage and current, and prevent reverse current flow during ac power failure. Standard primary voltages are 208, 230, and 460 volts, three-phase, 60-cycle. Standard dc ampere ratings are 25, 50, 100, 150, 200, 300, and 400. *Westinghouse General Control Division, P.O. Box 225, Buffalo, N.Y. 14240.*

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Index for the 1963–1964 issues of the Westinghouse ENGINEER is available upon request without charge. *Westinghouse ENGINEER, Westinghouse Electric Corporation, P.O. Box 2278, Pittsburgh, Pennsylvania 15230.*

About the Authors

The four authors of the 500-kv circuit breaker article, which appears in this issue, represent all phases of circuit breaker design and development.

R. N. Yeckley, a graduate of the University of Michigan (BSME, 1951), has spent a considerable portion of his time developing circuit breaker mechanisms. His major assignment for the past several years has been the design and development of SF_6 breakers. Yeckley obtained an MSME from the University of Pittsburgh in 1961.

C. F. Sonnenberg's principal field of interest is insulation. Since coming with Westinghouse from the Carnegie Institute of Technology (BSEE, 1953), he has worked on bushings and insulation for gas breakers and EHV breakers. He is presently an Advisory Engineer in the power circuit breaker engineering department, responsible for high-voltage insulation in the EHV design section. Sonnenberg obtained his MSEE last year from the University of Pittsburgh.

J. Brado, a graduate of Fenn College (BEE, 1957), has been the test engineer on the EHV breakers. Brado works at the high-voltage laboratory of the Westinghouse Engineering Laboratories.

R. C. Van Sickle, an Advisory Engineer in the EHV section of the power circuit breaker engineering department, has been involved in almost all phases of circuit breaker design, test, and standardization. He holds 32 U.S. patents ranging from component parts to complete breaker designs. Van Sickle's work with circuit breakers was interrupted briefly during the war years, when he was assigned to the Manhattan Project to work on electromagnetic isotope separation at the University of California Radiation Laboratory. Van Sickle holds degrees in both mechanical and electrical engineering from Cornell University (1923, 1924), and obtained his MSEE from the University of Pittsburgh in 1928.

Wesley L. McKeithan, author of this month's article on a new concept in control centers, is a graduate of the University of North Carolina, where he earned his BSEE in 1938. He joined Westinghouse on the Graduate Student Course in 1940, and then became a member of the Transformer Division, where he spent the next 20 years in a variety of assignments —except for a three-year interval when he served as a lieutenant in the U.S. Army Ordnance Corps during the war. He first became a design engineer, left for the service in 1943, and resumed his design engineer position when he returned in 1946. He became assistant to the engineering manager in 1951, and later the same year assumed responsibility for an engineering section in the distribution transformer activity. In 1955, he became superintendent of power transformer testing, a position he held until he moved into a new field in 1961; at that time he became engineering manager of the Low Voltage Distribution Equipment Division, his present position.

L. J. Lunas came with Westinghouse from the University of North Dakota with a BSEE in 1926. After attending Westinghouse Electrical Design School, he chose electrical instruments for his first professional assignment. His first choice was a good one, because he has spent his entire career in instrument engineering, in both design and supervisory work. Lunas is presently an Advisory Engineer in the Instrument Engineering Department, where he concentrates on new development problems. Lunas is actively engaged in IEEE, ASA, and NEMA work. He has served as chairman of several AIEE committees, and is presently chairman of ASA and of NEMA instrument committees.

Lunas obtained an MSEE degree from the University of Pittsburgh in 1939, and a Professional EE degree from the University of North Dakota in 1941.

The three authors of the transmission-line shielding article, **F. S. Young, J. M. Clayton,** and **A. R. Hileman,** have spent a good portion of their working time with Westinghouse on lightning problems.

Young joined Westinghouse on the graduate student course after graduating from Stanford University in 1955 with a BSEE degree. He was assigned to the Electric Utility Engineering Department in 1956, and became an Assistant Sponsor Engineer for the Southeastern Region in 1959. In 1963, Young was made a Sponsor Engineer for New England and New York State. In this assignment, he makes regular visits to electric utility customers to work on all phases of utility engineering problems. Although his principal interest has been in the area of lightning protection, he works on a wide variety of power system problems. Young obtained his MSEE from the University of Pittsburgh in 1962.

J. M. Clayton received a BS degree in meteorology from New York University in 1944 while serving in the Army Air Force. After completing a tour of duty as a meteorologist, he returned to Auburn University to obtain a BSEE degree. He joined Westinghouse on the graduate student course in 1947, and was assigned to the Electric Utility Engineering Department. For a number of years, he worked on lightning field investigations, coupled with analytical and computer studies aimed at improving methods for protecting electric power systems from lightning. In 1954, Clayton was made a Sponsor Engineer for the Southeastern Region. In early 1964, he was appointed Advisory Engineer and assigned the responsibility of providing technical direction for Westinghouse district electric utility engineers.

A. R. Hileman, Advanced Development Engineer in the Electric Utility Engineering Department, joined Westinghouse in 1951 upon receiving a BSEE degree from Lehigh University. He was first assigned to the Tidd high-voltage impulse tests, and then to the department's transmission section. From the transmission section, he became a Sponsor Engineer for the Central Region, and thence to his present assignment. He is also the Project Manager for the Allegheny Power System 500-kv transmission system design. Hileman has done extensive work in the fields of lightning phenomena and protection, insulation coordination, and switching surge investigation. He received his MSEE degree from the University of Pittsburgh in 1955.

Some 376,000 watts of lighting illuminate the exterior of the new Pan Am Building in New York City. Special incandescent lamps and fixtures were developed to illuminate the huge building evenly. The main faces (north and south) are lighted by a lamp developed by the Westinghouse Lamp Division; it has a compact 80-volt 2000-watt filament. A new quartz-iodine lamp was developed for the two smaller faces of the building. The lighting system was designed by Lighting by Feder, and the fixtures by Kliegl Brothers.