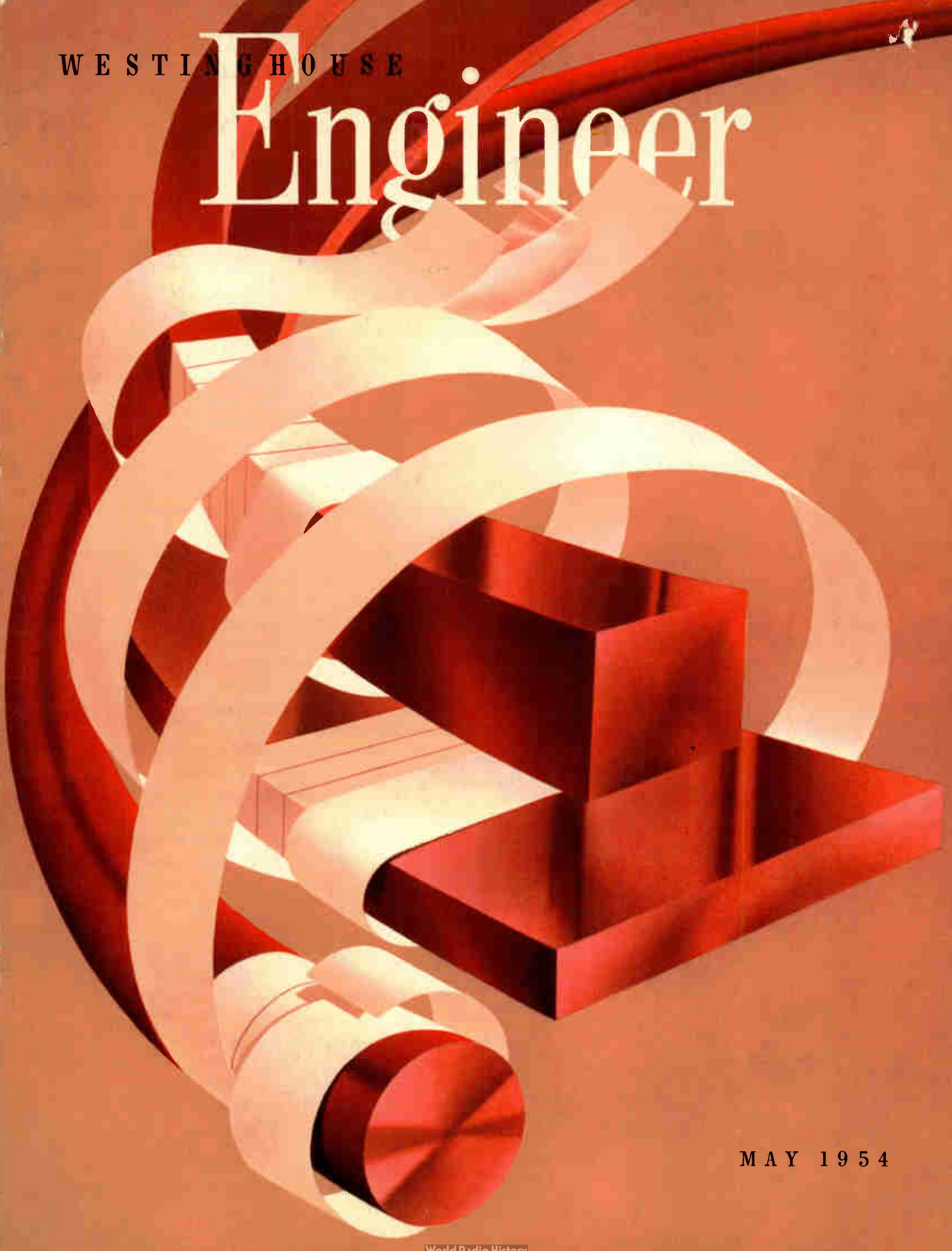


WESTINGHOUSE

Engineer



MAY 1954

The



without a Winner

The curious situation of two contestants participating in a race that neither wants to win—nor lose—is fairly common in the electrical industry. It is the perpetual race between equipment designers in different but related engineering fields. For example, machine and control designers. There is little purpose in building a super-precise control device if the machine it operates is too sluggish to follow its directions. Conversely, a delicately balanced and precision-made machine is of little value if its control is not capable of demanding the utmost from it. Thus the condition exists where machine designers and control engineers are in a continual race to keep up with each other's developments.

Such races are by no means run at a set and predetermined pace. In some fields the pace is slow; in others it reaches surprising speeds. But it never stops. If it did, either progress would come to a halt, or perfection would have been reached; either eventuality is improbable.

A most spectacular contest is the one that concerns high-voltage power circuit breakers and generators, or systems of generators. A seemingly insatiable demand for more electric power has brought about huge concentrations of power. Generator sizes are already over 200 mw, and pushing toward 300. But despite the tremendous increase in rating, circuit breakers have kept pace.

An amazing fact about this race is that since the days when a generator was a few turns of wire and some iron, and the circuit breaker was but a knife switch, neither contestant has held up the race more than momentarily.

With few, if any, exceptions, the technology of circuit breakers has always been able to keep well ahead of application requirements. Even more surprising is the fact that circuit-breaker designers have hardly batted an eye at the pyramiding demands of the past two decades. Twenty years ago the decision to build a 287-kv transmission line from Hoover Dam to Los Angeles led to a request for 2.5-million-kva circuit breakers at that voltage—and capable of operation in three cycles. This unheard of request was filled, and subsequently, in 1941, the interrupting capacity was raised to 3.5 million kva. After the war the pace quickened. In 1945, 3.5 million kva at 138 kv was requested; in 1949, 6 million kva at 138 kv; in the same year 5 million kva at 161 kv. Grand

Coulee asked for 10 million kva at 230 kv in 1947. The latter case proved how well circuit-breaker engineers were planning; a number of the older 3.5-million-kva units were rebuilt to handle the larger power—in the same tank. Soon TVA required even larger capacity—7.5 and 10 million kva at 161 kv. Then last year came the Ohio Valley project with its huge power concentration—and with it a request for 25 million at 330 kv.

Through this period of terrific growth, circuit-breaker designers have managed to remain calm. Not that keeping up with the demands has not been hard work, but the basic principles they have evolved have stood the test. One might logically conclude that the circuit-breaker engineer's time must have been occupied solely in figuring out how to keep up with rating increases. Actually, as pointed out in the article on page 106, he has made innumerable design improvements in other directions too. Tanks are smaller, meaning less oil is required; bushings are better; and interrupter mechanisms are constantly being improved, to mention a few.

In the course of circuit-breaker development there have been some major break-throughs, such as the first oil breaker, and much later the De-ion grid principle. But mostly progress has been a steady—but not so slow—progression of improvements. In the early days, the construction of a circuit breaker bigger than anything then available posed a serious problem. The proof of the design had to wait until power was available to test it, which in most cases meant the breaker was installed before its success or failure could be determined. The introduction of high-power testing laboratories—such as that created by Westinghouse in 1925—has been a major factor in the success of circuit-breaker designs.

In this race for progress between generators and circuit breakers, generators have an ace in the hole. The race is not as straightforward as it might seem because generators can double up, i.e., operate in parallel to produce more power; or their systems can be interconnected to provide a bigger power concentration. Despite this "unfair advantage" circuit-breaker designers have registered no complaint. While they have learned to be a little wary in making predictions as to the next increase in rating that will be demanded of them, they are confident of their ability to provide any required capacity. RWD

VOLUME FOURTEEN

MAY, 1954

NUMBER THREE

On the Side

The Cover—The shapes, sizes, and varieties electrical insulation comes in are almost endless, ranging from paper to complex chemical compounds. And the methods of application are almost as numerous. Rather than trying to portray the idea of insulation by such an elaborate and confusing accumulation of materials and processes, artist Dick Marsh has chosen a more direct approach on this month's cover—several shapes of copper wrapped with insulating tape.

• • •

Work is well under way on the new Westinghouse metals plant located at Blairsville, Pa. When completed, the new plant will have equipment for basic metal-working processes, such as melting, casting, forging, hot-rolling, cold-rolling, pickling, and heat-treating. Also, facilities will be available for investment and shell-mold casting, and for limited manufacture of powdered-metal parts.

The new plant is intended to bridge the gap between research and commercial use of metals in the electrical industry.

• • •

The first full-scale central-station nuclear-power plant will be constructed and operated by the Duquesne Light Company of Pittsburgh. Chosen by the Atomic Energy Commission from nine industrial firms that submitted proposals, the company will thus work in cooperation with Westinghouse, already at work on the nuclear reactor for the plant. Under the proposal, Duquesne Light would furnish the site, build and operate the new plant, operate the reactor, and assume part of the cost of research, development and construction of the reactor.

In This Issue

COLOR TELEVISION

Status Today 98

How It Works 102

PROGRESS IN POWER CIRCUIT BREAKER DEVELOPMENT..... 106

A. W. Hill

PERSONALITIES IN ENGINEERING—GRAHAM LEE MOSES 111

THE GROWTH OF THE *Nautilus* 112

FUNDAMENTALS OF ELECTRICAL INSULATION

I—Chemistry of Insulation 114

Jack Swiss

II—Physics of Insulation 120

T. W. Dakin

STATIC REGULATOR EXCITERS FOR A-C GENERATORS..... 125

S. LeRoy Bradley

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B



A

Color television is a lot of things: It is the result of cooperative effort within a strongly competitive industry. It is a tribute to the genius of electronics engineers. It is a spur to our national economy. It is here; colorcasts are being made regularly. And finally, it is a new and beautiful entertainment form.

color

TV



C



D

A COMMON stunt in chemistry is to add a quart of alcohol to a quart of water; after shaking, the mixture is less than two quarts of liquid. Television engineers are doing better than that. They have taken all the information required for black-and-white pictures, added to it the large amount of information needed to transmit color, plus additional synchronizing signals, shaken well and poured the whole mixture into the same six-megacycle bandwidth already used for monochrome, which presumably is already loaded to the last cycle with picture and sound information. Pictures are being colorcast in channels no wider than previously thought necessary for black and white alone. In fact, color television is here today because of this miraculous electronics shoehorning operation. In that trick alone there is more than enough grade A-1 accomplishment to justify engineers taking off their hats to their technical brethren in the television department of electronics.

Also they have accomplished the equally difficult trick of devising a color-television system, within the same standards set up in 1940 for monochrome transmission, such that any existing receivers can present a black-and-white picture of essentially unimpaired quality from a colorcast. Furthermore, color receivers will be able to show a black-and-white picture of good quality from a monochrome broadcast. These are the well-publicized principles of compatibility necessary for the continued and orderly growth of both black-and-white and color television.

The hope for color television is probably as old as that of television itself. To relate all the schemes that have been tried or proposed to transmit pictures in color would fill pages. To do so, while interesting, would be pointless. The impetus for color television as it is now reaching reality came since War II, when electronic research in non-defense matters was aggressively resumed—which it was by several companies on a blue-chip basis.

The first system to attract favorable attention of the FCC was the so-called mechanical field-sequential scheme. In this, a disc with red, green, and blue filters rotated in front of a receiver picture tube in synchronism with transmitted color signals. Each field was scanned by the camera in one color at a time, hence the term field sequential. Because of persistence of vision the eye saw the picture in the original colors. The sequential color-signal specification was approved for commercial use by the FCC in October, 1950 but it never became a public reality. Electronically controlled filters were not then available and the tricolor picture tube had not been invented. Hence, mechanically rotated filters were used, with the disadvantages of a moving mechanism, including the limitation of size. Also, the sequential system required the switching of a whole field at a time and, as the eye is sensitive to large-area color switching, flicker was a problem. With rapidly moving objects, some color-fringing occurred.

In spite of these weaknesses, pictures of good quality were possible with the sequential system. One defect, however, grew more serious daily, as black-and-white television sets were being purchased by the thousands. This was the fact

that a sequential color signal presented no picture on a monochrome set, i.e., the system was incompatible. The specter of set obsolescence was growing larger daily. The onset of the war in Korea, with its shortage of manpower and materials, also made it impossible to get materials and equipment to build color stations or, for that matter, color receivers. Meanwhile, the search continued for an all-electronic, completely compatible color system.

Then began a chapter in the costly history of color television, of which private industry and the free-enterprise system can be proud. This is the accomplishment of the National Television System Committee. In effect, the industry—the broadcasters, the telephone company, transmitter and receiver manufacturers, a camera manufacturer, and scientists from the National Bureau of Standards, etc.—formed a committee to pool existing information, to seek missing information, to formulate systems, and to make extensive field tests. The objective was a set of standards that could be offered with all-industry backing to the Commission as fulfilling all requirements as a national color-TV standard. The standards for black-and-white television had been created by similar industry action, but this new venture in industrial cooperation was on a much larger scale.

One might say that the industry had no choice in the matter since no one company had all the know-how to do the job. But it is to the everlasting credit of the industry that it did do it, and did what is universally recognized as a crackerjack job. And in surprisingly short time, too. In June of last year, the NTSC presented its recommended framework of standards to the Commission. These standards were adopted by the FCC last December and the first coast-to-coast colorcast under those standards was of the Tournament of Roses at Pasadena on New Year's Day. Thus, color television using the FCC-approved NTSC signal standards was launched.

The NTSC deserves another word. It was comprised of representatives of all interested branches of the television industry and was financed solely by industry. Anyone, whether a member of participating company or not, could present an idea to the committee. Many did. Any idea that seemed to bear favorably on the objective of unified standards was examined theoretically. Many were also field tested. Thus the NTSC standards as accepted by the FCC have been thoroughly tried in service under a wide variety of geographical and urban conditions. There is no doubt that with these standards for color signals, and even with the prototype camera, transmitter, and receiver equipment available today, clear pictures of both still and moving scenes can be reproduced in vivid, natural-appearing colors.

Those who see colorcasts for the first time are surprised at the brilliance of color, picture sharpness, and the greater satisfaction given by comparison with monochrome. Color greatly enhances the sense of depth. By comparison a monochrome scene appears flat. The line structure evident on black-and-white tubes is less apparent in color. One is surprised, too, to find that he has independent control not only of total brightness, but also of brilliance of each color. Thus the viewer, if he wishes, can increase (at least on sets being made now) the brilliance of the red or subdue it to pink, or emphasize the blue, much as the bass notes in electronically reproduced music can be augmented or depressed at will. On a color screen the red of a dress can be made to appear brighter

Prepared by Charles A. Scarlott, based on information provided by engineers and studio directors of the National Broadcasting Company, Inc., and Columbia Broadcasting System, Inc.; by the engineers of the Hazeltine Corporation; the engineers of Westinghouse Broadcasting Company, Inc.; and the engineers of the Television-Radio Division, Electronic Tube Division, and Research Laboratories of Westinghouse Electric Corp.

A and B—These rear and chassis-bottom views of a 12½-inch color receiver and a 17-inch black-and-white set shows the greater complexity required for color-picture reproduction. Color receivers with bigger picture tubes will not, however, be significantly larger. **C**—A small section of the color-television laboratory, showing a black-and-white and a color monitor, respectively. **D**—Color-television receivers are moving down the production line. (All pictures taken in the Westinghouse plant at Metuchen, New Jersey.)

—or less bright—than the dress actually is. Color-television pictures are not limited to weak colors or pastels.

A close look at today's color-tube productions shows, however, that perfection is not yet achieved. Color is not always uniform out to the picture edges. A slight fuzziness attends an object in rapid motion, mostly because the decay time of presently used red phosphors is too slow. However, considering the difficulties of the problem and the youthfulness of the art, color-picture presentations are remarkably good. The NTSC standards offer ample opportunity for improvement in picture quality and lower costs by virtue of equipment developments.

At any rate, the United States now has a set of color-television standards. It is important to remember that they are only that—standards for color-signal generation, transmission, and reassembly into pictures. They specify the bandwidth, the make-up of the total signal, including picture and synchronizing information, line- and frame-scanning rates, sound, and other factors that bear on colorcast reception.

These standards apply to the United States. Fortunately, however, Canada, Mexico, and Cuba adopted United States monochrome standards. Hence their use of the NTSC color standards appears likely.

Thus, for example, a program originating in Toronto can be seen in Buffalo and vice versa. It is probable that most, if not all, South American countries, Japan, and the Philippine Islands will also adopt them. In England and Europe, however, color systems now under development follow the sequential system, but this may change later.

The NTSC did not undertake equipment developments. The standards do not specify how color-television signals are to be created or converted to pictures. While the standards can be considered as having reached maturity, colorcast equipment—from the studio to the living room—is still in the learning-to-walk stage. But the learning process is proceeding rapidly.

From a studio and programming point of view, 1954 (and perhaps longer) is a period of experimentation with color television. As yet only a few hundred color-television receivers are in service. Virtually all of these are being used by engineers, equipment makers, program planners, studio designers and technicians, advertising agencies, and similar groups that need them for self-education in this new art. Even by year's end only a few thousand sets will be in the living rooms of people outside the industry. The National Broadcasting Company, Inc., and Columbia Broadcasting System, Inc., are telecasting selected existing sponsored black-and-white productions simultaneously in monochrome and color. As of March, each company was "doing" one or two shows in color a week. These, and extensive studio experimentation for the benefit of technicians, lighting engineers, program directors, set designers, costume designers, adver-



Westinghouse placed color-TV receivers with 12½-inch color kinescopes on the market last February. This is one of the production-line sets.



The RCA color-television camera scans a scene with three lens systems simultaneously, one for each of the primaries—red, green, blue.

tising agencies, manufacturers of inks, paints, cosmetics, and many more interested groups, continue to strain the color-studio facilities, which are still extremely limited. Some colorcasts are sponsored, but as yet no additional charge is made—obviously, because there is no purchasing audience, and won't be for an unknown number of months.

A visitor to any color-television studio senses the enthusiasm of all hands over the possibilities of this new form of telecasting. There is an air of excitement, a feeling of urgency to master the techniques of color so that the earliest possible use can be made of its fascinating possibilities. However, no one expects color to revolutionize television. For a long while color shows will be viewed on more black-and-white sets than in color. This will prevent any sudden change of program character. Obviously, during the transition period of possibly several years, no program can depend on color for observer understanding. However, color will inevitably have great impact on the presentation of pictures in the home. The advantages of color are too great to be denied. For ex-



An hour after the FCC approved new color-TV standards December 17, CBS made a colorcast of Rocky Graziano as a singing boxer.



This NBC color mobile unit, housed in two trucks, was used to colorcast the Pasadena Tournament of Roses' parade January 1.

ample, the assistance given by color in creating mood is great. The effect possible with a spot of color as simple as a single red rose or a yellow handkerchief is difficult, if not impossible, to achieve with black and white.

Even in this early stage some color-studio problems and trends are emerging. For one, the necessity for authenticity is much greater. This is particularly evident in costuming. In black-and-white presentations, the garb of, say, a Roman senator or of Shakespeare's Juliet could be a little faded or even a bit shabby. Not so in color. Any shoddiness of fabric or slight color mismatch becomes quite apparent on the color screen. Costumes will have to be of better quality, better sewn, better fitted.

Stage settings, on the other hand, will tend to become simpler. A complex set in many colors is confusing; it detracts from the action. Use of painted scenery will decrease; constructed sets will be more common. One studio director believes that the ratio of cost of scenery and costumes—which now is about three to one in favor of scenery—will just about reverse with the arrival of color.

Color helps tremendously in carrying over the personality of performers. With monochrome, various camera and lighting tricks must be utilized, for example, to hold interest on a singer during a song, or on an orchestra for the duration of a symphony. With color, interest is held easily, assuming proper attention has been paid to staging.

Clearly, many kinds of programs are possible in color that are almost meaningless in monochrome. This is particularly true in the educational field. For example, art objects, such as glassware, porcelains, paintings, or exhibits of flowers or birds will have something like their true significance in color. The same holds for scientific demonstration or discussions of fabrics, collectors' specimens of stamps, rocks, or similar items. Likewise color charts and illustrative material get their story across much quicker, better. Color will also have many

commercial advantages, as in the presentation of fashion shows and advertising displays.

Color brings no new serious mechanical problems to the television studio. But, the old ones are intensified. Obviously, the color temperature of light sources must be more closely regulated than for monochrome. Filament lamps, because of the light concentration and uniform spectral response, are most widely used in color studios. Arc lamps, for example, give too much blue for accurate color rendition. Fluorescent lamps are too large in area and too low in brightness. In amount, the light needed for color is two to three times that ample for monochrome. This, of course, increases the heat problem both for those under the lights and for general comfort. Certainly the studio air-conditioning load is increased.

One of the most important television questions is the relationship of black-and-white to color. There is no basis for thinking that color will, for many years at least, obsolete monochrome telecasts. Certain news events have little additional significance in color. The large increase in light inevitably required for color will handicap it for such things as field sports events on dark days or late afternoons or at night.

At the receiver end, the initial cost of color receivers and the cost of servicing and parts replacement will always be somewhat higher than for the simpler black-and-white sets. At the outset the initial cost of a 12½-inch color-tube set is three to five times more than for a 21-inch monochrome set. The best the experts hope for after set manufacture shakes down is a cost difference of about 1½. Barring unforeseen major development, a 21-inch color picture tube, even when the economies of mass production take hold, is likely to cost \$100 or more—which will make tube replacement a serious item. The life of a color tube is today only a question mark.

Predictions as to what the American citizen is willing to spend his money for are hazardous. The American standard

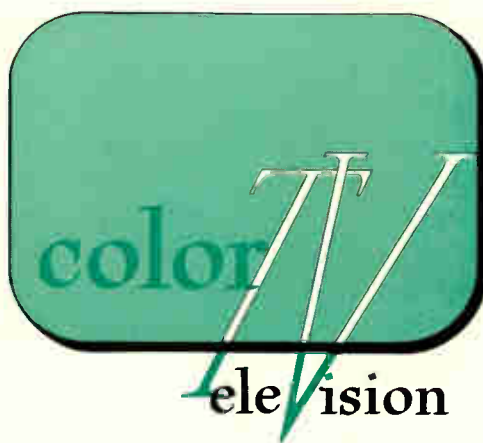
of living has a habit of rising to absorb each new development that has popular appeal. Also it must be remembered that the financial rewards of mass colorcasting are so great that extreme effort and vast sums of money will be spent to lower the costs. While no one has demonstrated a way now to build picture tubes, using present principles, for less than about \$125, it is most unwise to discount the possibility of development of a better, cheaper method. However, for the next few years cost factors are likely to limit color television in favor of monochrome for the low-income mass market. Also it is probable that the demand for monochrome sets will continue even from those families that can afford color. Remembering the pattern of use set by radio, it is probable that the second and third sets for, say, the children's room and the basement game room will be monochrome sets. Certainly any hesitancy

to purchase a black-and-white television set because of the imminence of color is unfounded.

A color set is expected to draw about 50 percent more wattage than the corresponding black-and-white receiver. While this is probably not enough more to bother even low-income families, it is of interest to power companies, which are already finding that television is having a marked influence on the pattern of energy use. Transistors, when and if developed to replace vacuum tubes in television sets, will have an effect on energy consumption, but how much is too early to say.

But, color is here. It is a great technical accomplishment. It is destined to have a great influence on industry, on employment, and on our pattern of living. Color television will bring a new order of entertainment enjoyment to the home.

The Mechanism of



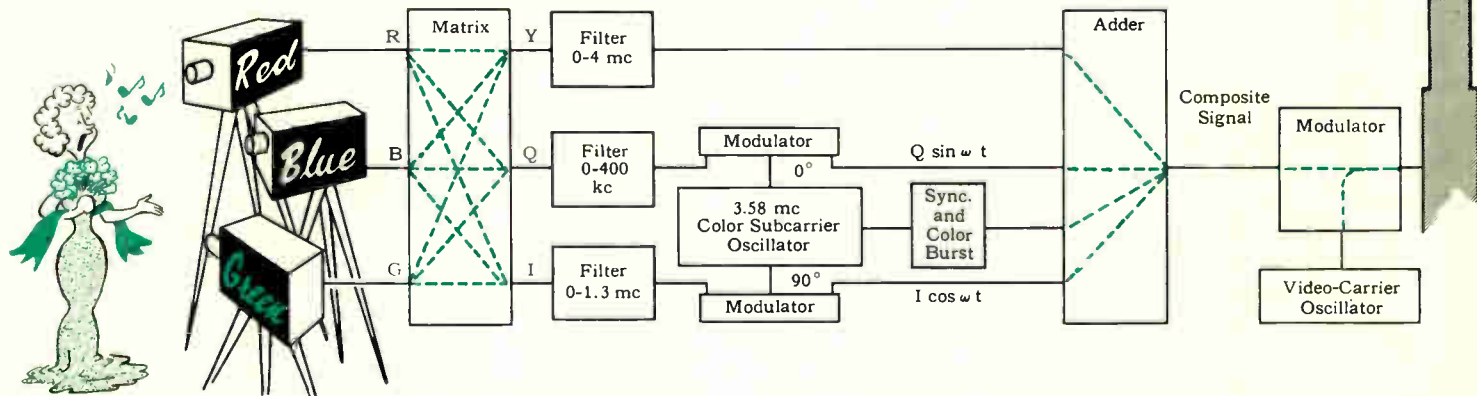
THE SCENE to be colorcast is scanned, as in conventional black-and-white television, by a camera or cameras that convert light energy to proportional voltages. This is done at 30 frames or 60 fields per second (since to make one frame a scene is scanned twice, the first scan covering the even numbered lines and the second the odd lines). The two scans, with lines interlaced, make a complete picture of 525 lines. The difference at the camera is this: whereas a monochrome camera provides one signal that is proportional at each instant solely to the brightness of the area being scanned, a color pick-up provides three voltages proportional to the brightness of the three primary additive colors—red, green, and blue.

Color cameras are presently of two types. The NBC method is to use three camera tubes, one for each of the primary colors. They are arranged to view the scene through a set of color-filter mirrors to give them a common viewpoint. In the CBS studios, a single camera tube is used. It scans the scene in the three colors in rotation, i.e., sequentially. These signals are stored electronically, then converted to the simultaneous signals of brightness and color

required for transmission by NTSC standards. Although present-day cameras do a creditable job, considerable improvement is expected. Perhaps fundamentally different cameras, possibly employing a single color pick-up tube, will emerge.

In any case, the color camera delivers three voltages varying in accord with the intensities of the three primary colors in the scene as it is scanned. The problem is to package these for transmission to the receiver and do it within the bandwidth allowed for monochrome pictures, and comply with the edict of compatibility. An obvious method would be to transmit independently the three separate color signals to the receiver. An excellent color picture could be created in this manner, but it would be wasteful of bandwidth. Also black-and-white receivers could fashion no picture from them.

To solve these problems color-television committee members studied the phenomenon of color and the physical and psychological mechanisms by which the brain perceives color images. They learned many interesting things. For example, the human color-sensing mechanism is not capable of seeing full color in fine



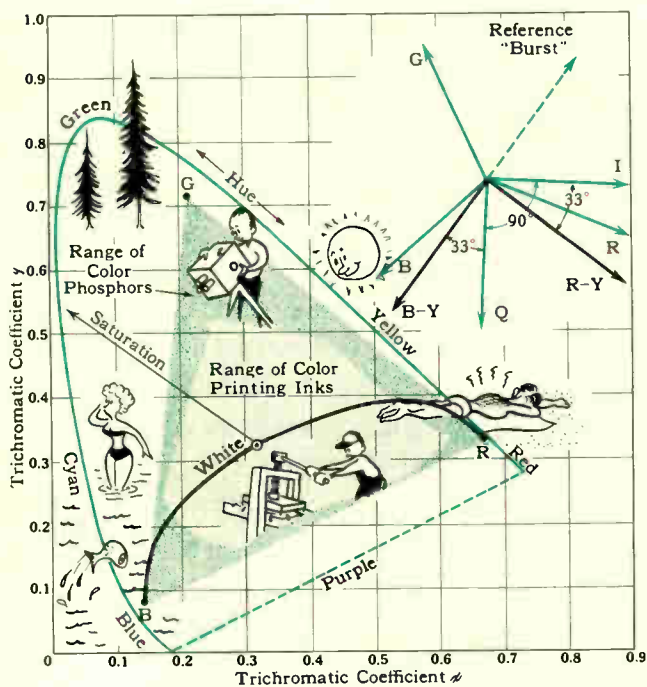


Fig. 1—All colors, natural or man-made, are enclosed within the horseshoe. Colors on the curve are saturated, i.e., are not diluted with energy from other parts of the spectrum. Colors within the triangle are possible in colorcasting, while the smaller irregular area represents the practical limits obtainable with printing inks.

detail. To transmit, at expense of channel width, information the mind cannot use is only a waste. The NTSC standards take advantage of this idea.

We ordinarily think of a color scene as being dissectible into various amounts of the three primary colors. However, there is another way to analyze it, a way that is far better from a color-cast standpoint. This method also divides a color picture in three ways. One is its brightness pattern, without regard to color. This is what we see in black-and-white photography, printing, and monochrome television. The second and third are aspects of color itself. One is called hue; the other saturation or chroma. Hue specifies whether an object is basically red, blue, green, or a mixture of any two of them. Saturation or chroma is the measure of dilution of the principal color with white, as whether an object is fire-truck red or one of countless degrees of pink.

Hue, chroma, and luminance can also be visualized in terms of the light spectrum. In a spectrum analysis of light the dominant wavelength specifies its hue. If all the light were concentrated at one wavelength, say, red, the hue would be saturated red. More

commonly in practice, however, the analysis shows lesser amounts of energy scattered along the spectrum. The degree of this dilution determines the chroma or saturation. On the other hand, the summation of amplitudes of all wavelengths present in comparison with the spectral response curve of the eye is luminance or brightness.

In colorcasting, information concerning hue, chroma, and luminance are not transmitted simply as three signals proportional to red, green, and blue camera outputs. To make up the brightness signal (called the *Y* signal), the outputs of the three color cameras are passed through combining circuits to provide one signal output that comprises 59 percent green, 30 percent red, and 11 percent blue. These are the respective contributions of the three colors in white light. For all practical purposes the luminance signal is the same as produced by a monochrome camera. In a colorcast it is mixed with the hue and chroma information—and the composite transmitted just as in black and white, along with synchronizing signals and sound on a 6-mc band, of which 4 mc carries the picture information. However, throughout transmission the luminance or *Y* signal retains its identity such that a black-and-white receiver recognizes it alone and ignores the chrominance information. Thus the ordinary set produces a conventional monochrome picture from a colorcast just as if it originated in a monochrome camera. Conversely, a color receiver can convert this luminance signal—if it were transmitted minus color from a colorcast, or received from a conventional monochrome camera—to an essentially black-and-white picture. Thus the NTSC system meets the requirement of compatibility.

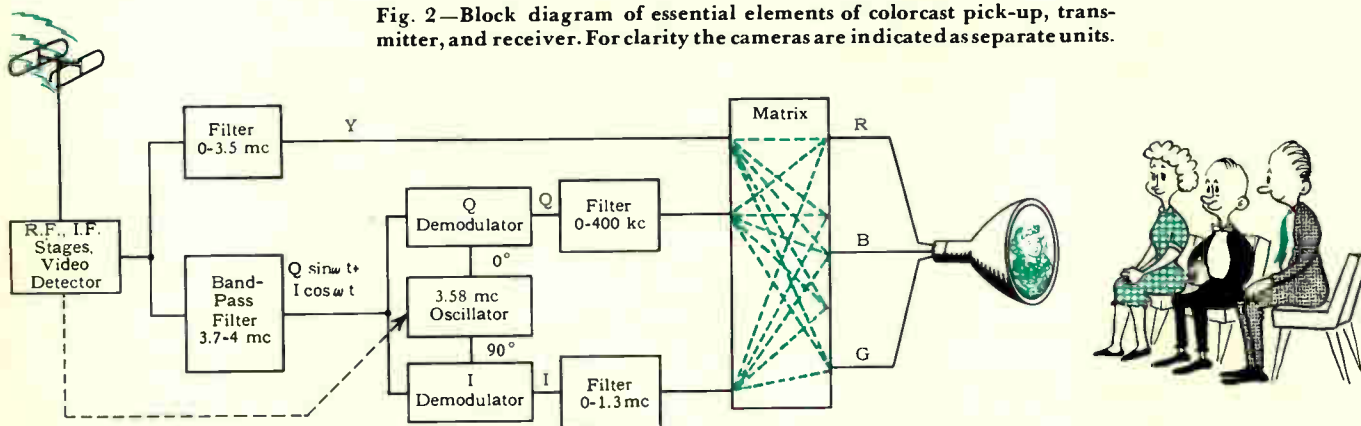
We have yet, however, to package the color information so that (a) it won't disturb the monochrome picture on the black-and-white set, and (b) so that it fits within the same channel that carries the luminance signal.

The chromaticity diagram of the International Commission of Illumination (CIE) has an important role here. As shown in Fig. 1, all color created by nature or man can be represented by an area resembling a horseshoe. At the left and right lower corners are blue and red. Green is at the top. These are the saturated colors of the spectrum, with no mixture of light of any other wavelength, bent into this shape for reasons of convenience. Near the center of the horseshoe is the region of white. Specifically the point marked has been selected as an international standard of white referred to as Illuminant "C" white.

With this curve and with white as a reference point, any color of nature or man can be specified. The direction of the line from white to the color defines the hue; its length, the degree of saturation or chroma. For example, the line from white to saturated red specifies the full gamut of pinks.

The horseshoe encloses the full possibility of visible light. With printing inks man can provide the color range included in the much smaller, irregular-shaped area shown. The limits chosen for and achievable in television comprise the triangular-shaped area. It is larger than obtainable with printing, which means that a greater range in vividness of colors will be possible on television

Fig. 2—Block diagram of essential elements of colorcast pick-up, transmitter, and receiver. For clarity the cameras are indicated as separate units.



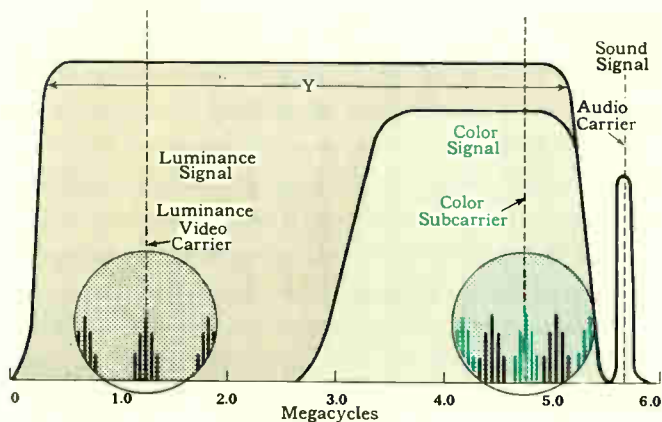


Fig. 3—The relationship of the luminance, color, and sound signals. The “magnifying glass” circles show how the luminance information is bunched around harmonics of 15 750 cycles and how the color information is fitted into the “empty” spaces between.

screens than printing can provide. This is possible because in television color will be made by adding light, whereas printing surfaces are colored because they subtract or absorb all light except that color. In fact, this television triangle of color excludes little but the extremes of blue-greens, which contribute little in the color-seeing process.

Clearly then, any point on the color diagram can be reached, with white as the starting point, by two vectors, one of a certain length along one axis (plus or minus), the other of the proper length at right angles to its terminus. Two color signals are created for this purpose. One is an in-phase or *I* signal synthesized by combining certain proportions of the red, green, and blue signals from the carrier. The second color signal is also built up from proper proportions of the three color signals and is called the quadrature or *Q* signal.

These two signals could be applied directly to modulate the amplitudes of the two color subcarriers, both of 3.58 mc, but one displaced in phase by 90 degrees from the other. These modulated subcarriers would give the two vectors needed to specify any hue and its saturation because their vector sum gives a length and direction from the reference point. This sum, combined with the luminance signal and the total applied to the carrier for that channel, would provide a perfectly satisfactory colorcast signal.

However, for electronic reasons that have nothing to do with understanding the principle of color television, and to effect certain economies in set manufacture, a further operation is made on the *I* and *Q* signals. They are, in effect, rotated in phase by 33 degrees before application to the two subcarriers, as shown in Fig. 1. They are then called color-difference signals. One is the blue signal minus luminance ($B-Y$) and the other is the red signal minus luminance ($R-Y$).

These two subcarriers modulated by the color-difference signals are combined and have their carriers deleted to produce a single chrominance signal that varies both in amplitude and phase (with respect to their original 3.58-mc subcarrier). It can be thought of as being the vector sum of two chrominance signals, and because it has two qualities—direction and length—can carry two kinds of information—hue and color brightness. The subcarrier is removed before transmission as a simplification because all the information is in the sidebands. To transmit the subcarrier is an unnecessary burden.

The two signals—the luminance or *Y* signal, and the color subcarrier carrying the two color-difference signals—together prescribe the color picture. One provides the brightness information as seen by a monochrome receiver, the other defines hue and color brightness. The next problem is to package these two signals for transmission within the same bandwidth without interference.

How this is accomplished is one of the neatest of electronic tricks, which is saying considerable. Analysis of the spectrum of

frequencies in a standard black-and-white telecast disclosed an extremely fortunate fact. (Actually this was first done by two Bell Telephone Laboratory engineers in 1937 and all but forgotten.) The useful energy in a monochrome signal is not spread evenly over the 4-mc band. In fact it is closely bunched around 15 750 cycles and multiples of it. (This number comes about because there are 525 lines per frame and 30 frames scanned per second. $525 \times 30 = 15\,750$.) In other words, there lies between 15 750 and 31 500 cycles, and again between 31 500 and 47 250 cycles, and so on, a band several thousand cycles wide that is comparatively idle. That is, it was idle before the color-television men rediscovered it. For that is where the color information goes. It is appropriately called frequency interleaving.

To achieve this frequency-interleaving the color subcarrier must be chosen so that it, with its load of color sidebands, falls into the empty spaces in the monochrome-transmission spectrum. It turns out that this frequency must be some odd multiple of one half the line-scanning frequency. Unless you are willing to wade through a batch of mathematics you had better not ask why this is so. Selection of the particular odd harmonic is a compromise of several desires. The odd multiple chosen is the 455th harmonic of one half of 15 750, which comes out 3.58 mc.

At first glance the narrow bandwidth of the color signal (Fig. 3) would seem to be a severe restriction on color quality. But here the electronics men turn two little-known facts about color vision to good account.

One is that the eye does not see small objects in full color. As well as the eye can detect, any small object, such as the size of a dime held 50 feet away in good light, can be matched in color by mixing only two, not three, colors—an orange and a greenish-blue (cyan). Furthermore, for still smaller detail the eye doesn't

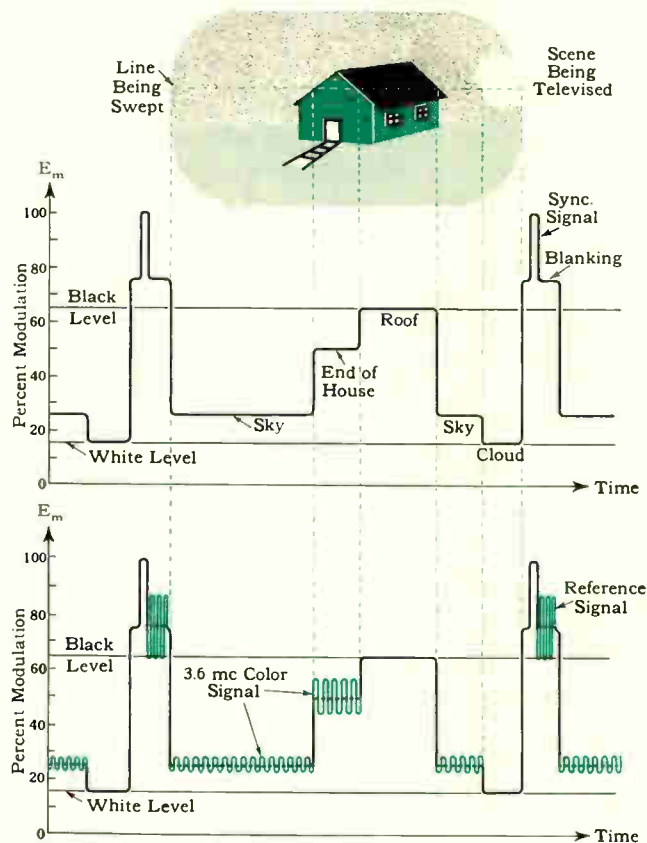


Fig. 4—When a scene is televised, the upper trace shows the information carried by a standard black-and-white signal. To transmit a color picture, a reference signal and a 3.6-mc color signal are superimposed over the standard black and white, as shown by the lower trace. The color frequency chosen is such that the following color signal is 180 degrees out of phase—hence, for a black-and-white receiver, the color signal is blanked out, and the resulting dotted-line trace is identical to the black-and-white signal.

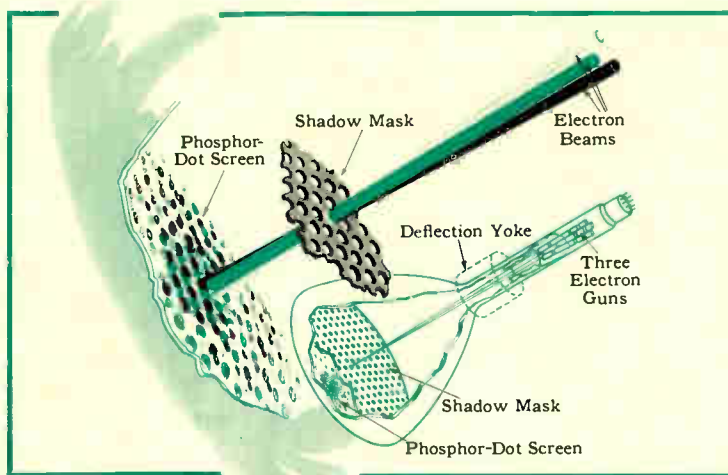


Fig. 5—Shadow-mask tube and an enlargement of mask and color-phosphor trios.

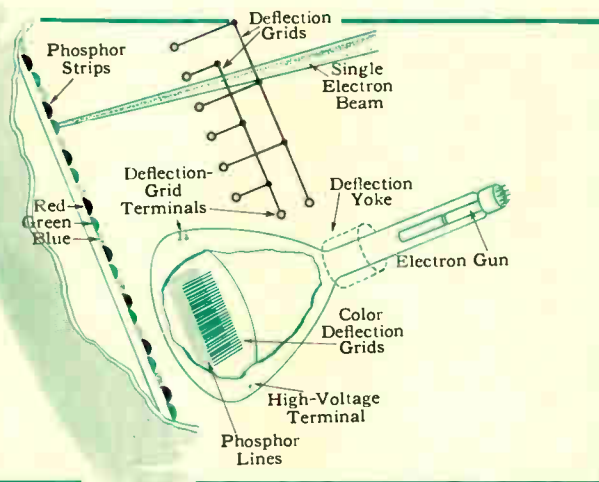


Fig. 6—Deflection-grid tube and its arrangement of phosphor strips and grids.

see any color at all—only brightness. To transmit the additional color information required for fine detail is only a waste.

Also, whereas to present all of the color information in a picture would require a bandwidth of 5 to 10 mc, in scanning a color scene, the bandwidth of frequencies in the signal varies with the rate of change of color, i.e., color detail. If an area of a single color i.e., no detail, is scanned only a single frequency, i.e., the sub-carrier itself, is required. However, when the color changes rapidly, i.e., as the amount of color detail increases, more sidebands are needed with the carrier to convey that intelligence. The finer the color detail the wider the band of frequencies the color signal occupies. But, fortunately for the electronics engineer and for your and my pocketbooks, the eye cannot see the detail requiring frequencies above about 1.5 mc.

Which brings us again to the philosophy that the goal of color television is not to reproduce a scene exactly but only in a fashion that is both pleasing and plausible to the viewer. This suggests a compromise with visual quality. Such, however, is not the case. But the imperceptible difference means much to the engineer.

With these facts in mind the color-transmission engineer chooses as his axis for the in-phase or *I* signal the line between greenish-blue and orangish-red. The quadrature axis is, obviously, 90 degrees to it. The particular portions of the red, green, and blue signals taken to make up *I* and *Q* are chosen so as to make the *I* axis align with the orange-cyan line of the chrominance chart, which is the line of greatest eye sensitivity to medium color detail. The green-to-purple color axis, which the eye sees with less color detail, is transmitted by the *Q* signal, with the lesser bandwidth of approximately 0.5 mc.

The complete package of signals required for color transmission, except for line and frame synchronizing and for sound, which are the same as for black and white, consists of (a) a luminance or brightness signal and (b) a 3.58-mc color subcarrier modulated with the *I* and *Q* signals. To recreate in each receiver the necessary 3.58-mc color subcarrier and to lock it in phase with the subcarrier at the transmitter, a burst of at least eight cycles of the 3.58-mc subcarrier frequency is added at the transmitter to the end of the horizontal blanking signal (see Fig. 4).

At the receiver the luminance (*Y*) signal is detected in the normal fashion. To detect the chrominance information, subcarriers are reinserted in synchronism with the transmitter subcarrier by shock-excitation of the receiver's 3.58-mc generator by the eight cycles of synchronizing burst. Since the three signals—*Y*, *I*, and *Q*—came originally from combining the outputs of the red, green, and blue channels of the color camera, they can, by use of suitable networks, be separated again into their original red, green, and blue signals for application to the color picture tube.

Today, two basic types of color picture tubes are in production—the earliest stages of production. One is the three-gun, shadow-

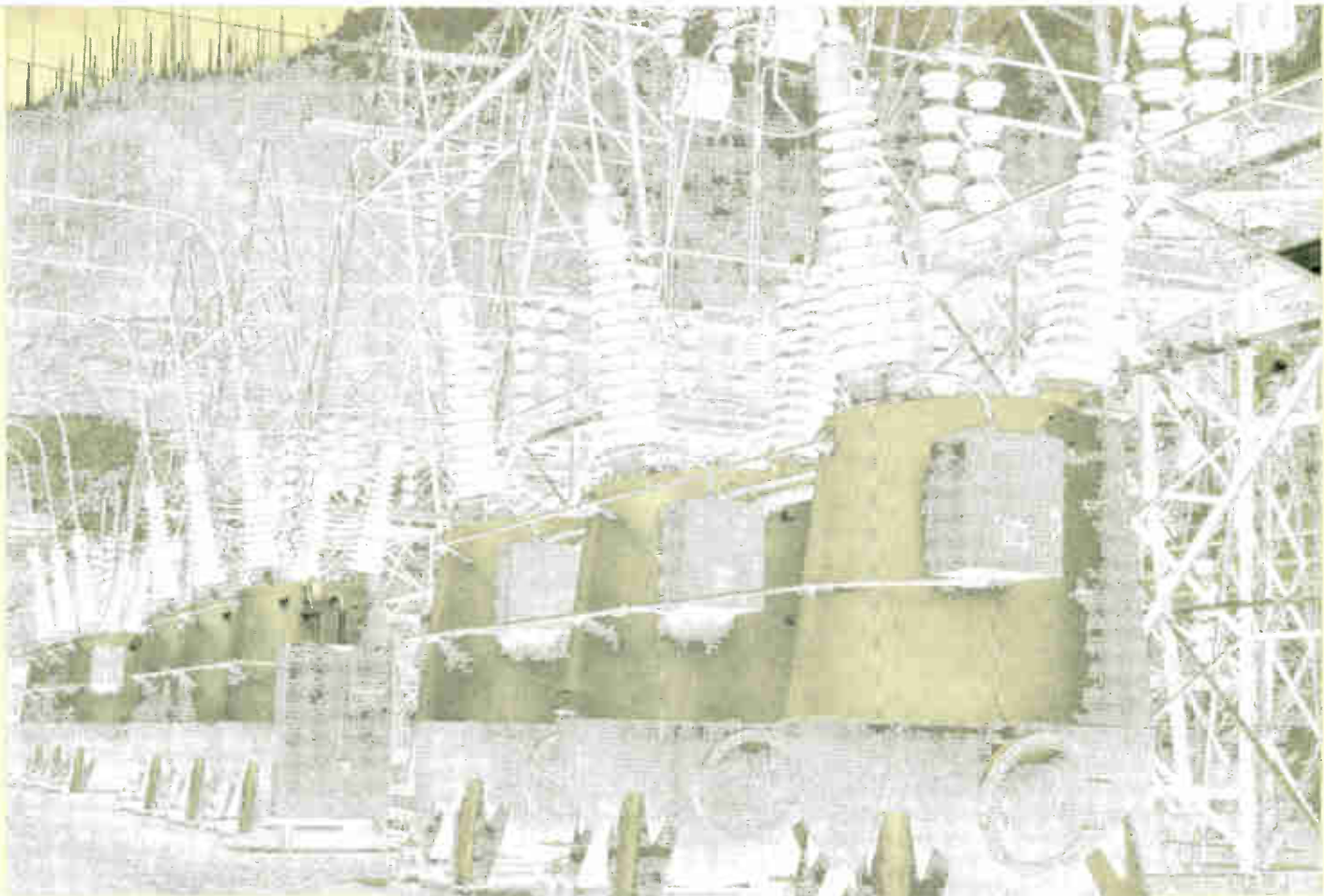
mask tube; the other is a single-gun, deflection-grid tube. In the shadow-mask tube, developed by the Radio Corporation of America, the phosphor dots are laid down on a flat plate behind the tube face, as tiny circles of red-, green-, and blue-sensitive phosphors, touching but not overlapping in a triangular pattern, as shown in Fig. 5. Each screen has 585 000 dots or 195 000 of these "trios." This is a precision operation, its successful development to a practical stage being a major technical accomplishment.

On the gun side of the phosphor plate is the shadow mask, consisting of a thin metal plate with tiny holes that match exactly the pattern of the trios. In the neck of the tube are three cathode-ray guns, one for each color, spaced 120 degrees apart around the central axis. The beams from all three guns are focused at the holes in the mask. Because of the angle of the guns with respect to the center line, the electron beam from the red gun, say, passes on through the hole to fall on the red phosphor of the corresponding trio, but is prevented by the mask from touching either the blue or green phosphor of that same trio. As the three color signals are fed to their respective guns and with the line and field scanning performed in the normal monochrome sequence, each dot is excited to an intensity corresponding to that color in the original.

Another version of the shadow-mask tube is produced by CBS-Hytron. It also uses three guns and a shadow mask but the phosphor trios are applied directly to the curved inner face of the picture tube by a method that has certain advantages.

In the single-gun deflection-grid tube (sometimes called the Lawrence tube) the color phosphors are laid down in narrow strips, behind which are rows of grid wires, as shown in Fig. 6. With no voltage on the grid wires, the electron beam passes straight on through to fall on the green phosphors. If, however, the set of wires behind the red-phosphor strips are made positive, and the wires behind the blue strips negative, the beam is deflected to the red-phosphor strip. The blue strip is excited by reversing the polarity of the grid wires. Hence, by applying a high-frequency sine wave (3.58 mc) to the deflection grid, the electron beam is rapidly switched across the three color-phosphor strips. The single beam must be modulated by, say, the red color signal when it is passing over the red phosphor, and likewise for the other two colors. This is done by feeding the three decoded color signals (red, green, and blue) sequentially to the single gun, in synchronism with the 3.58-mc grid-deflection voltage. This results in a three-color picture that, to the eye, appears a faithful replica of the studio scene.

It is generally agreed that color picture tubes are still in the early stages of development. Developments that will improve picture quality, lower cost, and lengthen life are certain. It is possible—some say probable—that some much better basic idea for a picture tube will be forthcoming. Certainly large sums of research money are being spent to find one if it exists.



Bonneville Power Administration installation of 7500-mva, 230-kv Watch-Case circuit breakers.

Circuit breakers, the “doors” of the electric-power system, have had to move fast to keep up with the “house.” As power systems grow, breakers have to keep pace. Five years ago, 3.5-million kva was a lot of “traffic” for one door to handle—today, 25-million kva doors are being installed.

Progress in *Power Circuit-Breaker Development*

A. W. HILL, *Manager, Power Circuit Breaker Engineering, Westinghouse Electric Corporation, East Pittsburgh, Pa.*

PROGRESS in any art is generally identified by increasingly larger numbers—ratings, performance characteristics, production units—everything but size. The development of large power circuit breakers above 1500 volts certainly has expanded in the last few years in these directions. At the same time improvements have been introduced to provide more reliable performance, better installed cost, standardization of parts for the benefit of the spare-parts storekeeper, and structural betterments that do not appear on the nameplate.

Outdoor Breakers

One outstanding gain in the past two years has been the introduction of a new and higher operating voltage—330 kv.

This is but one of the steps above 230 kv, and the industry naturally is giving serious consideration to standardization so that the best possible use can be made of designs for these high voltages. The studies of circuit-breaker requirements show no fundamental differences as the voltage is raised above 230 kv, and the breakers now being built conform in general to earlier designs for lower voltages. As voltages increase, so must breaker size. However, dead-tank construction can be used without exceeding practical limits of railroad shipping clearances, tank manufacturing limitations, or handling facilities in the field during erection and maintenance. Likewise, the conventional apparatus bushing can be built for higher voltages without requiring changes in design prin-

principles. Laboratory test facilities are quite ample to develop and test apparatus considered for 330 kv or even higher operating voltages.

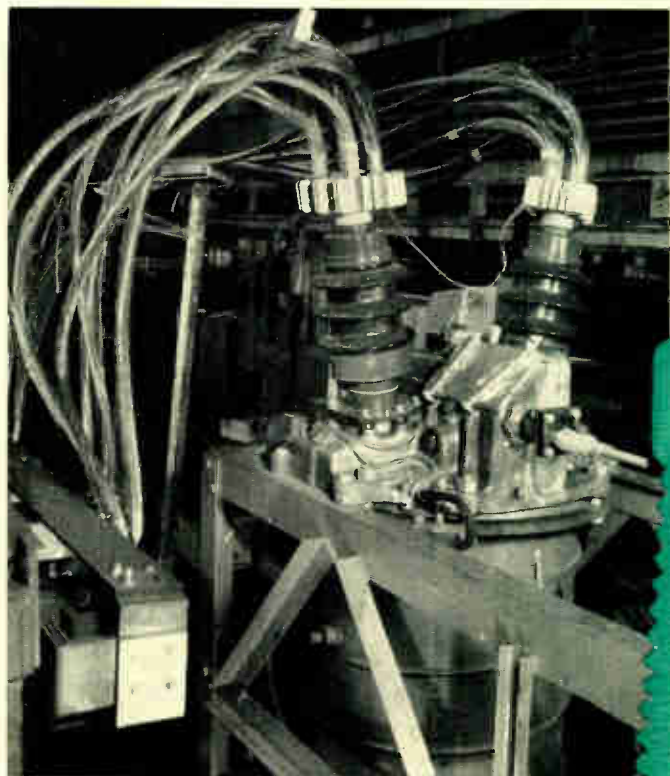
Interrupting capacity expressed in kva has also seen a remarkable rise during the past few years. Within the last ten years breakers have been built and installed with ratings increased from what seemed to be large—2 500 000 kva—to present designs actually in service at 15 000 000 kva, and being built for 25 000 000 kva. Increases in interrupting capacity mean more big generators installed and more interconnected tie lines. They also indicate the operator's confidence in laboratory development programs and the workmanship provided in modern factories.

The continuous-current rating of large power circuit breakers has also of necessity risen to values formerly considered entirely unnecessary. Under some circumstances each big generator may be switched by its own generator breaker. With generator ratings over 100 000 kw, the continuous-current requirement of the circuit breaker exceeds 4000 amperes and the need for ratings of 6000 and 7000 amperes, or even higher, has not been uncommon. The requirement might be met by adding to the cross section of current-carrying parts, but this would add considerably to the mass of the circuit breaker. High stresses produced also make this solution undesirable from a mechanical standpoint. An equally efficient and much preferred method is forced cooling for those parts of the circuit breaker where such cooling can be feasibly applied. Ratings often can be increased to meet these demands while still using mechanical parts suitable for the more moderate rating of 3000 or 4000 amperes.

For practical purposes, forced cooling is limited to applications where the cooling apparatus will not be near high voltage; the method is then safe and does not require high-voltage insulation. An outdoor oil circuit breaker normally rated 4000 amperes has been modified by water-cooling coils brazed to the grounded circuit-breaker top. This breaker has been in continuous service carrying 6000 amperes for several years. It could handle even more current by merely increasing the flow of cooling water. This same breaker was shown to be suitable for 6000-ampere, continuous-current service with only a moderate movement of air across tank tops, such as produced by an ordinary 14-inch household fan. Similarly an indoor compressed-air breaker normally rated for 5000 amperes continuous current is operating at 6000 amperes after the addition of a fan and forced-air system to carry away the extra heat. Should the occasion arise, it could be modified to carry 10 000 amperes with complete safety.

One feature peculiar to high-voltage power circuit breakers, and often required, is the ability to reclose quickly after a fault interruption. Experience with high-voltage transmission circuits has shown that better than 90 percent of system faults result from lightning flashovers to ground. Such faults are not permanent and a short period of zero voltage permits the insulator string to recover. Immediate reclosure of the breaker restores the line to normal service. Higher operating voltage means greater dollar investment in the circuit, and makes rapid reclosing of utmost importance. Reclosing times of 20 cycles (one third of a second) are commonly requested on transmission-line breakers. The apparatus designer is not happy unless he can demonstrate reclosing times of 10 or 15 cycles, even though this speed may not be used because of the time required to deionize space around the arcing fault.

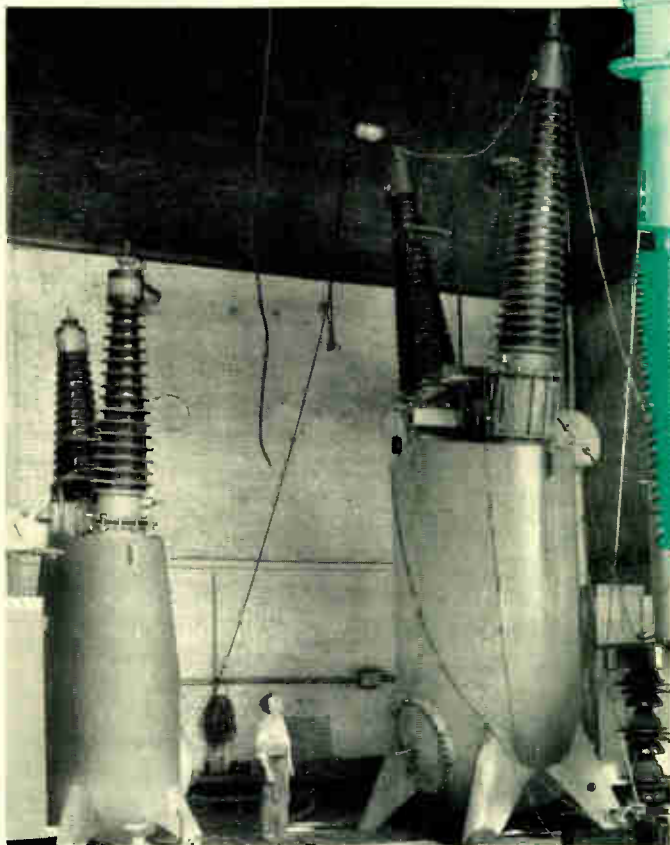
Features of modern breakers reflect that user demands and improved manufacturing facilities are directed to more eco-



In this water-cooled circuit breaker, tubing brazed to the tank top carries the cooling water for removing heat.

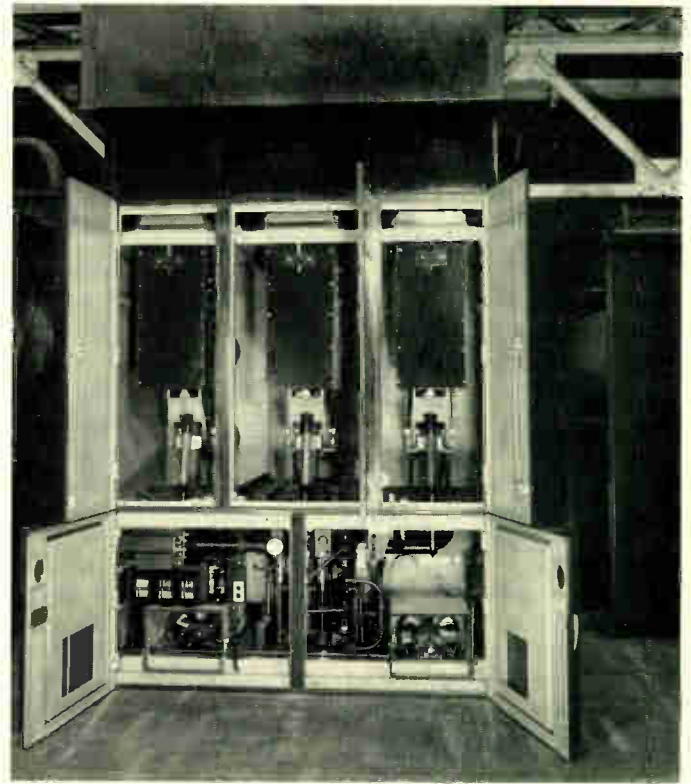
The 330-kv bushing is 18 feet long, weighs two tons—a lot of insulation is needed for a 1300-kv impulse.

The "bigness" of the 25 000-mva, 330-kv Big Ben is exemplified by a comparison with a 230-kv breaker pole.



nomical and reliable performance in the field. For instance, the problem of oil handling for large oil circuit breakers has long been recognized; it requires not only time (man-hours), but also investment in oil storage and filtering equipment. Improvements in interrupters during the last ten years have made it possible to reduce tank sizes approximately 50 percent. In the 230-kv class, the shape of the tank has been materially changed to reduce still further the volume of oil, by another 50 percent. This Watch-Case construction is now in common use for high-voltage breakers. The only reason it is not used at voltages of 161 kv and less is because there is not sufficient space for a man to work inside the tank if full advantage is taken of the possible close insulation distances. Watch-Case construction above 161 kv provides all the electrical clearances of the conventional round-tank breaker, is adequately strong under hydrostatic pressure tests, and makes all parts inside the tank just as accessible. Furthermore, it not only reduces the amount of oil to be handled but offers the opportunity to reduce breaker foundation costs in proportion to the lesser weight of the oil-filled breaker. In the case of breakers rated 330 kv or higher, the Watch-Case construction makes easier the problem of securing railroad clearances during the shipment of the breaker.

Many of the large floor-mounted tanks (69 kv, or above) are now assembled at the factory on sub-frames or skids and delivered into the field as one unit rather than three separate tanks as was formerly done. At first glance this might appear to add to the problem of the rigger, who now will have to handle one piece three times the weight of a single tank. This does not seem to worry the rigger and it does provide a big improvement in the cost of installing the connecting parts between the tanks after they are mounted on the foundation. All mechanical pull rods and cover pipes, tie rods for maintenance of tank spacing, and conduit and current-transformer secondary leads are assembled and adjusted at the factory. One operator reports that installation work formerly requiring a week is now done in a day. The obvious saving in man-hours and rental for power-hoisting equipment is quite significant. Here again, foundation designs can be simplified and a considerable saving realized by using two or three piers instead of a solid concrete pad, since the sub-frame under the breaker

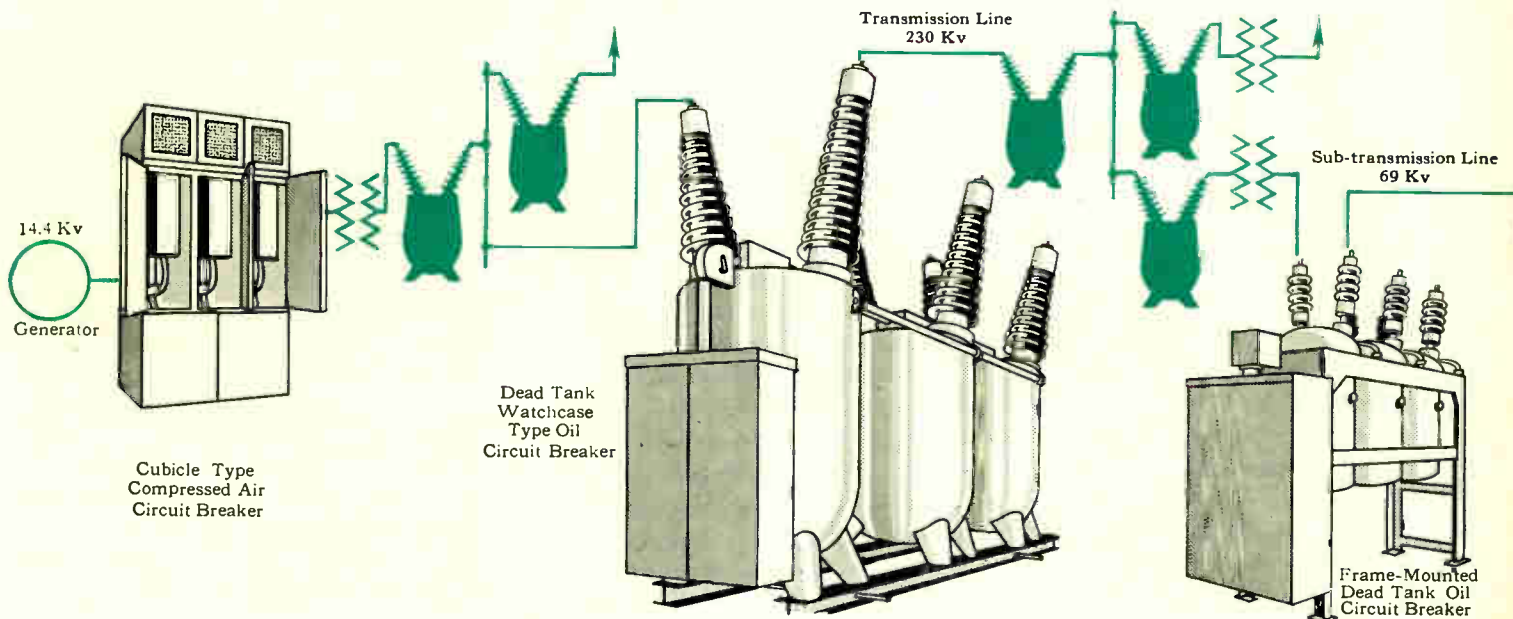


A set of fans located in the bottom compartment of this compressed-air circuit breaker provides a blast of cooling air across the contacts when needed, as determined by thermostats that measure temperature difference between outside and inside of the cubicle.

tanks provides much of the mechanical support needed.

Indoor Breakers

For indoor service, a strong preference exists for breakers having no oil—a recognition of the risk of serious fires, which fortunately have not occurred. Maintenance is easier also with no oil storage and filtering problems. Two factors govern the choice of an interrupting device—space and cost.



Magnetic Air Breaker

Most industrial plants and central-station auxiliaries require short-circuit interrupting capacities of not over 500 000 kva, and desire close spacing of several breaker units to keep building costs down. The magnetic air breaker meets these needs very easily with its narrow arc chute to receive and deionize the arc blown magnetically upward into it. The breaker has a long life in switching service since its butt contacts can be arranged to transfer all the current to arc horns to take the burning. Search for the best arc-chute material shows that ceramic plates of zirconium composition withstand the mechanical shock of high-power interrupting duty and do not suffer enough from high temperature to restrict unduly application of the breaker on instantaneous reclosing service. Heat storage in contacts and chutes is important in establishing reclosing duty cycles. While breakers of this type are only some 15 years old, and at first were supplied with limited insulation across the open gap, continued development in the past three years has removed this restriction, and full impulse strength is now given without reservation.

The magnetic air breaker has another important advantage in that it can be mounted readily in removable trucks for metal-clad gear. With complete assembly under factory conditions, the cost of circuit-breaker installation is much reduced, a significant point in view of rising costs of assembly labor in the field.

A d-c solenoid mechanism is used with magnetic air breakers, since it is economical to build and maintain. Even where no d-c voltage supply is available, as with unit substations remote from central stations, the same solenoid is energized through a rectifier to retain the solenoid simplicity.

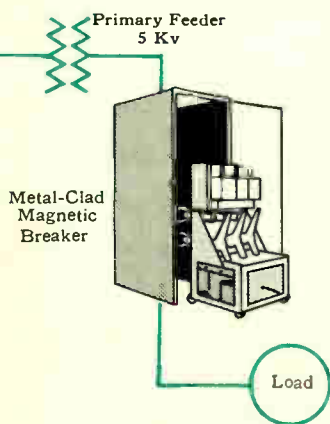
Compressed-Air Breakers

For large generators and main feeders in large stations, compressed-air circuit breakers are used because of their higher interrupting capacity. Even for short circuits of 2 500 000 kva, the cross-blast principle of forcing the arc upward into an arc chute and cooling chamber provides an efficient interrupting medium. They could replace magnetic breakers for the lower kva ratings except that accessories going with the air supply and control equipment are inherently too expensive to be practical. Recent development work on the breaker has resulted in a substantial reduction in size, in some cases by as much as one quarter of the original width. This has come about from a more efficient chute and arc control.

Compressed-Air Outdoors?

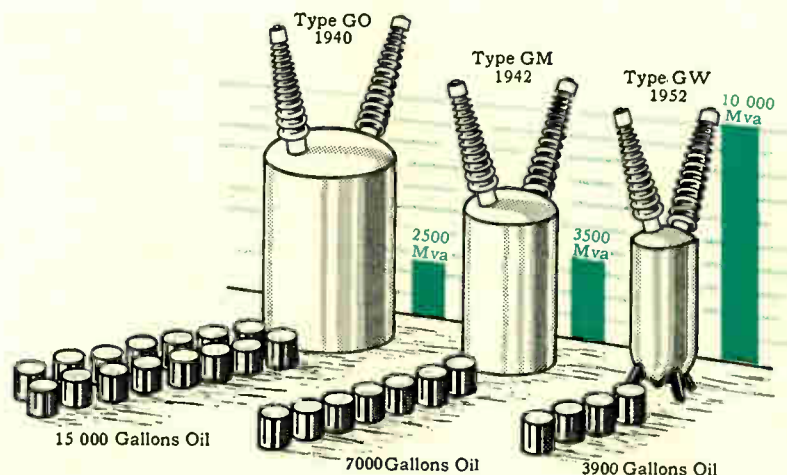
With the complete acceptance of compressed air for indoor circuit breakers, it would seem natural that efforts would be made to use the same principles in outdoor apparatus, especially

◀ The roles that four basic types of power circuit breakers may play on a power distribution system are shown in this simplified diagram.



because of the larger quantity of oil required for outdoor oil breakers. So, it is significant to note that the thinking of manufacturers and users has not changed appreciably during the past ten years. While Europe, with a scarcity of oil and steel, has favored the oil-poor and oil-less breakers, the American market, without these restrictions, definitely prefers the dead-tank bulk-oil circuit breaker.

The American manufacturer finds it difficult to justify the use of porcelain merely to reduce the amount of oil in large circuit breakers. Porcelain is mechanically fragile and as a principal support for a high-power circuit breaker is not readily accepted by most users. In this respect, conditions in this country are somewhat different from those of European countries where system design is limited to moderate short-circuit currents to avoid high stresses on circuit breakers and other apparatus resulting naturally from close interconnection. Porcelain is also susceptible to electrical breakdown if



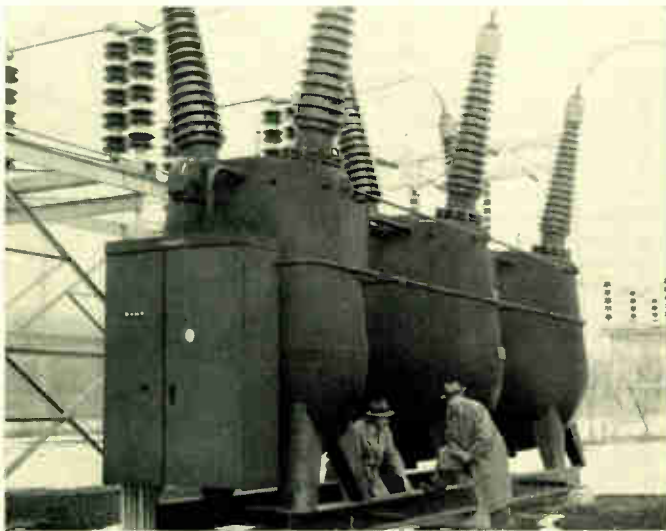
A "factor of four" figures in recent 230-kv circuit-breaker design — ratings have increased by four, oil has decreased by almost four.

small amounts of moisture collect on smooth inside walls. This in itself has been the cause of several disasters and the problem has not been entirely solved even when dry air is blown through the porcelain tubes. As a result, the trend in the high-voltage field remains the same as for many years past, i.e., in favor of oil-filled breakers.

One requirement of the American industry is that each high-voltage circuit breaker be provided with bushing current transformers, generally on each side of the breaker. Relay schemes commonly used are based on having current transformers on both sides of the circuit breaker to get overlap protection. Frequently, two and sometimes three transformers per terminal are required; it is obvious that relaying transformers can be provided in the dead-tank oil breaker with practically no increase in cost for insulation, since the transformer is merely slipped over the terminal bushing, and the bushing provides primary-to-secondary insulation. This compares very favorably to porcelain-clad circuit-breaker construction where bushing-type transformers are not possible and each current transformer must be built with its own full line-voltage insulation. Another item of considerable importance is the simple and economical source of voltage that can be obtained from potential devices on the condenser bushing of the dead-tank circuit breaker. Here again, this is often necessary for relaying installations and can be obtained di-

rectly from the breaker bushing at a negligible cost compared to a potential transformer that is otherwise required.

All modern high-voltage dead-tank oil circuit breakers can be supplied with at least two current transformers per bushing and the designer is not greatly embarrassed if the need for three is presented. In addition to the larger number of transformers, he frequently must provide for higher accuracy or greater output, and it is a matter of experience that the space needed for current transformers may often control the overall dimensions of the circuit breaker. Where bus-differential relaying is involved, it is not uncommon to find linear couplers used in place of current transformers and the performance, of course, is superior because there is no iron in the core to saturate under transient current conditions. In fact the popularity of linear couplers has made it necessary to pro-



The skid-mounted 230-kv, 3-pole breaker is delivered practically a "package" unit—addition of bushings completes the assembly.

vide designs for couplers that can be added to older breakers already in service.

Radio Interference

Television has emphasized the need for closer control of radio influence from high-voltage equipment. In the power circuit-breaker field recent studies have shown that it is possible to reduce the prescribed limits to one fourth of what they were during the past few years. The highest limit previously set by NEMA was 10 000 microvolts for 138-kv equipment. The reductions now being considered should eliminate serious radio interference, although it is encouraging to note that many breakers of even the highest voltage class will normally operate with far less radio influence than has been permitted by the ASA Standards. Recent tests on a 330-kv condenser bushing show that radio-influence voltages of less than 100 microvolts were measured with 110 percent of line-to-ground voltage applied to the bushing. Even when assembled into a complete breaker the radio interference would be far less than the proposed industry standards.

Standardization

A more specific item of standardization covers the electrical and mechanical characteristics of outdoor apparatus bushings. This is aimed to provide a bushing design that can be

used interchangeably in power transformer and circuit breakers of any manufacturer's design. Obviously, the outcome is a compromise since bushing requirements for circuit breakers are quite different from those for transformers and, of course, different manufacturers have ideas peculiar to their own apparatus. The standard, when adopted, will not be retroactive but will cover all future apparatus.

Actually, benefits from the new standard soon will be realized; based on the present rate of industry expansion, as many circuit breakers will be manufactured in the next ten years as are now in active service. Future possibilities of bushing standardization seem promising, especially to an operator who may need a spare bushing in a hurry during an emergency. The use of an industry-wide standardized bushing also will be very helpful to the manufacturer. Naturally the bushings of earlier design cannot be ignored, and replacements for apparatus produced within the past 25 years or more will be possible either through the use of adapters on the new standard bushing or special designs made to the old dimensions.

Further efforts of the ASA Standardizing Committee will soon result in a test code for power circuit breakers. This will be based on many years of experience in laboratories and in the field, and is now being reviewed and modernized so that a purchaser and a designer can refer to a common specification when development tests or routine tests are being discussed. Here again the successful use of this test code will depend upon the cooperation of the entire industry.

Throughout all this program of improvement and standardization, the aim of the designer has been to provide a breaker for any condition of service. The circuit breaker should not be a bottleneck to expansion of any system, and at the same time features to assist the user in getting economical installation and reduced maintenance throughout the life of the apparatus should be incorporated.

American Standards Association committees are doing much to improve and enlarge upon standardization of breakers and parts. A principal object of standardization is to improve equipment reliability, making possible longer periods between maintenance inspections. Also, greater dependence on laboratory development at the factory is replacing field testing, which has been necessary frequently during the past 20 or 30 years.

The *ASA Standards on Preferred Circuit-Breaker Ratings*, an outgrowth of the work of the EEI-AEIC-NEMA Joint Committee, provides ratings for all common needs. The committee has eliminated ratings where demand was too light to justify several manufacturers carrying the unit in regular production. The general trend has been toward higher interrupting-capacity ratings. Consequently, some low kva ratings are dropped from the Standards when higher rated breakers become available at no great increase in cost. These rating charts are being reviewed continually and the committee welcomes comments from all users so that the ASA Standards will be truly representative of the needs of the industry, as well as the ability of manufacturers to produce.

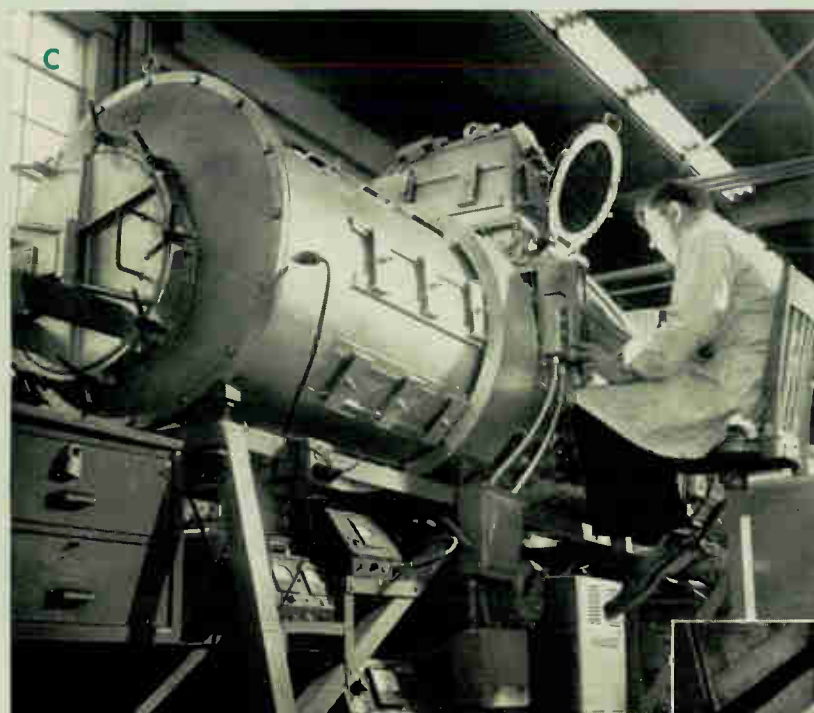
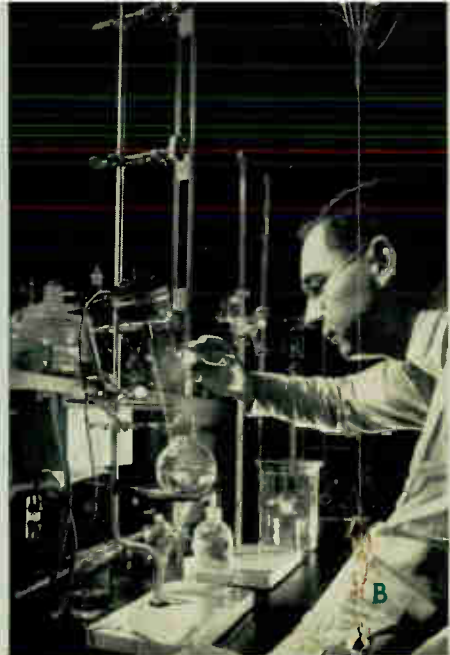
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Permanent-Magnet Alternators—A new a-c generator, with only permanent magnets for field supply, and occupying less space than an eight-inch cube, delivers one kilowatt. The two-pole permanent magnet is of an Alnico alloy that has high magnetic energy per unit volume and high tensile strength. These qualities permit operation at high speed—which gives high output. Such generators are suited for small emergency power units where a separate d-c source for the field would be inconvenient.

ON JANUARY 21, 1954 a new concept in ships—a nuclear-powered submarine—glided smoothly down its ways into Connecticut's Thames River. This was the U.S.S. *Nautilus*, constructed at the Groton shipyard of the Electric Boat Division of General Dynamics Corporation, and to be propelled by a nuclear power plant built by Westinghouse.

Behind this revolutionary new power plant lie countless hours of research, development, and testing of materials, components, and, of course, a complete prototype. The pictures on this page show portions of this vast program, accomplished under contract with the Atomic Energy Commission. Much development and construction work was accomplished at the Bettis Airport site near Pittsburgh, with testing of the prototype Mark I done at the Idaho desert site of the AEC.

When the vessel embarks on its maiden voyage, a large scale nuclear power plant will be put to practical use for the first time.

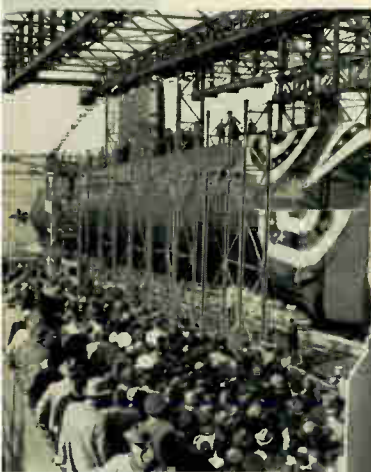


A—Seven feet of concrete stand between this technician and the radioactive object he is handling by remote control. Manipulation of the claw-like hands inside the cell is accomplished by the controls shown here. **B**—Water—ultra pure water, that is—is one of the most important “ingredients” of the system. This is the water used as a heat-transfer medium from the reactor to the boiler via the primary-loop piping system. Ordinary water may contain some 300 parts per million of impurities; distilled water, 5 ppm. But the reactor water is even purer, to reduce the amount of corrosion and prevent radioactivity from reaching too high a level. **C**—Zirconium is well suited for use in a nuclear reactor because it does not absorb neutrons as do many other metals. But welding zirconium is another matter—it absorbs oxygen and nitrogen if welded in open air. With this specially designed vacuum tank, the operator can control positions of both the electrodes and the part being welded.

The Growth of the Nautilus

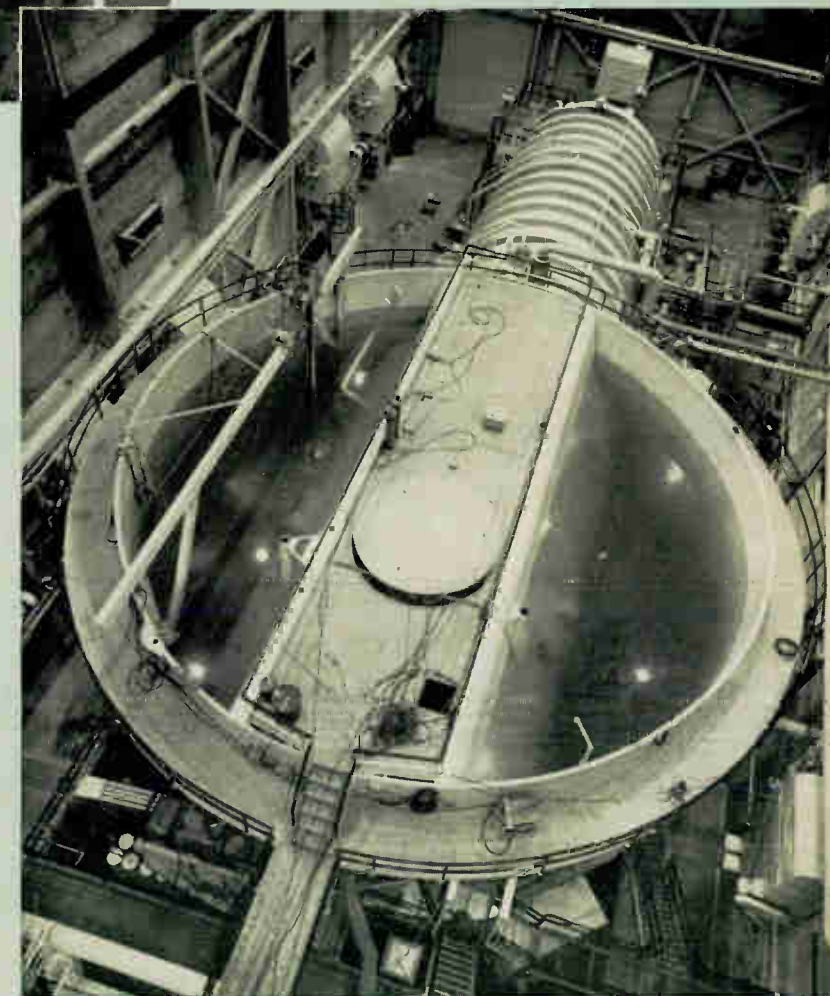
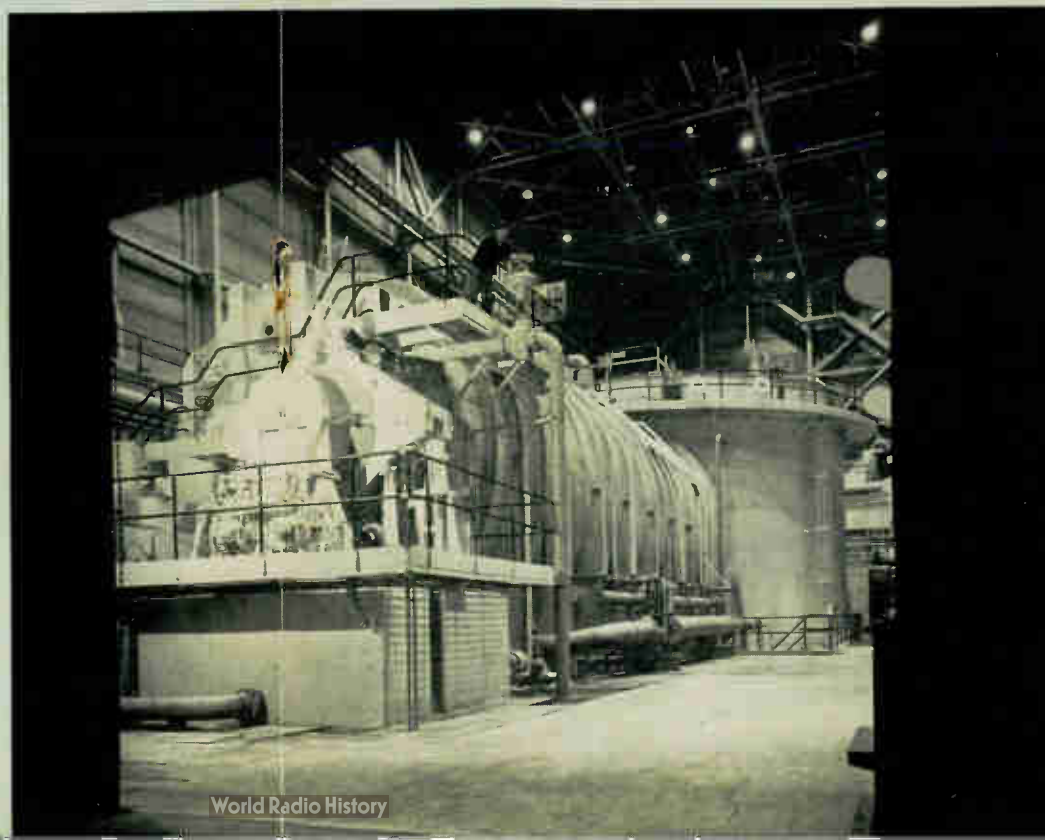
Behind the launching

.....a tremendous amount of development

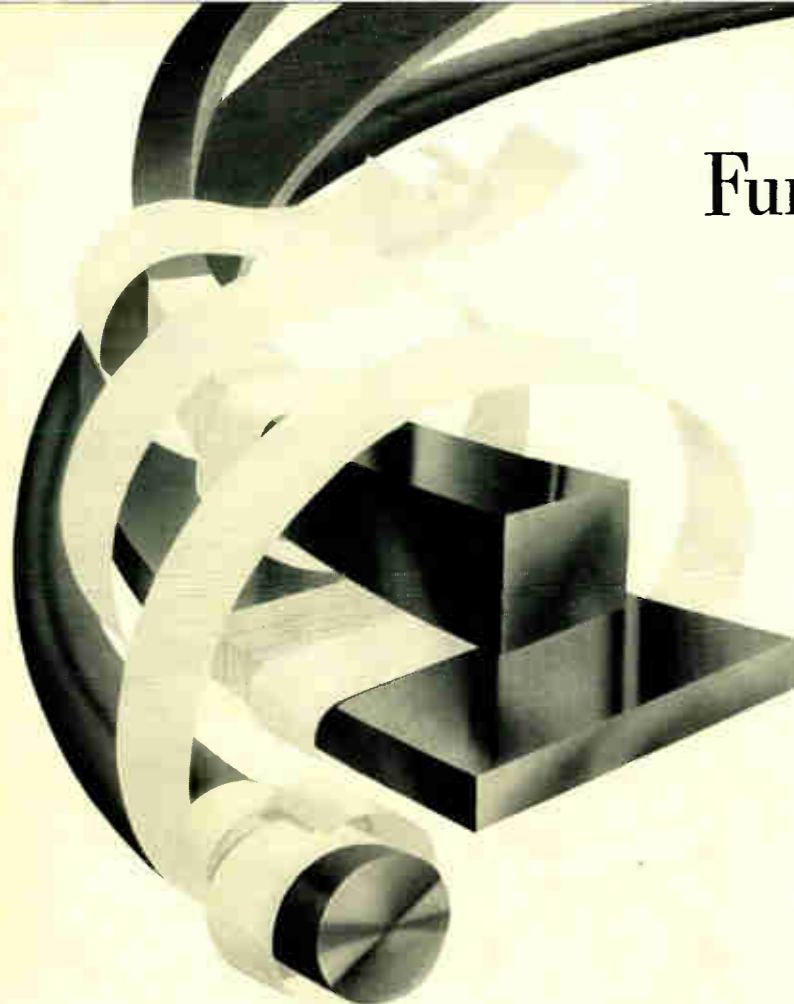


Inset, at left, shows the U.S.S. *Nautilus* getting its feet wet for the first time as it glided down the ways. Seconds later the submarine was afloat in Connecticut's Thames River, and shortly afterward was tied up at her pier (left). Thus another step in the development of the first nuclear submarine was taken; the next will come when it takes its maiden voyage.

Inside this section of a submarine hull is the first atomic-power plant ever to produce substantial amounts of power. This is the Mark I, the prototype for the actual engine that will drive the U.S.S. *Nautilus*. As announced by the Atomic Energy Commission, Mark I reached criticality on March 30, 1953; by May 31, substantial amounts of power were produced. This nuclear power plant was built for long-range testing and operation. Below, the aft end of the hull and the tank that surrounds the reactor compartment.



A top view of the sea tank and hull section containing the Mark I nuclear power plant. The sea tank is about 50 feet in diameter and almost 40 feet high. The hull passes completely through the tank, so that the reactor compartment is located within the tank, completely submerged in water.



Fundamentals of *Electrical Insulation*

The electrical industry without insulation would be like the steel industry without iron ore—it just wouldn't exist. Every electrical device from a toaster to a giant 200 000-kw generator is feasible only because of the availability of good insulating materials. Great strides have been taken since engineers first used varnished-cloth insulation; much of the progress is directly attributable to a better understanding of the mechanism of insulation, i.e., the physics and chemistry that explain the phenomenon.

I—*Chemistry* of Insulation

JACK SWISS, Manager, Insulation Department, Westinghouse Research Laboratories, East Pittsburgh, Pa.

THE UNIQUE ability to insulate electrically one conducting material from another is explained largely as a physical phenomenon, rather than a chemical one. However, the task of designing proper materials—to provide the necessary electrical and mechanical properties—falls mostly to the chemist. Stated simply, the problem does not appear tremendous. For example, almost any organic material is a good insulator if it can be formed into a continuous film that excludes moisture, and if the continuity of the film can be maintained through the hazards of manufacturing operations and the operating life of the apparatus concerned. Also, many inorganic materials, such as mica and asbestos, are insulators.

Chemically, one primary difficulty arises from the need for a "continuous film." To form such films of acceptable mechanical strength, molecules of huge size are required. This requirement has led to a vast amount of research on the structure of such large molecules, and the methods by which they are formed and held together. In forming an insulating material the chemist must be careful to limit the number of conducting particles, and at the same time provide mechanical strength, and other desirable physical properties. This he can do by judicious selection of materials.

Types of Chemical Bonds

Until a few decades ago, the prevailing opinion was that substances like rubber and cellulose were composed of small aggregates of atoms, held together by mysterious forces. How-

ever, research by such pioneers as Dr. Herman Staudinger, last year's winner of the Nobel Prize in chemistry, showed conclusively that substances like natural rubber were actually made up of very large molecules, held together by the same types of chemical bonding action that hold atoms together in small molecules.

Consider the different methods of bonding two atoms. Elements in the groups at the left of the periodic table (Fig. 1)—i.e., those with few electrons in their outer shell, such as sodium and hydrogen—have a strong tendency to form a stable outer electron shell by losing their valence electrons. In this process they become positive ions; such elements are said to be electropositive (or basic). In any one group this tendency to lose valence electrons is greater as the atomic radius (i.e., the distance from the center of the atom to the outer electron shell) is increased, thereby decreasing the attraction between the nucleus and the outermost electrons. For example, the tendency to lose valence electrons is greater in sodium, with a radius of about 0.95 Angstrom (one centimeter equals 10^8 Angstroms), than in hydrogen, with a radius of about 0.3 Angstrom.

On the other hand, the elements at the right of the periodic table—such as chlorine—have a strong tendency to form a stable outer electron shell by completing their nearly filled octet. In this process they sometimes become negative ions; the elements with such tendencies are said to be electronegative (or acidic).

Personalities

IN ENGINEERING

GRAHAM LEE MOSES

A good development engineer cultivates—quite intentionally—a mild form of split personality. On the one hand he must think and discuss problems from the standpoint of the research scientist; but at a moment's notice he must put himself in the shoes of the manufacturing engineer and consider his complex problems. Such mental acrobatics require an unusual combination of talents. In addition to the usual extensive knowledge of his own field, he must have much of the imagination and scientific vision of the research scientist, and the ingenuity and practical foresight of the manufacturing engineer.

By these criteria, or any other, Graham Lee Moses is a topnotch development engineer. A quick glance at a few of his activities in the past 20 years is ample evidence. Moses was one of the earliest sponsors of fiber-glass insulation for rotating machines in the middle 30's. He helped pioneer the use of silicone resins; in fact, his engineering section produced the first sizable quantity (ten gallons) of silicone varnish, for use in their experiments. Moses was an important figure in the development of Thermalastic insulation, having had the responsibility for bringing it to practical application. He took an active part in early development work on insulation for high-altitude aircraft. During the war he was chairman of the Navy-industry committee on insulation, and received a citation for his outstanding contributions to the naval development program. He helped develop the concept of testing insulation on machines rather than separately, of accelerated testing of insulation, and of the effects of aging on insulation. Moses is now in charge of the development of insulation for large rotating machines.

A readily apparent personal characteristic is Moses' direct, simple approach to problems. He has the valuable ability to reduce problems to their simplest terms, to get at the heart of a subject quickly. Moses has a most unusual explanation for this ability. As a boy he lived in a school for the deaf and dumb, where his father was superintendent. Because many of his playmates were students of the school, Moses gradually learned sign language. He soon found that this called for the ultimate in conciseness, and acquired this characteristic as a lasting trait.

This direct and concise approach is, of course, a valuable asset in his development work. Also important is its effect on his writing. Here Moses has really put his talents to work. Altogether he has authored over a hundred technical articles and papers. In fact, in 1944 he received honorable mention for the best AIEE paper in the field of research, and the following

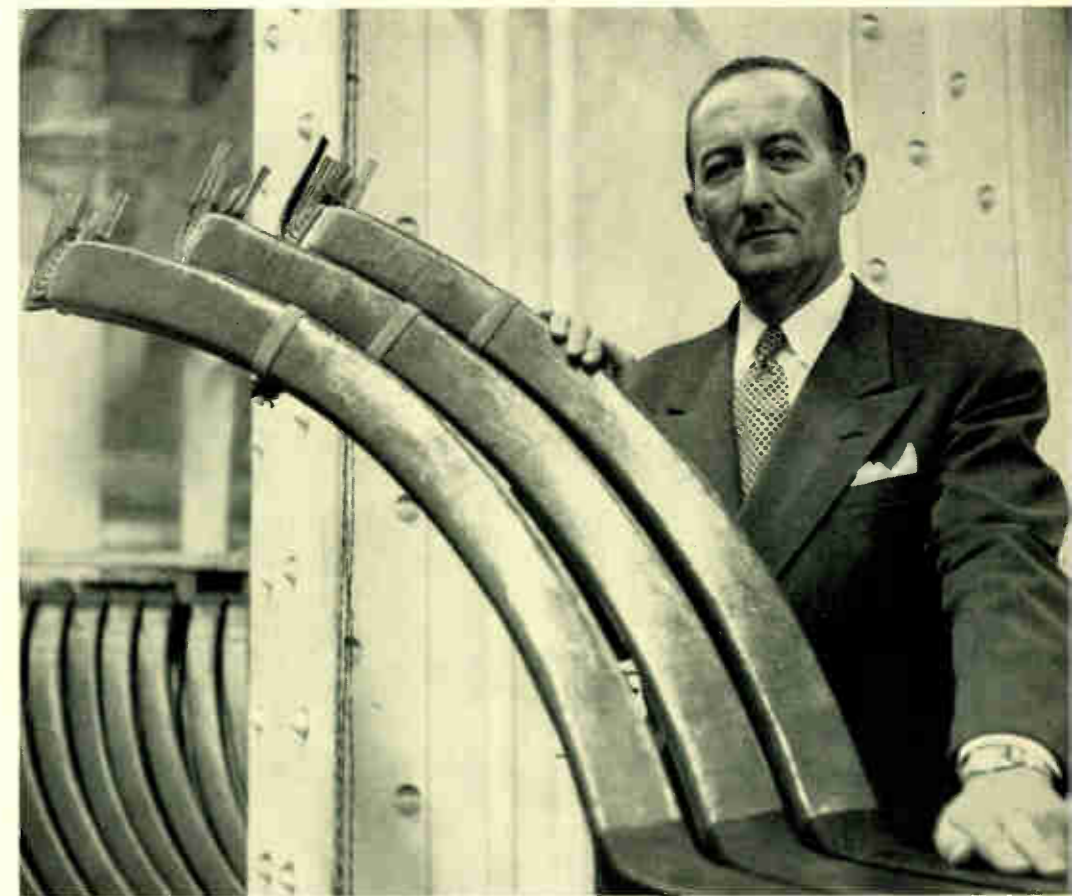
year won first prize for the best paper in the field of engineering practice. (The diversity of the subjects is perhaps one of the best indications of Moses' versatility.) In 1951 Moses finished the task of writing a book entitled *Electrical Insulation*, now widely used by the Navy as its insulation manual.

Moses came to Westinghouse in 1923, after graduating from Bliss Electrical School. His first job was in the Transportation Department. Here he participated in the design of several railway controls, including those for early PCC cars. In this work he had good opportunity to observe one of the most difficult jobs performed by insulation, that on traction motors. He was much impressed by this aspect of engineering; when the opportunity presented itself in 1936 he got himself assigned to work on insulation, first for transportation motors and generators, later for large generators. When an insulation development group was formed he became a member, and in 1944 its manager—the job he now holds.

A few years ago Moses was an ardent devotee of dog races, drawn perhaps by a double attraction—a love of dogs, and curiosity as to whether statistical methods

could be applied to determine the winners. After discovering that standard deviation was not exactly applicable to canines, he settled for acquiring a racing dog, and now has a beautiful whippet. Moses now confines his statistical analysis to insulation problems; he has long been an ardent proponent of its use in development, testing, and manufacturing.

The development of Thermalastic insulation is probably one of the most outstanding examples of cooperative effort that Moses has been involved in. The new insulation was no one man's brainchild. The synthetic resin was a research development; the idea of combining the resin in some manner with mica also probably originated at the research laboratories. Materials engineers contributed concrete assistance, as did other engineering groups. But the responsibility for bringing the whole development to the production point rested with Moses and his section. The coordination and cooperation involved in utilizing the information and assistance supplied from so many individuals and groups in a final end result is an outstanding example of development engineering. As such, it is also a credit to Graham Moses.



In the extreme case of a chemical compound involving a highly electropositive element such as sodium, and a highly electronegative element such as chlorine, the transfer of electrons from sodium atoms to chlorine atoms is essentially complete (see Fig. 2). The compound sodium chloride (common salt) is a solid material consisting of a geometric structure of positive sodium ions and negative chloride ions. The forces holding this structure together are primarily electrostatic in nature, thus this situation is referred to as electrostatic or *ionic bonding*. Such substances in the dry, solid state are excellent insulators, because of the immobility of the ions. When molten or dissolved, however, these materials become good conductors. This complete turnabout in affairs occurs because the net effect of a solvent is to destroy the geometric structure, thus leaving the ions no longer rigidly bound but free to move. Because movement of charge constitutes conduction, the materials lose their insulating ability.

Some insoluble substances containing similar ionic bonds are good insulators, even in the presence of water, their insolubility and resulting ion immobility making conduction impossible. Mica is such a substance.

When a chemical bond occurs between two atoms that are not of widely differing electronegativity, such as between silicon and carbon, completion of the octet of each is usually achieved by sharing valence electrons. Such a bond is called *covalent*. The extreme case of a covalent bond occurs when two atoms of the same element are involved; for example, in Fig. 3 two atoms of fluorine, each having seven outer-shell electrons, share two between them—giving the effect of completing the octet of each (i.e., there are no longer any vacant electron spaces in the outer shell of either atom).

Atoms in the central part of the periodic table are neither strongly electropositive nor strongly electronegative. Therefore they tend to form covalent bonds with all other elements, and especially with themselves. Such bonds are excellent for the purposes of electrical insulation, because the resultant molecule is electrically balanced. Unlike the ionic bond, no ions are produced, thus no conduction is likely.

Still another type of bond exists. Consider the case of a hydrogen-chloride molecule (Fig. 4). Basically this appears similar to the sodium-chloride combination, in that both hydrogen and sodium have one outer-shell electron. However, the hydrogen electron is held more strongly to the atom because the atomic radius is less than that of sodium. The

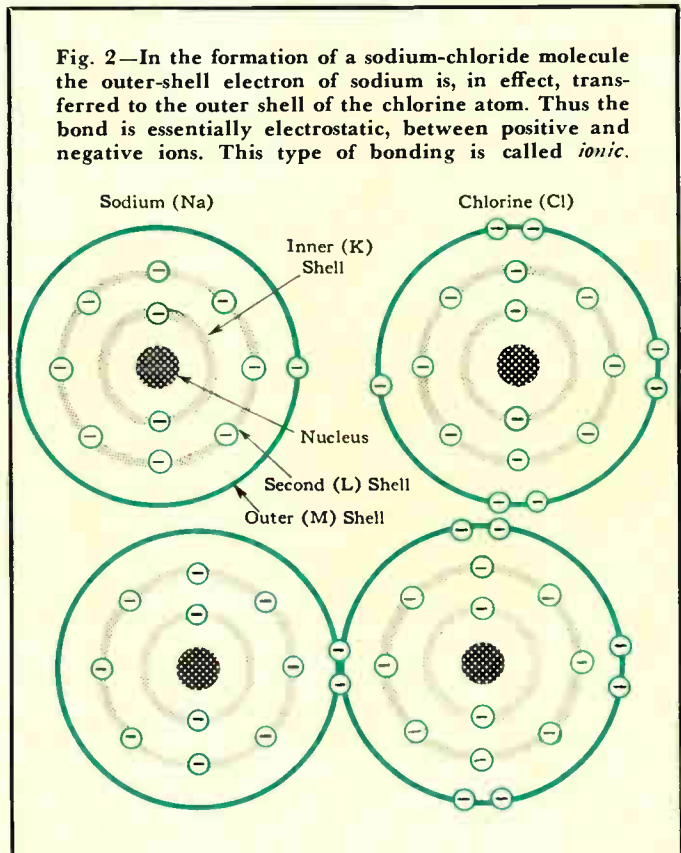


Fig. 2—In the formation of a sodium-chloride molecule the outer-shell electron of sodium is, in effect, transferred to the outer shell of the chlorine atom. Thus the bond is essentially electrostatic, between positive and negative ions. This type of bonding is called *ionic*.

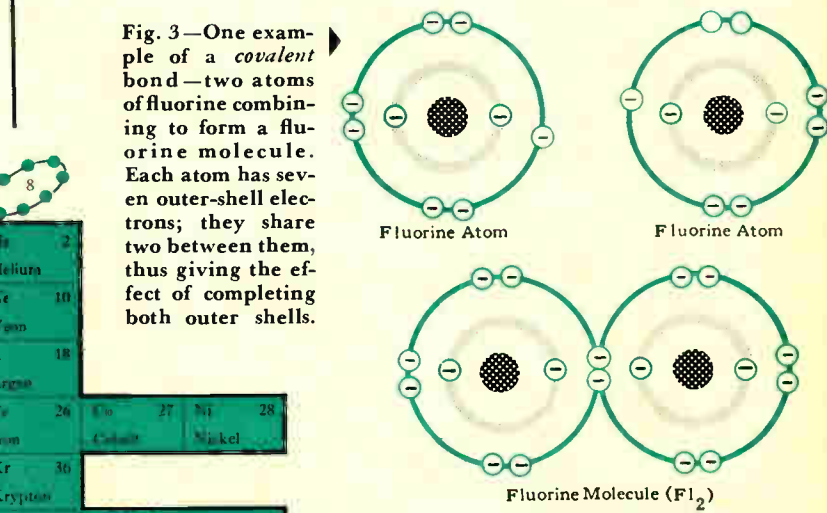


Fig. 3—One example of a *covalent* bond—two atoms of fluorine combining to form a fluorine molecule. Each atom has seven outer-shell electrons; they share two between them, thus giving the effect of completing both outer shells.

PERIODIC TABLE OF ELEMENTS
Number of Valence Electrons

No. of Shells	1	2	3	4	5	6	7	8		
1	H 1	He 2							Li 3	Be 4
2	B 5	C 6	N 7	O 8	F 9	Ne 10	Na 11	Mg 12		
3	Al 13	Si 14	P 15	S 16	Cl 17	Ar 18	K 19	Ca 20		
4	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28		
5	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36	Cu 29		
6	Rb 37	Sr 38	Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44		
7	Cs 55	Ba 56	La 57	Hf 72	Ta 73	W 74	Re 75	Os 76		
8	Pb 82	Bi 83	Po 84	At 85	Rn 86	Ir 77	Pt 78	Au 79		
9	Ra 88	Ac 89	Elements 58-71—Rare Earths				Elements 90-103—Rare Earths			
	← Electropositive				← Electronegative →					

Fig. 1—As indicated, elements to the left of the table tend to be electropositive, those to the right electronegative. In the interest of simplification, much data was omitted; for example, atomic weights, effect of atomic radius. Groups A and B were not separated in the columns.

sodium outer-shell electron, being in the third shell from the nucleus, is less firmly held and actually transfers to the chlorine atom, when these atoms combine chemically. The hydrogen electron, however, finds a place in the chlorine outer shell, but is not released by the hydrogen. The net result is a combination that has both covalent and ionic characteristics. In this combination the molecule becomes effectively polarized, with the hydrogen end being positive and the chlorine end negative. This type of bond is called *polar*. Such a molecule tends to rotate in an electric field, and this movement of charge constitutes conduction under some circumstances (see discussion of dipolar molecules on page 122).

Although polar bonds appear to be undesirable in electrical insulation because of their tendency to aid conduction, it is sometimes necessary to include some bonds of relatively polar character to achieve such properties as resistance to non-polar solvents, higher softening point, and greater mechanical strength, among others.

The property of forming covalent bonds is most pronounced in carbon. Compounds containing this element far outnumber those of all other elements combined. There are over 400 000 known organic compounds (those containing carbon) as com-

pared with less than 100 000 compounds of elements other than carbon (inorganic compounds).

The simplest organic compound is methane, CH_4 ; it is a gas, as are its homologs (compounds derived from it by successive additions of CH_2 groups) up to those containing four carbon atoms. The saturated hydrocarbons (i.e., those whose bonds are made up of single electron pairs; see Fig. 5) containing from 5 to about 20 carbon atoms are liquids, and those containing more than about 20 are solids. Thus, as the molecular weight (the sum of the weights of the atoms in each molecule) increases, a gradual change occurs in the physical properties. In solids, the most important effects of increasing molecular weight in any series of compounds are higher softening temperatures, decreased solubility, and increased mechanical strength. This point is illustrated by the behavior of paraffin wax and polyethylene. Both are composed of chains of carbon and hydrogen. A wax molecule consists of a chain only 20 to 40 carbon atoms long; in polyethylene, the chain is 4000 to 6000 carbon atoms in length. Wax melts at about 60 degrees C; polyethylene softens at about 113 degrees. The wax is readily soluble in benzene; the polyethylene is not soluble to any appreciable extent at room temperature. Wax can be torn apart easily with a fingernail; the polyethylene is much tougher.

Molecular weights of ordinary organic compounds do not usually exceed several hundred, while those of some materials used in electrical insulation are in the range of thousands or hundreds of thousands.

High Polymers

The large molecules referred to above are usually designated as "high polymers." (The term polymer is derived from the Greek *polus*, meaning many, and *meros*, meaning part.) A polymer is a substance in which a chemical structural unit occurs repeatedly. A monomer is the simplest unit from which a polymer can be formed. (See example, Figs. 6 and 7.)

Some polymers contain more than one repeating structural unit in the same molecular chain. Such substances are called copolymers. A familiar example is the synthetic rubber commonly used in making automobile tires, which is made from the monomers, styrene and butadiene. The resultant high

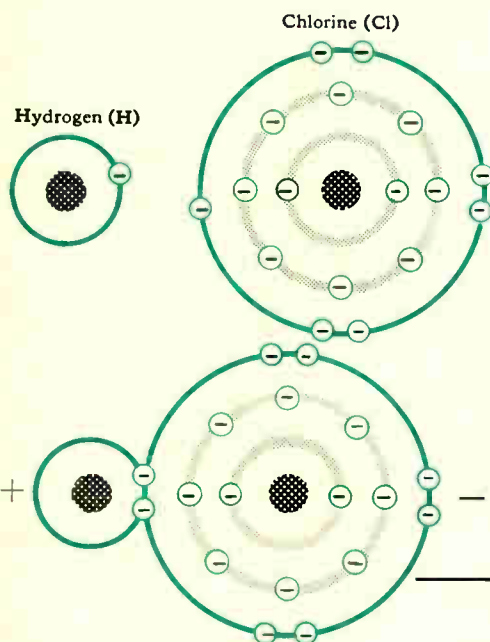


Fig. 4—A *polar* bond has characteristics of both covalent and ionic bonds. In the formation of the hydrogen-chloride molecule, the chlorine outer shell is completed, but the hydrogen does not tend to give up its electron completely, as happens in an ionic bond. The resultant molecule is polarized, the hydrogen portion being effectively positive, the chlorine end being negative.

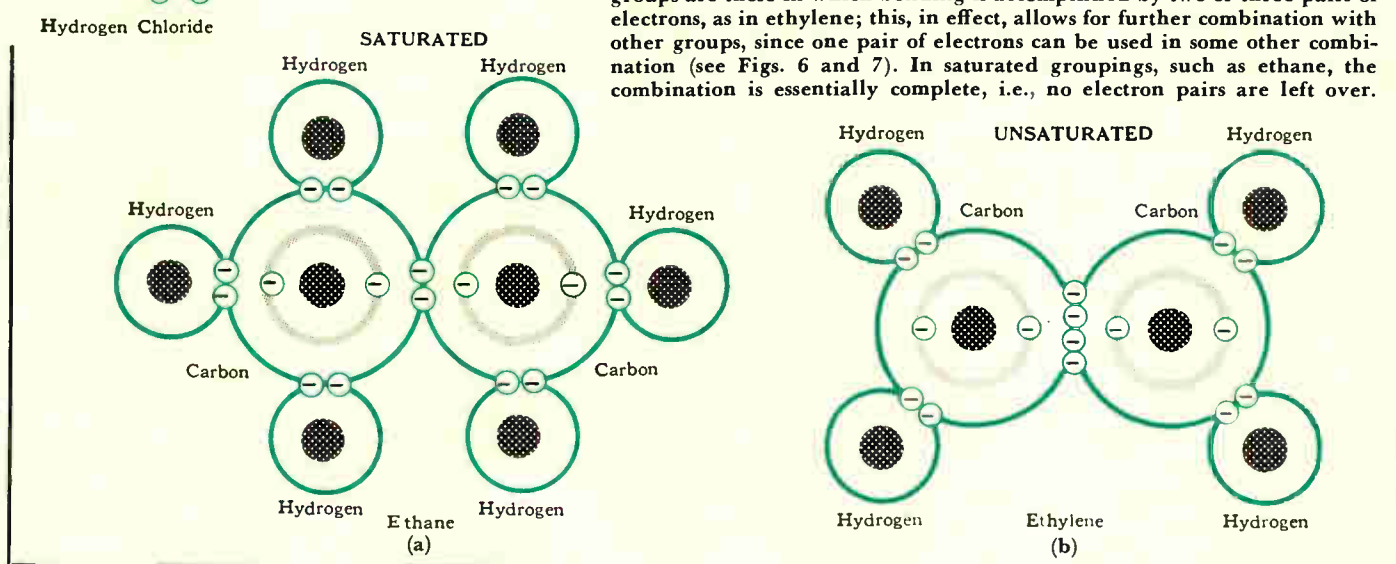
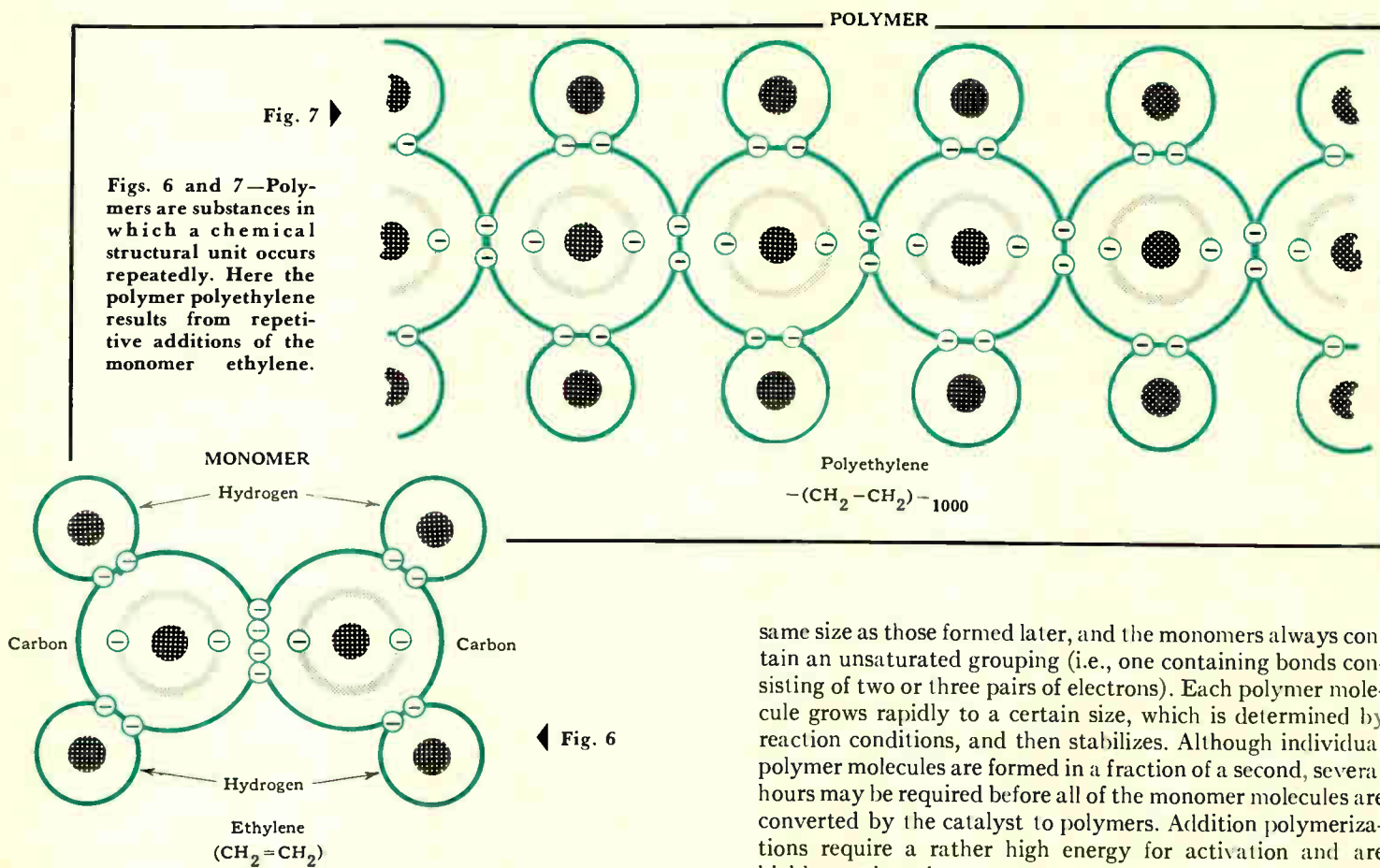


Fig. 5—Examples of saturated and unsaturated compounds. Unsaturated groups are those in which bonding is accomplished by two or three pairs of electrons, as in ethylene; this, in effect, allows for further combination with other groups, since one pair of electrons can be used in some other combination (see Figs. 6 and 7). In saturated groupings, such as ethane, the combination is essentially complete, i.e., no electron pairs are left over.



molecular-weight substance contains styrene and butadiene units in the same chain.

The term high polymer merely denotes a polymer of molecular weight of thousands rather than one of a few hundred, to which the term low polymer is applied. Cotton, mica, Plexiglas, and most resins are high polymers; paraformaldehyde, gasoline, and motor oil are low polymers.

Formation of High Polymers

In organic chemistry, a group of atoms that can undergo reaction is called a functional group. Glycerol, for example, has functionality of three because it has three hydroxyl (OH) groups that can undergo reaction; similarly, ethylene glycol has two hydroxyl groups and a functionality of two. In a sense the functionality represents the number of points at which a particular molecular structure can react. Bifunctional molecules therefore form thread-like two-dimensional structures; these are called linear polymers and generally dissolve in the proper solvents, and are fusible. Another name for such linear polymers is thermoplastic resins; polyethylene and polystyrene are examples. When the functionality is more than two, the molecules can form in three dimensions, instead of in the long, thread-like structures. Such three-dimensional structures are insoluble and infusible and are referred to as thermosetting.

Many ways are known of forming the desirable (for electrical insulation) larger molecules from smaller molecules, but all can be classed under two main headings—condensation and addition reactions. In addition reactions, one molecule adds to another by rearrangement of valence electrons and nothing is eliminated. An example is the formation of polyethylene. Addition polymerizations are characterized by the fact that the polymer molecules first formed are essentially the

same size as those formed later, and the monomers always contain an unsaturated grouping (i.e., one containing bonds consisting of two or three pairs of electrons). Each polymer molecule grows rapidly to a certain size, which is determined by reaction conditions, and then stabilizes. Although individual polymer molecules are formed in a fraction of a second, several hours may be required before all of the monomer molecules are converted by the catalyst to polymers. Addition polymerizations require a rather high energy for activation and are highly exothermic.

In condensation reactions a simple molecule such as water, ammonia, or sodium chloride is always eliminated. An example is the formation of phenolic resins, in which water is eliminated. Condensation polymerizations require lower activation energies, are only mildly exothermic, and proceed in the same manner as condensations to form small molecules. While an addition-type polymer molecule may be formed in a microsecond, the formation of a polymer by condensation proceeds stepwise and may require several hours.

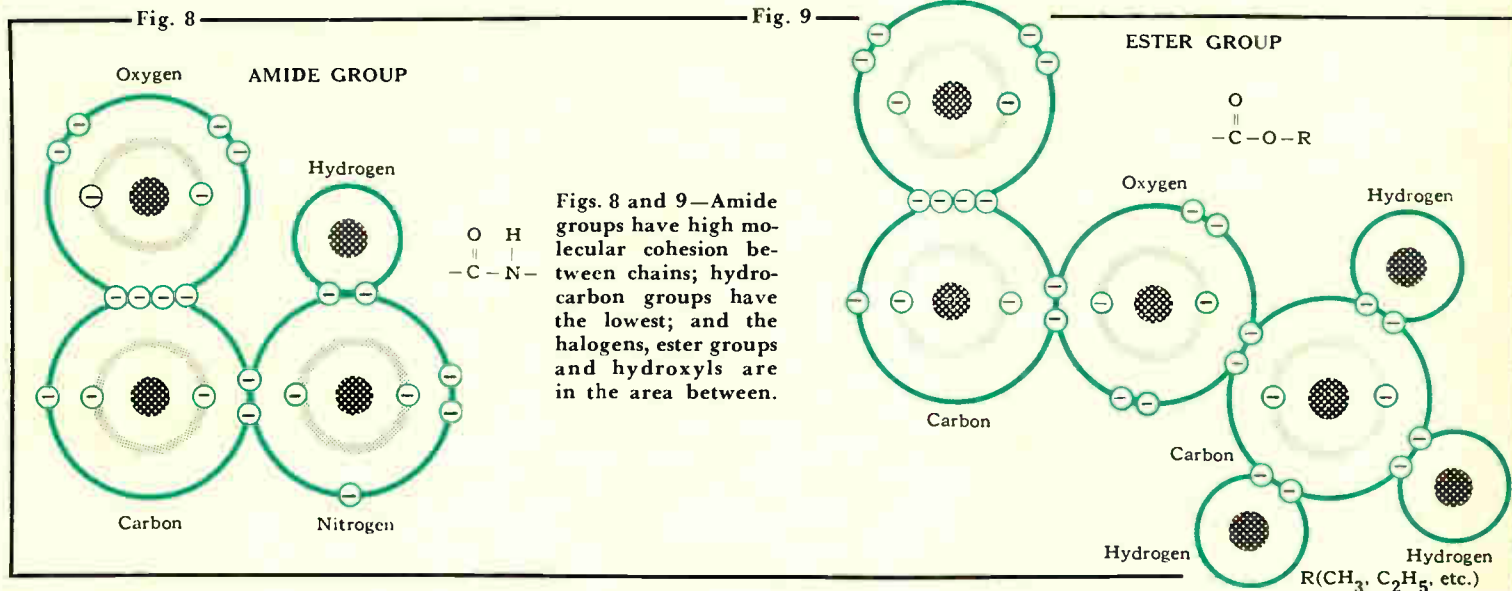
Natural High Polymers

High polymers occur extensively in nature. The structural parts of all living things comprise high polymeric materials (bone, muscle, nerve fiber, skin, hair, etc.). Cellulose is a constituent of all plants. It occurs in wood to the extent of 60 percent; cotton, 90 percent; straw, 35 percent. Because of their excellent availability and low cost, cellulosic materials are widely used in electrical insulation.

Shellac is a polyester-type polymer of molecular weight about 900. It is secreted by the lac insect—a small, louse-like creature that lives on trees. These insects thrive in India where the natives gather this secretion and purify it for shipment to the world market. It is estimated that 1 500 000 insects are required to produce enough lac for the manufacture of one pound of shellac. Cellulose and shellac are polymers of the condensation type.

Copals are a large class of natural resins, some of which have found use in insulating varnishes and in soft flexible bonds for mica. These natural resins are exudations of trees, either living trees or fossilized products of those long dead. Chemically they are addition polymers.

Inorganic polymers also occur in nature. Two of the most prominent of these in electrical insulation are asbestos and



mica. Like organic high polymers, these minerals have chain or net structures formed through covalent bonds. Unlike the organic polymers, however, ionic or polar valences form the bonds between individual chains or nets.

Asbestos is a general name given to a group of the silicates that contain magnesium, calcium, aluminum, and iron. Chrysotile asbestos, the most useful type, is a hydrated magnesium silicate. Even when treated with varnishes, asbestos does not possess outstanding insulating properties because of its tendency to absorb moisture, and because of the presence of conducting ionic materials.

Micas are compounds of hydrogen, potassium, magnesium, ferrous iron and alkali metals. The two most important types for electrical uses are muscovite $H_2KAl_3(SiO_4)_3$, or white mica, usually gathered in India; phlogopite, $H_2KMg_3Al(SiO_4)_3$, or amber mica from Madagascar. Muscovite is harder than phlogopite, but it cannot be used at temperatures above 500 degrees C. Above this temperature it loses water of crystallization and becomes powdery. Phlogopite will stand 800 degrees C without disintegrating. Inorganic glass-like polymeric bonding materials, such as sodium borophosphates, also stand these extreme temperatures. Water glass is another example, although it is not capable of withstanding such extreme temperatures. The micas in large splittings, unlike asbestos, are not sensitive to moisture.

Although synthetic micas have been produced in Germany, the process is by no means perfected. However, the product formed is clear and the cleavage is the same as that of natural mica. Possibly this type of material may find use in the manufacture of the so-called mica papers.

Synthetic High Polymers

Rubbers, Fibers, Plastics—Rubbers, plastics, and fibers are not intrinsically different materials. Their difference is a matter of degree rather than kind.

If the forces of attraction between the molecular chains are small and the chains do not form readily into a regular geometric pattern, or lattice, the normal thermal motion of the atoms tends to cause the chains to assume a random, more or less coiled arrangement. These conditions lead to a rubber-like character. If the forces between chains are strong and the chains fit easily into a regular geometric pattern, the material is a typical fiber. In intermediate cases, where the forces are

moderate and the tendency to form a lattice is also moderate, the result is a typical plastic.

In general, the tendency to crystallize is determined by two opposing factors: (1) the forces between the molecular chains, and (2) the geometrical bulkiness of the chains. The forces between chains are determined by the nature of the groups in the polymer. Purely hydrocarbon groups (CH₂) have the lowest molecular cohesion, whereas amide groups (C, H, O, N compounds—see Fig. 8) have the highest. In a general sense, this is because the amide groups have more outer-shell electrons available for interaction than do the hydrocarbons. Halogens (Cl, Br, I), ester groups (Fig. 9), and hydroxyl groups lie in between.

The manner in which elements are joined in such chains—as well as the choice of elements—has a decided effect on resultant properties. For example, two polymers with the same constituents, and in the same quantity—such as polyisobutylene and polyethylene—may vary considerably in their form and characteristics. In the case of these two compounds, polyethylene has all its carbon atoms joined together in a straight chain; polyisobutylene, on the other hand, has methyl groups (CH₃) attached to alternate carbon atoms. These methyl groups have the effect of spreading the chains apart and making polyisobutylene at comparable molecular weight a viscous tacky liquid rather than a solid. Because of its tackiness and its nonpolar character, polyisobutylene is used as a low-loss bond for flexible mica products.

Some high polymers are used as three different materials—rubber, plastic, fiber. Polyethylene, for example, is used as a substitute for natural rubber in wire covering, as a plastic in housewares such as tumblers, refrigerator containers and food-packaging bags, and as a fiber in acid-resistant filter cloths, where high fiber strength is not required.

The same polyester, derived from terephthalic acid and ethylene glycol, is the fiber Dacron and the plastic Mylar. To make the fiber, the filament extruded from the polymer melt is "oriented" by rewinding it from one spool to another, rotating at five times the speed of the first. This stretches the filament 400 percent, drawing the chains of molecules closer together, and causing crystallization in the direction of the fiber axis. This increases the flexibility and tensile strength of the fiber markedly. Synthetic fibers are thermoplastics, albeit high melting; this is necessary to permit orientation.

Fig. 10

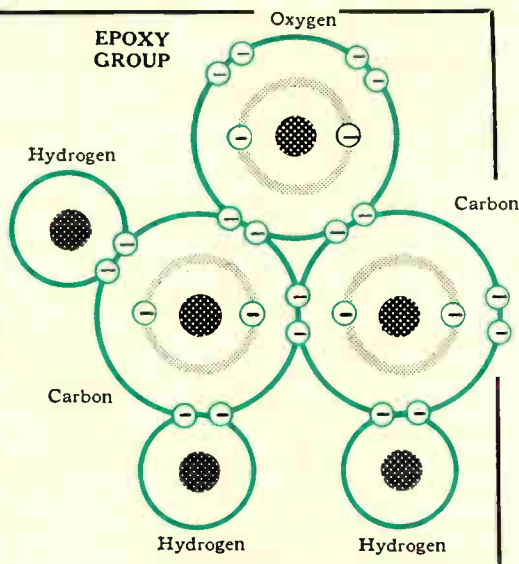


Fig. 10—Epoxy resins, of which this group is representative, are formed by addition reactions; in general they have low shrinkage, and excellent adhesion to metallic and ceramic surfaces.

To form the plastic film Mylar, the extruded melt is oriented by stretching in two directions. The orientation is not nearly as complete as is the case with the fiber, and a material with the properties of a plastic results. The lack of complete orientation in such films results in a tendency for recrystallization to occur in a random manner at elevated temperatures (above 150 degrees C), with resulting embrittlement; life is often limited by physical change rather than chemical deterioration.

Rubbers can also be prepared from polyesters. Usually long-chain dibasic acids are used to impart flexibility, short chain glycols give the best thermal and oxidation stability, and a few percent of an unsaturated acid provides a means for vulcanization. Such substances have appreciably better thermal and oxidation stability than natural and most organic synthetic rubbers, and also better resistance to some solvents.

Reactive Solventless Resins

Solventless resins are widely used either as solid insulation, or in combination with another insulation, such as mica. Resins such as Fosterite, liquid in their initial state, can be used to vacuum impregnate completely the voids in small transformers and similar apparatus. On curing, these set up to form three-dimensional polymers of very high molecular weight. By selecting the kinds and amounts of components, materials can be designed for flexibility at high temperatures or low temperatures, low power factor, etc. The resin used in Thermalastic insulation for high-voltage generators is of the solventless polyester type.

Another general class of solventless resin is the so-called epoxy type (Fig. 10). These also are formed by addition reactions, and no water or other small molecule is split out. Epon, Araldite, Devran, Scotchcast, and Bakelite C-8 are of this type, and exhibit low shrinkage and excellent adhesion to many types of metal and ceramic surfaces.

The principal advantage of these solventless resins over conventional types is that they give better fill, which results in better moisture resistance, better thermal stability, lower operating temperature because of better heat transfer, and higher dielectric strength.

Varnishes and Wire Enamels

Because very large molecules are usually difficult to dissolve, or dissolve to form solutions of very high viscosity, they

are often formed in the place they are needed from molecules of intermediate size by a baking or curing process. Thus the molecules of an insulating varnish or a magnet-wire enamel may have an average molecular weight of one or two thousand when applied to the conductor, but this increases to many millions during curing.

A typical varnish of the alkyd type is the reaction product of a drying oil, such as linseed oil, with the components of a three-dimensional polyester resin. Other frequently used insulating varnishes are based on the reaction product of phenolic-type compounds with formaldehyde. The unmodified phenolics are used to prepare laminates and to serve as rigid bonds for coils. Those phenols having sufficient hydrocarbon groups attached to the ring to make them soluble in drying oils form the basis of the oil-soluble phenolic-type varnishes. The drying oils have the effect of softening these varnishes and making them more flexible and more water resistant. Alkyd and phenolic-type varnishes can be used continuously at temperatures up to about 125 degrees C.

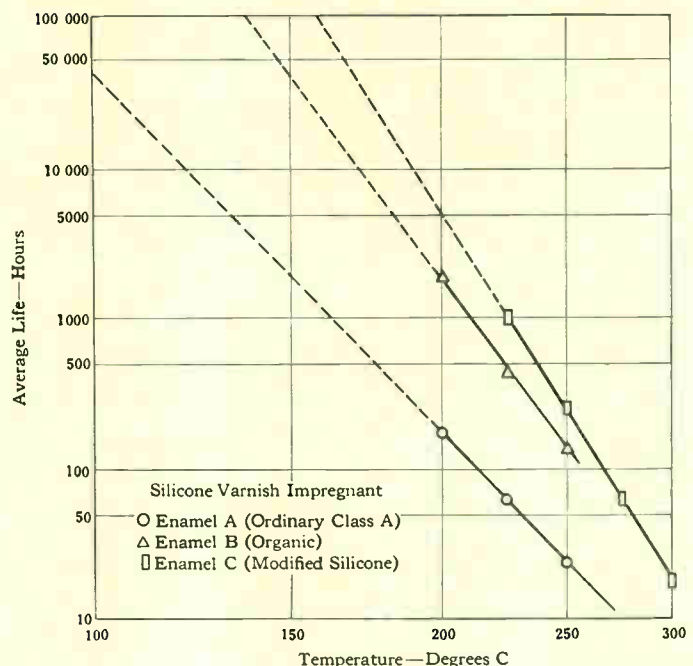
Since 1942 a radically different group of varnishes has been available, based on a polymer chain consisting of alternate silicon and oxygen atoms. These silicone varnishes are capable of continuous operation at 180-200 degrees C.

Silicone impregnating resins have a ratio of organic groups to silicon of about 1.5 to 1.8. In the harder laminating resins this ratio is approximately 1.0 to 1.2. The ordinary variety of silicone varnishes do not have good abrasion resistance. To obtain good abrasion resistance with glass-covered wire a modified silicone varnish is used, containing about 35 percent of organic components.

By increasing the number of organic groups per silicon atom to two or slightly more, silicone liquids, suitable as dielectrics, and rubbery gums capable of being compounded with fillers and vulcanizing agents into rubbers, result.

Other high-temperature types are the perhalocarbons ("perhalo" meaning hydrocarbon in which the hydrogen is

Fig. 11—The time at elevated temperatures required to cause the dielectric strength of a twisted pair of enameled wires to drop to 1000 volts. Enamel B is an organic material specially designed for high-temperature operation, and is not typical of such materials.



completely substituted by a halogen). Polytetrafluoroethylene (Teflon) is a highly crystalline, high melting (327 degrees C) thermoplastic and is insoluble in all solvents; but aqueous emulsions prepared with the finely divided polymer can be used for coating magnet wire. It can be used up to 200 degrees C under light mechanical loading, but undergoes cold flow under high unit pressures.

Before 1938 nearly all of the wire enamel used commercially was of the oleoresinous type, a typical example of which was the reaction product of limed rosin and tung oil. Since then several synthetic types of greatly improved mechanical properties and solvent resistance have gained wide commercial acceptance. Two of these, Formvar and nylon, are composed of approximately 60 percent high molecular weight linear polymer and 40 percent low molecular weight phenolic resin. In these the flexibility is provided by the long hydrocarbon chains, and the solvent resistance and toughness by the polar oxygen atoms in the Formvar and the polar oxygen and nitrogen atoms in the nylon. The phenolic resin adds thermosetting properties to both of these materials.

The Westinghouse Bondar (M-1880-6) enameled wire is made with a condensation polymer designed for improved thermal stability as well as good mechanical properties and solvent resistance. These properties are achieved by keeping the hydrocarbon groupings between the polar groupings as short as possible.

Modification of condensation polymers with less than 50-percent silicone-resin components also greatly improves ther-

mal and oxidation stability with only a moderate sacrifice in mechanical properties.

Deterioration of Electrical Insulation

Recent experiments show that deterioration of electrical insulation can be treated as a chemical rate phenomenon. By measuring the change of a significant property of insulation over a period of time, at several elevated temperatures, a curve of insulation life can be prepared; this curve can then be extrapolated to give a good estimate of life at any selected operating temperature.

In magnet-wire enamels a property commonly observed is the time at elevated temperature required to cause the dielectric strength of a twisted pair of enameled wires to drop to a predetermined value, such as 1000 volts. Curves of this type are shown in Fig. 11. The curve at the left represents a standard class A insulating material. The two at the right represent newer Westinghouse enamels, which for the same life can be operated at much higher temperatures than the older material. Accelerated life tests now being carried out in motors confirm these results.

An attempt has been made to show briefly how advances in our understanding of the chemistry of large molecules in the last 30 years has resulted in many new and improved synthetic electrical insulating materials. The rate of accumulation of new knowledge is being constantly accelerated, and advances in the future will probably take place at an even more rapid pace.

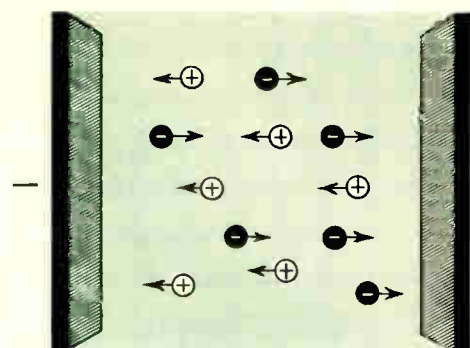
II—*Physics* of Insulation

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A GOOD insulating material has a specific resistance of the order of 10^{15} ohm-cm, while a good conducting material, metallic copper, has a specific resistance of 1.7×10^{-6} ohm-cm. This vast difference in resistivity between conductors and insulators makes possible the construction of modern electrical apparatus with closely spaced conductors at greatly different potentials. The difference is largely a consequence of the fact that the valence (outermost shell) electron of each atom in metallic copper is free to move throughout the entire volume of the metal, whereas the valence electrons in an insulating

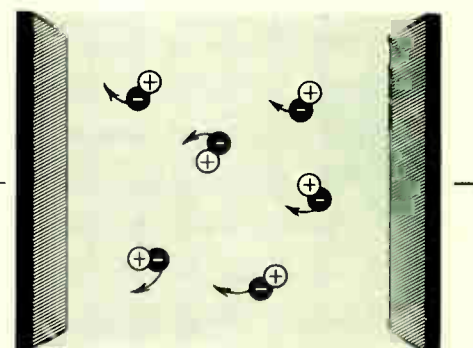
material are normally restricted to single atoms or several atoms in a molecule.

In contrast to metals, insulating materials are believed to have a negligible electronic conductivity except at electric fields near breakdown. However, they have other conducting particles—ions, and molecules with electric “dipole moments” (Figs. 1 and 2). The conductivity of these particles never approaches the magnitude of electronic conductivity in metals since they are much larger than electrons, and thus more restrained in their motion by surrounding particles.



Ionic Conduction

Fig. 1—Charged atoms, i.e., ions, contribute to conduction in insulators. Positive ions tend to migrate to the negative plate, negative ions to the positive.



Electric Dipole Conduction

Fig. 2—Dipole molecules, as the name suggests, possess electric polarity. Under the influence of an electric field they rotate, as indicated.

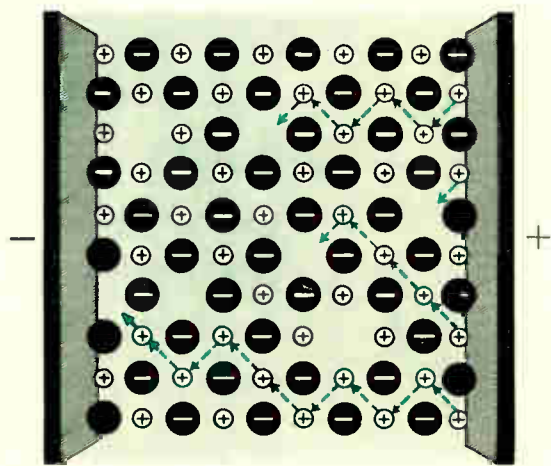


Fig. 3—Even a good insulator, such as dry crystalline salt, has crystal imperfections, i.e., vacant lattice points. This allows a movement of sodium ions through the crystal by jumping from one vacant point to another. This ion movement results in a small amount of conduction in the crystal.

The fact that insulating materials do have some conductivity makes a knowledge of this property of prime importance, because the continued proper operation of apparatus without failure is dependent on a nonexcessive conduction through the insulation.

Ionic Conduction in Insulation

Insulating materials differ widely in their ionic conductivity, which depends on the number of ions per cubic centimeter of the material and the mobility of the ions. Common salt, sodium chloride, represents one extreme where all atoms are ionized. Positive sodium ions and negative chlorine ions result from the very large electron affinity of the chlorine atom, which extracts the valence electron from the sodium atom. But dry crystalline salt at low temperatures is an excellent insulator with very low electric conductivity, since the ions are not able to move in the tight regular crystal structure. It has a slight conductivity as a result of imperfections in the crystal—vacant lattice points, where ions are missing (see Fig. 3). The smaller sodium ions can diffuse slowly through the crystal by jumping into these vacant spots.

If the temperature is raised, ionic conductivity increases for two reasons. First, the number of vacant lattice points increases, because there is an increasing probability of their occurrence at higher temperatures. Second, the mobility increases because the ions more frequently acquire enough energy (from thermal agitation) to jump into adjoining vacant spots. This negative temperature coefficient of resistivity is characteristic of all insulators, in contrast to metallic electronic conductors, which have a positive temperature coefficient of resistivity. The latter results from the thermal agitation of atoms impeding the movement of the small conducting electrons, which move more easily between the atoms when they are colder and quieter.

With some exceptions (notably sulfur and diamond) solid inorganic insulating materials are ionic crystals, or glasses that have amorphous structures. In such structures all atoms are ionized but restrained, with only a few able to move. The smaller positive ions—hydrogen, sodium, potassium, etc.—move more easily and contribute most to the conductivity, when present.

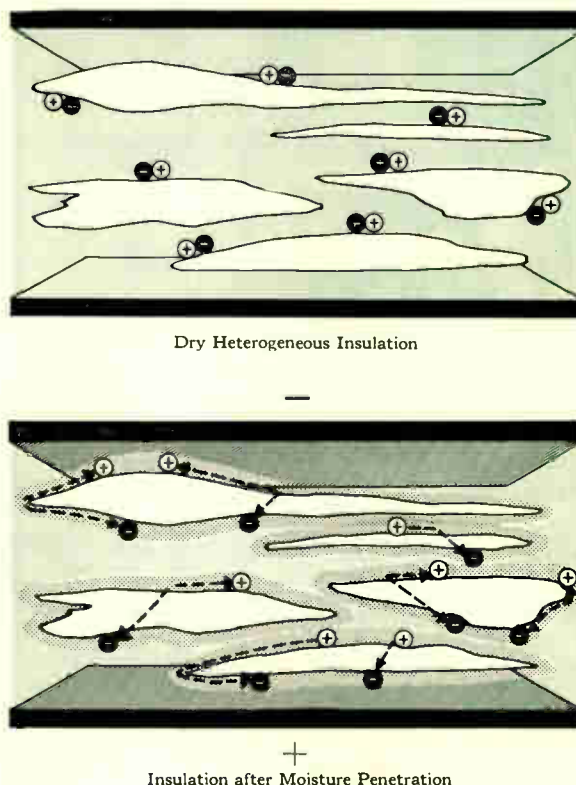
In contrast, organic materials contain relatively fewer ions,

the atoms of organic molecules being bonded by non-coulomb forces, wherein electrons are mutually shared, rather than being completely transferred from one atom to another. The few ions present in organic plastics and liquids (such as Fosterite or Inerteen) as a result of the dissociation of a few ionic compounds are more mobile than in an ionic crystal due to the looser structure and weaker forces holding them in the surrounding matrix. The ions present in organic insulating materials are often impurity materials, or products of oxidation or other degradation of the insulation. Therefore the ionic conductivity of electrical insulation is subject to wide fluctuations, depending on the purity or history of the material. Water will, when absorbed by the insulation, enhance the ionic conductivity a great deal by associating with the ionic compounds and making them more conducting. Therefore the percent water in insulation, affected by the ambient humidity, grossly influences the ionic conductivity (See Fig. 4).

In organic plastics and liquids ionic conductivity varies, for the same number of ions, inversely as the viscosity of the material. Thus mobile liquids are usually more conducting than very viscous liquids and flexible plastics more conducting than stiff plastics of the same chemical type.

Another important factor affecting the ionic conductivity of this type of material is the dielectric constant (see Fig. 5). A high dielectric-constant material is both a better solvent for impurity ionic compounds and a better medium for dissociating these compounds. The coulomb attraction between ions is reduced inversely as the dielectric constant of the medium in which they are dissolved.

Fig. 4—These diagrams illustrate the effect of water on insulation. Top sketch shows a dry, heterogeneous insulation, with ions held together by strong attractive forces. Lower sketch is the same material after water penetration. Moisture film around the particles of hygroscopic filler decreases the attractive force (Coulomb's law) between ions, thus allowing them to dissociate and migrate according to the direction of the electric field.



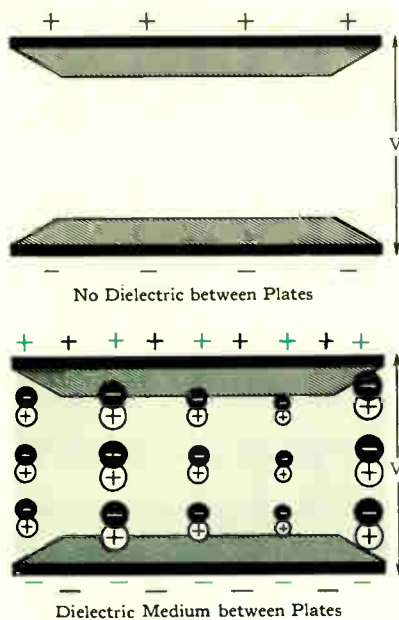


Fig. 5—A representation of the mechanism of dielectric constant. The top sketch represents a capacitor without a dielectric medium between plates (i.e., a vacuum). Here the charges soon balance after a voltage is applied. In the bottom sketch, with a dielectric medium between the plates, the electric dipoles in the material draw more charges to the plate and thus an increase in capacitance results.

Dipole Conduction in Insulation

The dipole molecules mentioned previously also conduct for short periods of time by rotating in the direction of the electric field (see Fig. 2). However, such conduction stops when they have turned as much toward the direction of the field as their random thermal motion permits. Therefore, dipoles contribute to d-c conduction only for a short period after voltage is applied and to a-c conduction only at higher frequencies. The time during which dipolar conduction occurs varies, of course, inversely as the rate of the dipole turning, or directly as the viscosity. Thus the frequency at which dipole conduction begins to become appreciable is lower for more viscous materials.

Unsymmetric organic molecules have electric dipole moments varying in magnitude with the nature of the bonded atoms in the molecule. The dipole is to a large degree associated with a particular pair or group of a few atoms known as the functional group. Examples of such groups are hydroxyls, esters and amines. Unsymmetric, or dipolar molecules, have electric dipole moments due to a difference in electron affinity between unlike atoms. Elements with a nearly completed outer electron shell, when combined with those having a deficiency in the outer shell, tend to pull electrons away from the more deficient atom; one atom of the resultant molecule becomes relatively negative, the other relatively positive.

Variation in Conductivity with Time and Frequency

The familiar decreasing current with time curves for insulators tested with d-c voltage are an example of the variation of conductivity with time. This can result from a limited movement of ions through the material and, as already stated, the rotation of dipoles to their limit. Movement of ions can be limited by the space charge established within the material by the accumulation of a layer of positive ions near the cathode and negative ions near the anode. This space charge creates an electric field in the opposite direction to that produced by the applied voltage. Such a mechanism is dependent on an energy barrier at the electrodes preventing the discharge of ions approaching them, or the supply of new ions from the electrode metal to permit continuing electrolysis.

Another mechanism by which ion migration can be limited

is a result of internal heterogeneity in the material, i.e., existence of interfaces between different substances having different conductivities. A more obvious example is liquid-impregnated paper; ions move freely through the liquid pores, but slowly or not at all through the paper fibers, on the surface of which they are restrained.

This limited movement of charge in an insulator has been known as *dielectric absorption*, since the current that decays while voltage is applied reappears when the voltage is removed; the ions migrate and the dipoles rotate back to their original, random positions, at the same time releasing the charge that they held by electrostatic attraction on the electrodes. These same effects also operate, insofar as the time of each half cycle permits, when a-c voltage is applied.

It has become customary to express a-c conductivity, g , of insulation in terms of a ratio of the conduction current (current in phase with the voltage) to the total current (including the charging or capacitance current, which is 90 degrees out of phase with the voltage). This ratio is the *power factor** of the insulation or the cosine of the phase angle. The term, *dissipation factor,** is the ratio of conductivity to angular frequency and capacitance. For a constant conductivity and capacitance the dissipation factor and approximately the power factor decrease inversely as the frequency. This behavior is noted in mobile liquids—such as transformer Inerteen—where conductivity except at high frequencies is largely ionic. With plastics or extremely viscous liquids, where ion movement and dipole rotation is slower, conductivity increases with frequency due to decreasing amplitude of movement wherein the limit of ion migration or dipole rotation is not reached during a half cycle. This effect leads to a maximum in power factor and in dissipation factor, with variation in either frequency or temperature, since the viscosity decreases with temperature. The maximum occurs approximately when the viscosity and time of half cycle are such as to allow a maximum amplitude of movement in phase with the voltage.

An increasing power factor occurs with increasing voltage in porous insulation where corona can occur within internal voids. Corona in the insulation acts as both a shunt and series resistance to parts of the insulation. Power-factor measurements at high voltage are often a useful tool in determining the extent of corona in the insulation.

A decreasing power factor with increasing voltage can be observed in porous liquid-impregnated insulation because the amplitude of ionic movement in the liquid reaches the extremity of the pores in a half cycle. As voltage increases, the velocity of the ions increases and the time to reach the pore boundary decreases. The ions, therefore, conduct during a decreasing fraction of the cycle. This is a fortunate situation, which helps to give a low power factor at the high operating voltage stresses used in such devices as Inerteen capacitors.

Applications Demanding Low Power Factor

A low power factor or high insulation resistance has usually been considered a criterion of high-quality insulation. However, in many applications, insulation with a moderate power factor or intermediate resistance is quite satisfactory. The power factor of insulation becomes dangerously high only when it leads to excessive dielectric heating or perhaps indi-

$$* \text{Power factor} = \cos \theta = \frac{g}{(g^2 + \omega^2 c^2)^{1/2}} = \sin \delta$$

$$\text{Dissipation factor} = \tan \delta = \frac{g}{\omega c}$$

In the above formulas, θ is the phase angle, g is conductivity, ω is angular frequency, c is capacitance, and δ is loss angle (complement of phase angle).

cates dangerous imperfections or impurities that could lead to breakdown.

The amount of heat generated* per cubic centimeter of insulation by the a-c conductivity of the insulation is a function of the electric field, the frequency, and the dissipation factor. Heating represents a power loss, which at low frequencies is a negligible part of the power handled by the apparatus, but if excessive heating occurs it may melt or decompose the insulation, leading to breakdown. Excessive dielectric heating occurs whenever the voltage gradient, dissipation factor, or frequency are too high. An a-c capacitor is an example of a situation where, because of the very high gradients (300-400 volts/mil), low power factor is necessary. A second feature of capacitors necessitating low power factor is the construction such that heating occurs within a thick section of insulation, which has a relatively low thermal conductivity. This allows a large temperature gradient between the center and the surface, a situation obviously favorable to extremely hot spots. A similar situation is met in thick sections of insulation in high-voltage apparatus.

In high-frequency applications the a-c conductivity of insulation also leads to a large amount of dielectric heating, and low power factor is a necessity to prevent destruction of the insulation. For sharp tuning in radio circuits, it is also necessary to have a low dissipation factor insulation. Normally it is stated that the Q , which is the reciprocal of dissipation factor, should be as high as possible.

*Heat generated=watts/cubic centimeter $= (5/9) \epsilon' \tan \delta f E^2 \times 10^{-12}$, where E is the field in volts/cm, f is frequency, ϵ' is the relative dielectric constant, and $\tan \delta$ is the dissipation factor.

Fig. 6—Two unit cells of a chain in a cellulose crystal. The hydroxyl (OH) dipoles and their rotation is indicated. The relatively large number of rotating dipole groups in paper accounts for its wide use in capacitors.

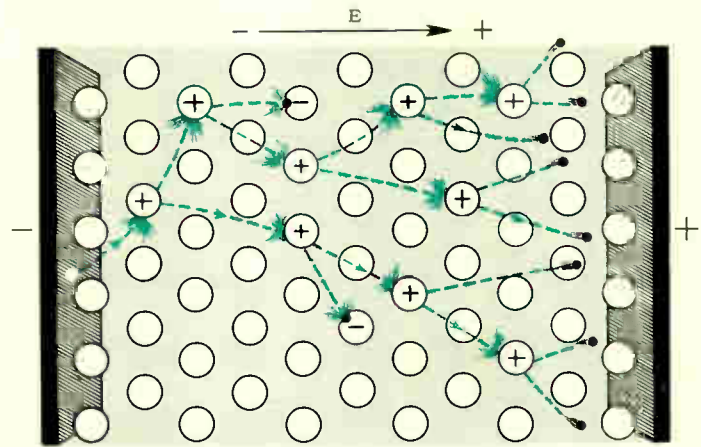
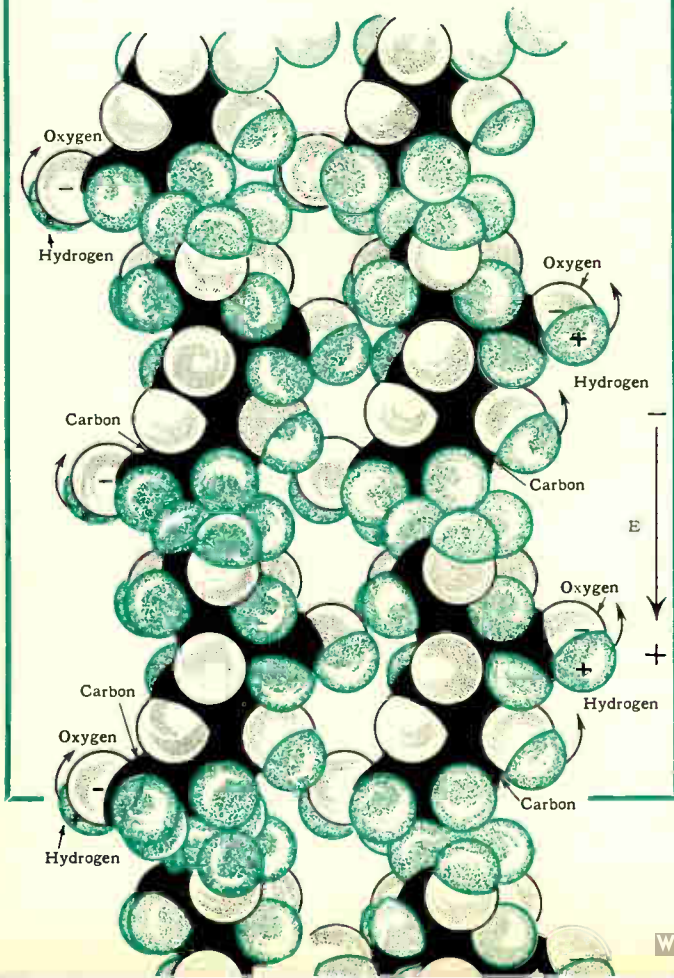


Fig. 7—A pictorial representation of an electron avalanche, which occurs at the beginning of electric breakdown. An initial electron from the cathode, accelerated by the electric field, collides with an atom or molecule, causing secondary electrons to be emitted. These in turn are accelerated and collide with other atoms or molecules. As the number of electrons multiplies, a conducting path develops through the insulating material.

Polarization and the Dielectric Constant of Insulation

Whenever the conducting ions or dipoles discussed in the preceding paragraphs are able to move rapidly enough to go to the limit of their movement within a small fraction of a cycle they produce a current that is maximum at voltage zero. This, of course, is characteristic of a capacitance, which is proportional to the dielectric constant. At the extremity of their movement the dipoles or ions are said to be polarized and produce a polarization voltage gradient within the dielectric in opposition to the applied voltage (see Fig. 5). Materials that have a large number of dipolar molecules or parts of molecules able to rotate rapidly have a high dielectric constant. The dielectric-constant enhancement is roughly proportional to the concentration of dipoles and to the square of the magnitude of each. Two thirds of the dielectric constant of cellulose (paper), of which most capacitors are made, is due to rotating hydroxyl group (OH) dipoles (see Fig. 6), while about the same proportion of the dielectric constant of capacitor Inerteen is due to its rotating molecules (chlorinated diphenyl).

Enhancement of the dielectric constant by migrating ions is usually, but not always, smaller than the dipolar effect. When present it is often accompanied by a high conductivity and power factor.

All substances have another mechanism of polarization that results from the slight shift of the electrons in the atom with respect to the positive nuclei when an electric field is applied. This occurs most rapidly and is essentially elastic in nature. It is largely responsible for the dielectric constant of non-dipolar substances, which is about two.

Ionic crystals, including ceramics, demonstrate still another form of polarization in addition to the electronic polarization. The ions in these crystals shift slightly from their normal position in an essentially elastic manner when an electric field is applied. In certain types of crystals this effect produces an extremely large dielectric constant as a result of the complete polarization of all the atoms in large domains of the crystal; because of its analogy to ferromagnetic polarization this has been called ferroelectric polarization. Barium titanate and analogous compounds, rochelle salt, and potassium hydrogen phosphate show this behavior. The titanates have been used

in small radio capacitors and recently in dielectric amplifiers, the latter as a result of the variation in their dielectric constant with voltage.

In other crystals only a small fraction of the ions are completely polarized at normal electric fields because of the opposition of random thermal agitation. This is also true of dipolar orientation.

Dielectric Breakdown

The effectiveness of an insulating material electrically is determined by its ability to withstand puncture by the normal or chance voltages applied to it. Dielectric breakdown usually results from an electron avalanche in the dielectric (see Fig. 7). In a few cases breakdown results from excessive heating of a high conductivity insulation by the electric field until it decomposes to conducting carbon (in the case of organic insulation), or becomes a molten electrolyte (in the case of ceramics). Electron avalanches are now believed to occur not only in gases but also in solids and liquids. Each avalanche results from the acceleration of an initial electron, which, gaining velocity from the electric field, causes—by impact with atoms or molecules—secondary electrons, each of which by the same mechanism produces other electrons until a large number result, sufficient to make the insulator a conductor. At least in the case of gases it is necessary to presume that secondary mechanisms (photon and positive-ion bombardment of the cathode) occur to maintain the supply of initiating electrons at the cathode, since an avalanche resulting from a single electron does not constitute a complete breakdown. In a liquid or solid it is presumed that cathode-field emission of electrons can supply electrons. A very few free electrons are believed to be present in all materials although their occurrence in gases, especially at lower pressures, must be considered as intermittent.

The intrinsic dielectric strength, which is the breakdown electric field of a homogeneous substance in a uniform (non-divergent) electric field is dependent on the restriction shown by the substance to the acceleration of electrons. It depends very greatly on the density of the substance, because of the greater probability of collisions that slow down the electron. Also it depends markedly on the electron-trapping ability of the atoms, molecules, or structure of the substance. The range of observed intrinsic dielectric strengths for materials at 25 degrees C is shown in Table I.

TABLE I—INTRINSIC DIELECTRIC STRENGTHS

Material	Volts/mil
Air, 1 atmosphere (1 cm gap).....	79
Sulfur hexafluoride, 1 atm (1 cm gap).....	200
Air, 6 atmospheres (1 cm gap).....	385
Sodium chloride crystal.....	3 800
Wemco C mineral oil.....	5 000
Polyethylene.....	16 500
Polymethylmethacrylate.....	25 000
Mica, perpendicular to laminations.....	24 500

Anyone familiar with the dielectric strengths of commercial insulating materials as conventionally tested will immediately note that the values listed in the table are much higher. The dielectric strength values obtained in practical tests are markedly lower for several reasons: (1) the existence of defects, holes, conducting and foreign particles in commercial insulation; (2) the presence of a stress concentration at elec-

trode edges or points where the breakdown can be initiated, because the electric field is much higher than the average; (3) in a-c tests due to the damaging effect of electric discharge during testing; (4) because of dielectric heating, which raises the temperature and lowers the breakdown strength.

The presence of defects lowers the dielectric strength at points in a somewhat random manner and produces a dispersion of test results. Larger areas exposed to voltage have a lower dielectric strength, since it is more probable that they include a few bigger defects.

Electric stress concentration at edges and points has, in the case of gases, the effect of producing corona, a local breakdown at the edge or point but not a complete breakdown of the gap. However, in the case of small gaps or high pressures in gases, breakdown at a positive point propagates by means of a streamer completely across the gap. In homogeneous solid insulation it is probably not possible to have a partial breakdown at a point without propagating the breakdown completely through the insulation. However, in the case of a composite dielectric such as a solid sheet in mineral oil, the oil can break down at an edge or point, forming corona, without immediately resulting in the solid breakdown.

The ratio of the electric field strengths in different dielectric materials in series varies inversely as the ratio of their dielectric constants. This effect places a higher electric stress on the low dielectric-constant constituent of a composite insulation. Often this constituent has a lower dielectric strength, which insures that it will break down at a lower voltage. This effect in itself usually lowers the overall dielectric strength of the composite insulation, since, when partial breakdown of one part occurs, a higher stress appears on the remainder.

When corona appears and continues for a time at the surface of insulation under electric stress, it erodes the surface by decomposing the insulation with electron bombardment and the associated heat of the corona discharge. This effect seems to begin immediately and even fractional seconds of exposure at a-c voltages near the breakdown voltage lower the breakdown strength appreciably.

A consequence of the stress concentration at points and edges is the decrease of the breakdown gradient (volts per mil) of all materials with increasing thickness or spacing. This factor is not generally appreciated in engineering circles, where volts per mil dielectric-strength values are often quoted and compared without reference to the insulation thickness used in determining the values. It is apparent that the electric-field gradient at the point or edge of an electrode decreases less than proportional to the reciprocal of the spacing. In fact, for simpler geometric electrodes, it can be calculated that the gradient near an edge or point decreases as an inverse fractional power of the spacing. Present knowledge indicates that once breakdown begins within a solid at an edge or point it continues through the material. This is contrary to the case of gases at lower pressures and larger spacings, where local breakdown can occur at an edge or point, giving the well-known corona, without completely bridging the gap.

Conclusion

Electrical insulation as used in apparatus is a tremendously complex material from the atomic viewpoint. This description includes only the more general principles influencing its behavior, and points out a few of the important factors, deviations and details of the behavior. Many of the details connected with the mechanism of dielectric breakdown, for example, are not yet understood. A fuller understanding of the physics of insulation will be attained only by more research.

WESTINGHOUSE ENGINEER



The U.S.S. *Bold*, a Navy minesweeper that uses the new regulator.

Static Regulator-Exciters

for A-C Generators

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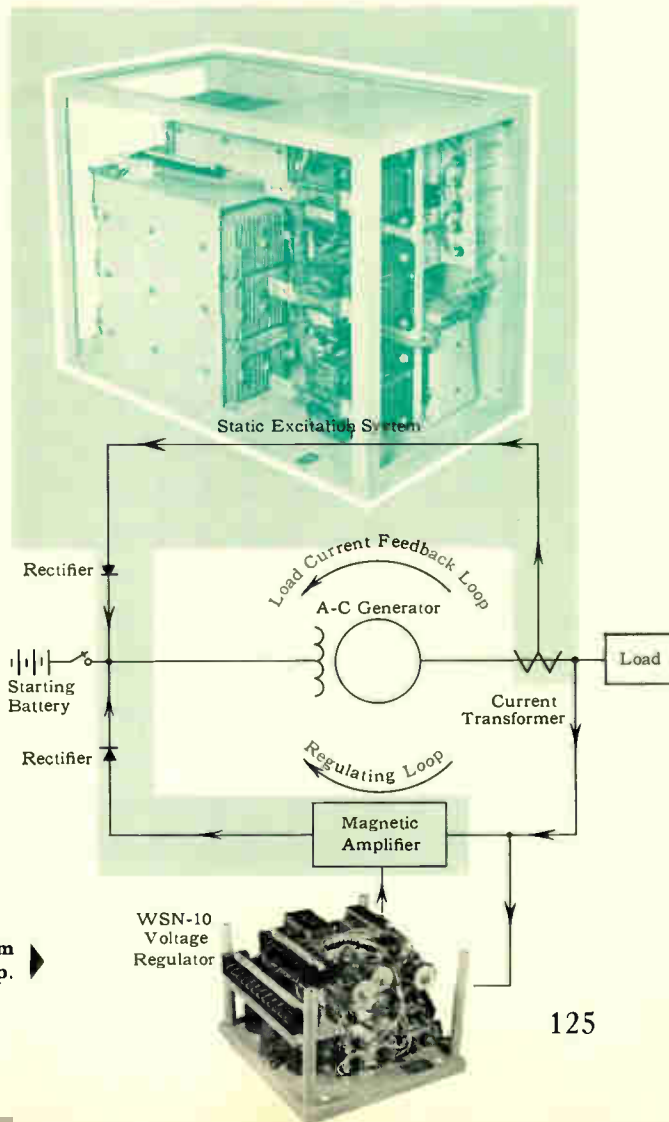
The Magamp is "sailing" into another marine application, and, as usual, is proving a topnotch performer. As a result, a lot of "hands" will soon be out of work—rotating elements and delicate parts are going ashore to make room for the more maintenance-free static devices.

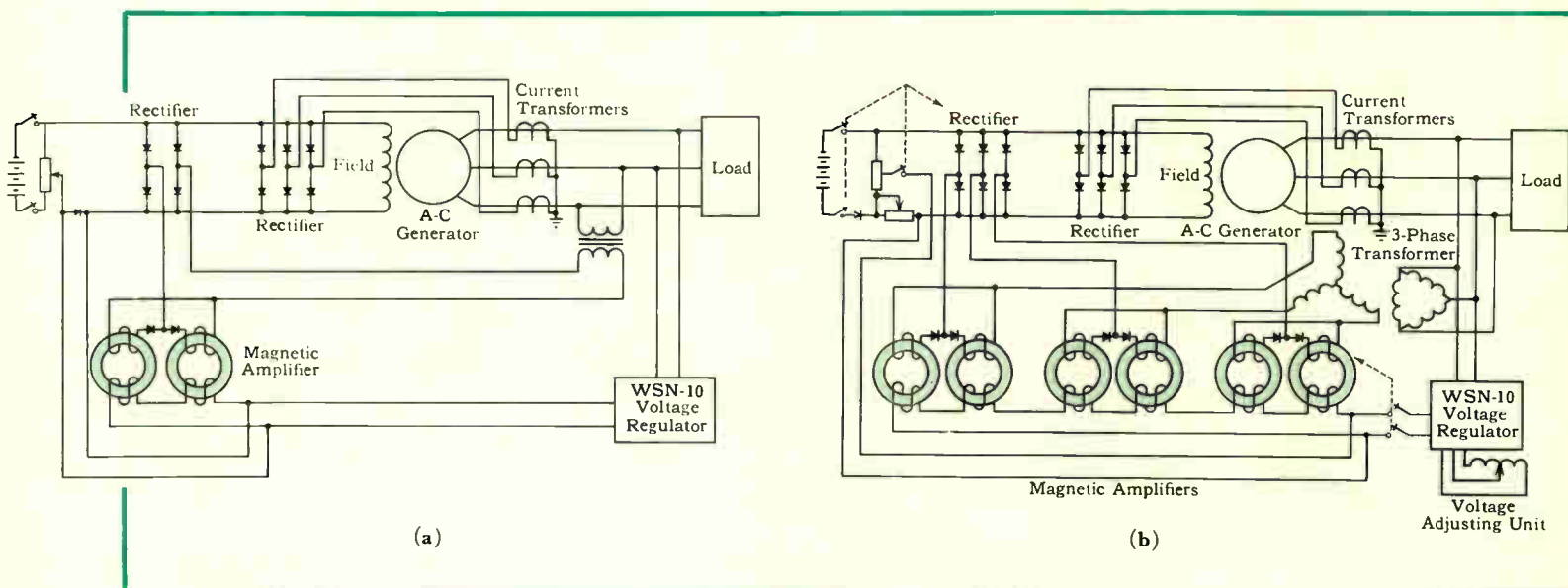
RECENT developments in self-saturating circuits for magnetic amplifiers have made possible a marine generator regulator-exciter with no moving parts—Magamps have replaced the rotary amplifier. The excitation system is completely composed of static equipment—resistors, transformers, reactors, capacitors, selenium rectifiers, and magnetic amplifiers. Rotating commutators with brushes, as well as vacuum tubes and other delicate parts have been eliminated. These static-type regulator-exciters are now being used on a-c generators aboard U. S. Navy vessels. Most of the present units are on submarines and minesweepers, but several other trial installations on larger vessels are under way.

The static Magamp-controlled excitation system is made practical by the use of current-transformer feedback from generator output through rectifiers, to supply the major portion of d-c field excitation required. Magamps serve as a vernier for small excitation adjustments from no load to full load. Hence, powerful field-forcing action is provided by current transformers so that the magnetic amplifier need not operate over a wide output range. The size generator on which the system will work is governed by the practical size of dry-type rectifiers presently available. The largest static-excited generator now in operation is 950 kva.

Design of the regulator-excitation system was guided by the duty it was expected to perform. The system is required to provide regulation of ± 1 percent from no load to full load. It is expected to have a voltage recovery to ± 3 percent two seconds after sudden application of half-normal load. This kind of regulation is needed because

Fig. 1—A simplified diagram of the regulator-exciter. Main excitation is from the load-current feedback loop—small adjustments from Magamp regulating loop.





single loads approaching half the capacity of the generator might be applied. On a three-phase short circuit, the system must produce at least three times rated short-circuit current. Sustained short-circuit current allows selective tripping. Breakers are timed to trip at approximately three times normal current. Hence, the generator must be able to supply short-circuit current for the longest time period set.

With the scheme used it is not necessary to provide bias windings or feedback windings that require adjustment. Since the only Magamp used is a power amplifier that will supply current in but one direction, an inefficient push-pull type amplifier is not necessary. With these systems the only adjustments that can or need be made are those in the voltage regulator. These are adjustments of regulator sensitivity and frequency compensation. Once these adjustments have been properly made no additional adjustments or changes in settings are anticipated in the life of the regulator.

Principle of the Static Regulator-Exciter

There are several variations of the same general Magamp excitation system now being built. The simplest scheme, which is typical of other types, is shown in Fig. 2a. It uses a single-phase magnetic-amplifier circuit that receives power from the output of the a-c generator.

No-load excitation for the generator is supplied from a single-phase rectifier that receives its power from a self-saturating magnetic amplifier. The voltage regulator senses changes in generator output voltage and makes corrections by changing control current to the Magamp.

When a load is applied to the generator, additional field excitation is supplied by the current transformers. The ratio of the current transformers is such that they provide more excitation to the field of the generator than is required by the additional load. Consequently, the excitation needed from the Magamp decreases as the generator load increases.

The operation of the magnetic amplifier as the generator load changes is shown graphically in Fig. 3. When the generator is operating at no load, the Magamp operates on the voltage transfer characteristic (1). When load is applied, the additional field current supplied by the current transformer

raises the voltage across the field so that the Magamp must work into a higher voltage. Since this occurs while the amplifier is supplying the same or a smaller amount of field current, it effectively works into a higher resistance load and, therefore, operates on a different transfer curve. With full-load (unity power factor), the Magamp operates on transfer characteristic (2).

A three-phase short circuit on the generator drops the voltage output to such a small value that no excitation is supplied from the Magamp circuit. However, the high initial short-circuit current through the current transformers produces a high exciting current in the field of the generator, and the sustained short-circuit current settles to a value determined by the voltage that the current transformers can produce before they saturate. The system sustains a short circuit of approximately four to six times rated current.

An advantage of this type of regulation system is that nearly the same sustained short-circuit current is available on line-to-line faults as on three-phase faults. With the same amount of excitation, line-to-line fault current is about 1½ times as much as three-phase fault current. This is undesirable from the standpoint of adjustment of breaker tripping time for selective tripping. However, in this system, where all the short-circuit excitation is supplied by current transformers, the excitation supplied during a single-phase line-to-line fault is approximately two thirds of the excitation supplied during a three-phase fault. This is true because only two current transformers are supplying excitation during the single-phase fault, whereas three current transformers supply excitation during a three-phase fault.

A system very similar to the single-phase Magamp circuit employs a three-phase Magamp reactor, which also receives power from the output of the a-c generator (Fig. 2b).

Generator Voltage Build-up

The systems shown in Figs. 2a and 2b must have some external means for initial voltage build-up. When a battery is available, battery voltage is used to deliver a small initial current through the field of the a-c generator to start the build-up action. However, there is no need of relays, or field-

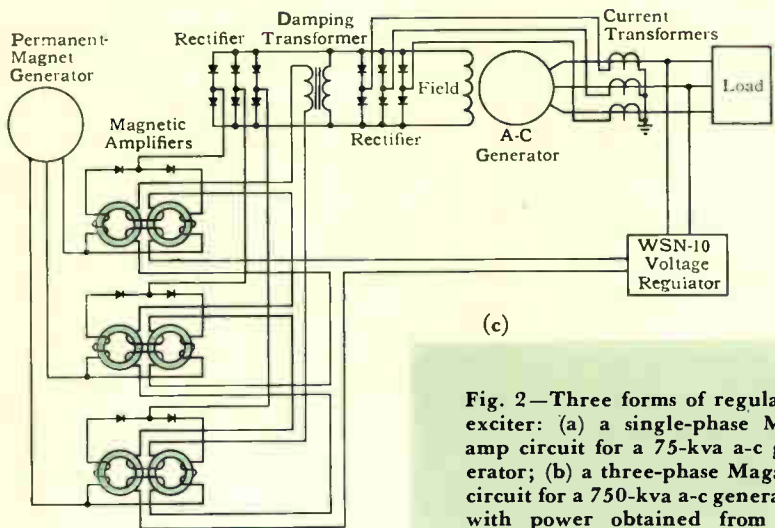


Fig. 2—Three forms of regulator-exciter: (a) a single-phase Magamp circuit for a 75-kva a-c generator; (b) a three-phase Magamp circuit for a 750-kva a-c generator, with power obtained from the generator voltage output; and (c) a three-phase circuit employing a permanent-magnet generator to supply energy to the Magamp.

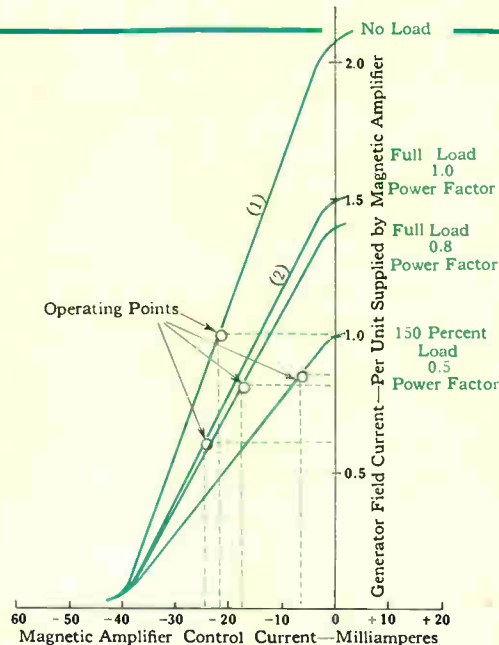


Fig. 3—Operating curves showing Magamp output as a function of Magamp control current at various generator loads.

flashing contactors. The start-up circuit is so connected through the control windings of the Magamp that when the exciter voltage reaches a given value, determined by the setting of a resistor, the field current ceases to build up. When the switch is turned to the start position, generator voltage builds up to a predetermined point. It remains there until control is switched over to the automatic regulator, whereupon the voltage rises to the normal operating point.

Another variation of the system is shown in Fig. 2c. A permanent-magnet generator supplies the power to the Magamp circuit. An advantage of this scheme is that this generator can be built to operate at a relatively high frequency, thus enabling the Magamp reactors to be smaller and have less time lag in their response to control signals. Another advantage of the permanent-magnet generator system is that power is available when the machines are running and the system requires no external means for voltage build-up. Voltage can be built up by starting the machines and turning the regulator switch to the automatic position. The voltage will immediately build up to a point determined by the setting of the voltage-adjusting unit. The permanent-magnet generator is a very reliable type of machine having no brushes, slip rings, or commutator. The rotor itself is cast in aluminum, making a very compact and sturdy structure. The only moving parts in the whole system are the rotors of the a-c generator and the permanent-magnet generator.

The Voltage Regulator

The same voltage regulator, (WSN-10) appears in all of the systems described. This regulator (Fig. 4) was first developed for a lightweight static regulator-exciter system for the U. S. Navy.

The WSN-10 uses as a voltage reference the impedance characteristics of a circuit containing a saturating reactor and a capacitor connected in parallel, and a circuit containing a saturating reactor, capacitor, and resistor in series. The characteristics of these two circuits are shown in Fig. 5. When voltage across the circuit rises, more current flows through the series circuit than through the parallel circuit and the output of the regulator is in a direction to lower

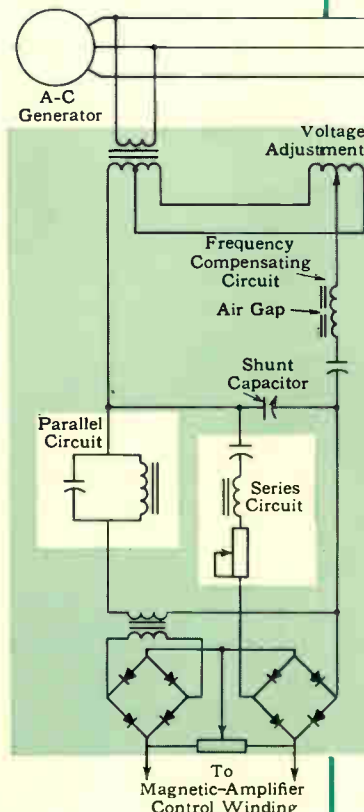


Fig. 4—A schematic of the WSN-10 regulator.

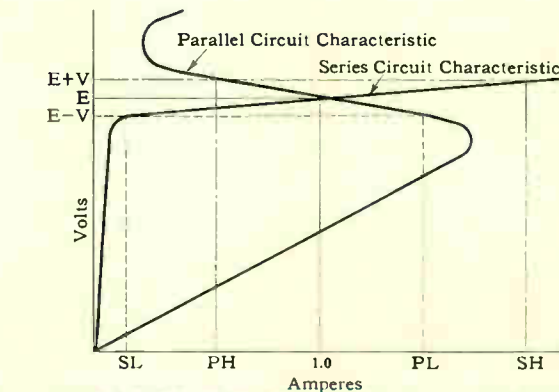


Fig. 5—Volt-ampere characteristic curves for series and parallel circuits. The output is proportional to the difference between the current SL (series low) and PL (parallel low), is also proportional to the control current that would be applied to the Magamp if generator voltage dropped to the value $E-V$.



Static regulator-excitors are now being used on a-c generators aboard submarines; above is the U.S.S. *Tang*.

excitation; when the voltage decreases, the current flowing in the series circuit decreases rapidly while the current in the parallel circuit increases. This causes the output of the regulator to be in a direction to raise the excitation of the a-c generator and thus bring the voltage back to normal.

Regulators have been made responsive to positive-se-

quence voltage or to average three-phase voltage in the past because of the possibility that the regulator would respond in the wrong direction under certain fault conditions. When a fault appears on this system, control is completely taken away from the regulator by the action of the current transformers. The current transformers raise the voltage so high on the field that the Magamp circuit is unable to produce any effect on the excitation of the machine. Therefore, the excitation will be forced up from the start of any fault that occurs on the generator. Consequently, provisions for three-phase sensing or positive-sequence response are not needed.

The performance of these systems as determined by a number of tests has been as good and in many cases much better than the best excitation systems now in general use. In every case the voltage regulation from no load to full load at rated power factor has been held well within the ± 1 percent band. The voltage recovery on sudden application of a two per-unit impedance load is shown in Fig. 6 for two of the systems tested. The recovery time has varied from 6 cycles to 22 cycles.

Static excitation systems that furnish the same performance as that provided by rotating machines are lighter in weight and require approximately the same volume as the rotating-machine systems. About one half of the total volume taken up by the static system is that required by the dry-plate rectifiers. These rectifier structures must be built in such a way that sufficient ventilation is available to keep the rectifiers cool, and it is therefore necessary for them to take up a considerable amount of space for a small amount of weight. In the future, improvements in rectifiers may make it possible to provide static excitation systems in considerably less space, and thus give these systems a space advantage along with their other desirable characteristics.

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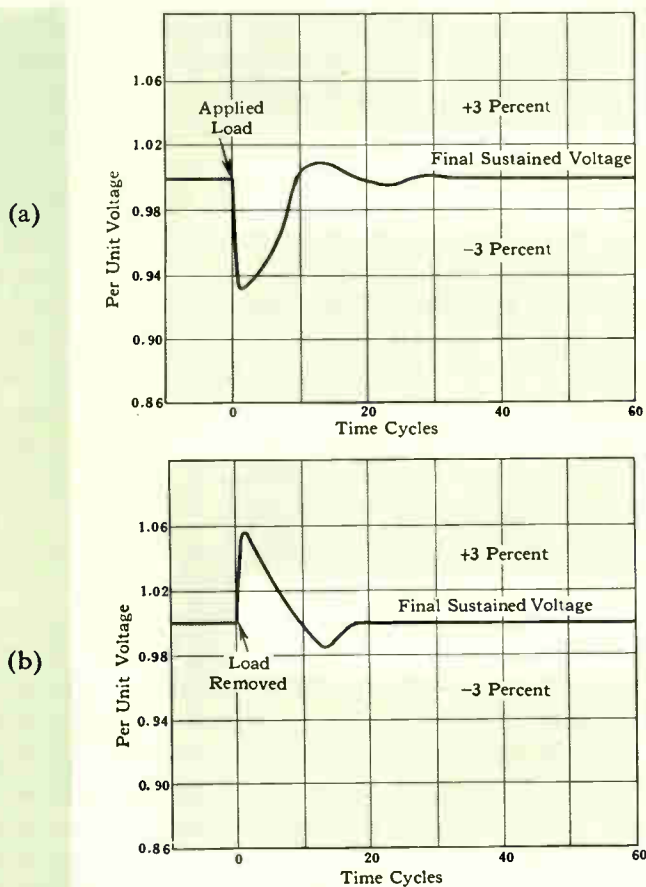


Fig. 6—Generator voltage recovery after application (a) and removal (b) of half-rated generator load. The ± 3 -percent band is allowable variation after initial change.

Distribution Transformers Hide within the Walls—

Designers of a modern school in St. Louis wished to keep building service equipment as much out of sight as possible. To assist them, transformer engineers provided dry-type distribution transformers of 15, 20, 25, and 30 kva mounted in metal cabinets set flush into the walls. Louvers in the removable front panels allow adequate air circulation. The transformers were suspended and other precautions taken to prevent noise amplification.

Personality Profiles

S. LeRoy Bradley has been associated with the marine business almost continuously since he came with Westinghouse.

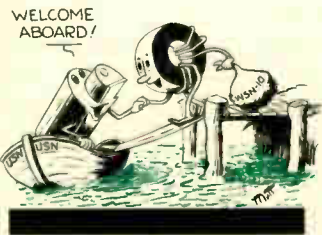
A graduate of Oklahoma A & M in 1938, Bradley came on the rotating test course in 1940. His first permanent assignment was with the marine section of the Engineering Service Department where he began following marine equipment.

In 1946, Bradley went to work designing voltage-regulator systems, most of them for Navy applications. Many have since been brought ashore and placed in "land-based" power systems—in fact, Bradley was instrumental in the conversion. A shining example is the present Magamp regulating system, which has just been placed in operation with West Penn Power at their Springdale Station.

Bradley has an unusual pastime of quoting poetry; when asked to quote something appropriate, he summarized his outlook on life with a recitation from James Graham, a 17th century poet:

"He either fears his fate too much,
Or his deserts are small,
That dares not put it to the touch,
To gain or lose it all."

Not a bad philosophy at that.



Two articles in this issue, dealing with fundamentals of electrical insulation, are designed to pave the way for future articles on the application of insulation. Appropriately, the two authors are in the business of paving the way for insulation applications—both are concerned with research on insulation. The author of the chemistry aspect of the story—*Dr. Jack Swiss*—is manager of the Insulation Department of the Research Laboratories, while his running mate, *Dr. T. W. Dakin*, is the section manager in charge of the physics of insulation research. Each, therefore, has an intimate acquaintance with his subject.

Swiss came to Westinghouse in 1940, as a member of the same department of which he is now manager. A 1933 graduate of the University of Nebraska (B.S. in Chemistry), he remained at college and secured his master's degree in 1934. He then became a graduate student in chemistry at Iowa State College, where he

earned his Ph.D. in 1939. In 1945 he was appointed manager of the Chemical Development section, and in 1952 assumed his present position. During this time, Swiss's work in the insulation field has covered many different types of insulating materials, including varnishes, wire enamels, polyester resins, and silicones.

Dakin, a physical chemist, is a graduate of the University of Minnesota, 1935. He received his master's degree in 1938, from Michigan State College. For the next three years he held a fellowship at Harvard, where he continued his study of physical chemistry and received his Ph.D. in 1941. Dakin came to the Research Laboratories in the same year, and since has devoted his time largely to investigations into dielectric properties of materials, microwave spectroscopy, dielectric breakdown, and other insulation aspects.

Neither Dakin nor Swiss is any stranger to this business of teaching insulation fundamentals; both have taught courses on the subject at the Westinghouse Design School, and have lectured on the subject to the engineers in several of the Company's divisions.

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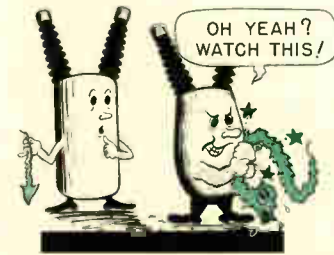
There can be little doubt that when bigger circuit breakers are built, *A. W. Hill* will be part of the act. Hill's interest in the subject started back in 1920 when he came with the General Engineering Laboratories in East Pittsburgh, and was soon involved in circuit-breaker testing. In 1925, he moved to the Circuit Breaker Engineering Department, and continued to follow test work in the new High

Power Laboratory on large circuit breakers. "Circuit-breakitry" back in the 20's was not the exact science that it is today. The art and the breakers grew together—in the test laboratory.

In December, 1943, Hill became manager of the Power Circuit Breaker Engineering Department.

During his career with Westinghouse, Hill has been continuously associated with the giants—the Hoover Dam 287-kv and Coulee Dam 230-kv breakers, and now the new 330-kv breakers for the AEC.

A graduate of Worcester Polytechnic Institute, Hill has been very active in



association work. This activity includes membership in AIEE switchgear committees, ASA Bushing Standardization, EEL-AEIC-NEMA Committee on Power Circuit Breakers, and the NEMA Power Circuit Breaker Technical Committee. He has been chairman of the latter two.

In his spare time Hill is a gentleman farmer. When asked to clarify this activity, he explained that he owns a dairy farm but his son actually runs the show and does the work—in other words, he calls himself a "part-time handy man" on his own farm.

Engineering Notes

Making One Instrument Transformer Prove Another—An improved production-line method of detecting a fault in instrument transformers involves comparing one against the next. Two units are given simultaneous and repeated surges. One unit is connected to one pair of deflecting plates of an oscilloscope, the second is connected to the opposite pair. The scope indication of each alone, if the windings are sound, is a straight line; the two lines are at right angles to each other. When the two transformers are surged together, the result—for perfect units—is a straight diagonal line. But if one transformer is faulty, the line is distorted—and indicates which unit is guilty.

Better Filters Mean More Carrier Channels—The squeeze is on to get more channels in the available spectrum of frequencies for power-line carrier. One relief from the traffic jam has come from a new set of filters, termed Linophase. By making the sides of the selectivity curve steeper—i.e., reducing the response to unwanted frequencies, the filters permit up to twice as many channels to be accommodated in a given bandwidth, depending on the application. The Linophase filter also reduces the amount of phase distortion for reception of FM signals. Although the filter comprises 15 stages—an uncommonly high number—its enclosure is the size of a cigar box.



Testing—of materials, components, and the finished product—is an essential part of any development. One step in motor development is determining the dielectric strength of the slot or phase insulation by applying a voltage to a sample until it breaks down. Here a combination of Mylar polyester film and rag paper—each 0.005 inch thick—is withstanding a voltage of over 15 kv. This is the slot insulation used in the new Life-Line A motor.