WESTINGHOUSE

Engineer

March 1944

ACKERSON

Electric Power AFTER THE WAR

What will happen to the electric-power curve when the war-production job has been finished? This question is in the minds of most engineers. That a drop will occur is agreed to by all. The estimated amount of the drop depends upon the degree of optimism or pessimism of the guesser; the actual drop will hinge on the imagination and diligence of the industry in finding and applying new or more extensive uses of electric power. Recently a group of Westinghouse technical men—each expert in his own field—assembled to pool their respective ideas as to war possibilities for electric power. Here is the essence of a few of their observations.

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Increasing the electric-power load can obviously come about in two ways: by finding new uses for electric power and by extending old ones. The latter is less glamorous but more promising.

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We think of the U.S. as a highly electrified nation. But is it? Air conditioning was applied first and most aggressively to motion-picture theaters. Yet only 15 per cent of the theaters in the U.S. have modern equipment. Only three per cent of the restaurants are air conditioned. More than 60 per cent of all lamps installed for street lighting are 100 candle power or less, whereas 200 cp is widely recognized as a minimum. More than 100 000 factories are in need of better lighting to remain competitive. Something like 1 200 000 stores are expected to be modernized after the war, and this includes major revamping of the lighting. Forty eight of the 124 primary steel-reduction mills are still steam driven. We are pretty proud that the average home consumption of electric power reached the all-time peak in 1943 of 1060 kwhr. Nevertheless this is but one half of that of advanced pre-war European countries.

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We do not always trust the lessons of history. Throughout the entire industrial era, entire new industries have continued to arise, each demanding large blocks of power, usually electrical. The automobile, the radio are outstanding examples. Synthetic rubber, high-octane fuels are more recent ones. Are there to be no more? One industrialist has estimated that as our supply of high-grade iron ore runs out (distressingly close) it will be necessary to establish, at ore sites, plants for concentrating the ore before shipment to steel mills. Perhaps 20 plants will be constructed in the next ten years, with a connected load of 200 000 kw. . . . Hydrogenation of coal is looming as a strong possibility as our petroleum reserves diminish. It has been said that about one half of our requirements for liquid fuels and lubricants will be produced by hydrogenation of coal, requiring substantial blocks of power.

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Furthering the use of electric power is not just a matter of devising new uses or coaxing consumers to use more of it. The percentage of homes sold with the famous No. 14 wire is as great now as in the days before electric refrigerators, washers, ironers, cleaners, or radios. Half of our wired residences are more than 40 years old. Half of the electrical-radiation devices available (postwar) cannot be used on the existing home-wiring circuits. The estimated 600 000 to 1 000 000 new homes to be built annually in the immediate postwar years must be wired, not according to the minimum standards of the safety codes; not with two-wire entrance service, nor five-ampere meters, nor limitations of ten amperes per branch circuit—but with capacity for at least double the peak demands of today. Also a way must be found to rewire or "up-wire" the majority of the old homes, lest these cease to be growing markets.

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Lessons learned by industry in solving the problems of war production can soon be applied extensively. One of these is that the total power cost in a manufactured article is usually insignificant in comparison to the total value. Specifically, a mold was heat treated in a controlled-atmosphere electric furnace for $250 and of this the power cost was 4 per cent. But to have treated the mold in an ordinary gas furnace would have increased the cost by 30 per cent because of the need for removing scale. . . . Complicated parts have been made up from simple pieces by brazing in an electric furnace instead of from complex shapes requiring expensive machinery. A certain die made by brazing cost $500, a small portion of which represented power costs, but machinery time was reduced by 20 per cent. . . . Typical new jobs for high-frequencies include brazing of cutting tips to tool shanks, rapid soldering of many leads to terminal blocks in one few-second operation, localized heating of metal parts for forging, and the curing of laminated plywood in minutes instead of hours. . . . Hundreds of new uses for infrared drying have been uncovered in this war.

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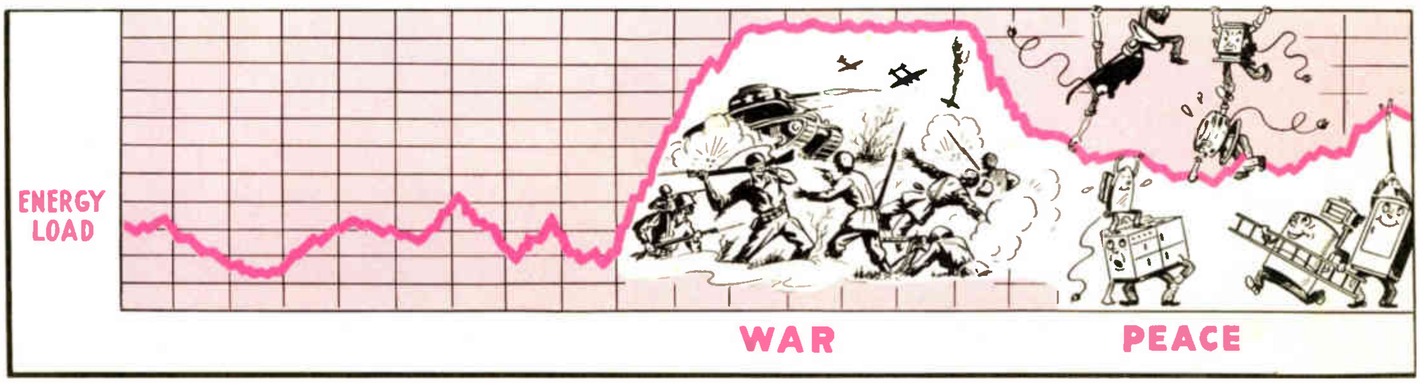
One factor affecting postwar lighting is a psychological one. From almost every home will come one or more war workers who have been exposed to 50 foot candles of illumination in modern plants. The engineer will be ready to serve these desires for better illumination at home in many new ways. He promises a wide variety of fluorescent lamps for the home, including circular fluorescents for reading lamps, baby-sized units for night lights, and lamps to be built into the rooms and for inclusion into the furniture. . . . A half-kilowatt connected load for home Sterilamps—in kitchen, bathroom, nursery, etc.—is not out of the question. . . . Infrared drying lamps will be useful in bathroom, kitchen, and laundry.



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WESTINGHOUSE Engineer

In This Issue

COVER: *Magnesium is a metal with an interesting past, an exciting present, and an enticing future. Something of the spirit of that future is caught by the artist, F. G. Ackerson.*

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Capacitors Aid Resistance Welders

One of the agreeably surprising factors in this war of production has been how power companies have shouldered the greatly augmented industrial load. Shortages of manpower and materials preclude the installation of additional distribution equipment and power users must cooperate to minimize the demand load. Users of resistance welders can almost double the capacity and current consumption of their machines, not by adding transformers or increasing the power demand, but through the addition of series capacitors.

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Wide-spread acceptance of the resistance welder as a high-speed production tool has imposed an enormous single-phase load on power circuits. The capacity of resistance-welding equipment now installed in the United States totals some eight million kva. If all these machines were operated simultaneously, the maximum instantaneous demand load on the power systems would exceed twenty million kva.

The power demand of massed welders in numerous plants in industrial areas has occasioned concern among power companies. Cooperation between the power companies and manufacturers, particularly in the welding industry, has greatly reduced the demand load. This has been done chiefly through the application of series capacitors to increase the load power factor.

Improving Power Factor and Minimizing Voltage Dip

The effect of introducing capacitance into a series circuit is demonstrated by the vector diagrams in Fig. 1. This approach to unity power factor (where line voltage and current, E_L and I_L, Fig. 1 (a), are in phase) depends upon the vectorial value of the voltage drop across the capacitor, E_C. The desired correction is obviously the amount of capacitance that increases the E_C in Fig. 1 (b) about to E_C in Fig. 1 (a). In the vector diagram Fig. 1 (c), the relative values of the components are shown for a leading power-factor condition.

The resistance welder inherently has a large kva demand. Because the load is largely inductive, the power factor is low. Except for welders of the stored-energy type, resistance welding is primarily a single-phase load, which unbalances the three-phase supply lines. Further, the combination of a large peak kva demand and the great rapidity of operation can create a flicker problem. All of these undesirable load characteristics can be greatly improved by the proper application of series capacitors to the primary circuit of the welding transformer.

A leading power factor can, of course, be created by introducing sufficient capacitive reactance in the circuit. However, a leading power factor introduces a current and voltage phase relationship that makes the operation of tube control difficult. For ease of firing in electronic control of resistance welds, the power factor should be slightly lagging.

Application of Shunt Capacitors

The type of condenser commonly used for power-factor correction is the shunt capacitor. It is simpler and easier to apply for the average application such as motor loads, because relatively little change in an existing installation must be made. To prescribe the correct size of capacitor installation, it is necessary to know only the line voltage, the power factor, and the kva of the load. The capacitors are placed across the line near the load.

Why, then, have shunt capacitors found but little use on resistance welders? Shunt capacitors inherently have an objectionable characteristic when used with intermittent and brief loads such as are offered by resistance welders, although their use does result in improvement of power factor. When a shunt capacitor is first connected to the line it draws a fairly high charging current, the magnitude of which depends on the point on the voltage wave at which the switch is closed. Ordinarily shunt capacitors in industrial plants are connected to and disconnected from the lines infrequently; hence, the occasional current surge is not objectionable. However, if a shunt capacitor is connected to the circuit each time a resist-

Mr. Ponkow and Mr. Smith examine one of the largest series-capacitor applications to resistance welders made by the Federal Machine and Welder Company. Designed to house the capacitor units within the machine, the welder uses two 660-kva welding transformers and a program timer to control the welding cycle. Used to weld the cap to the body of a 75-mm shell, the welder requires 200 000 amperes.

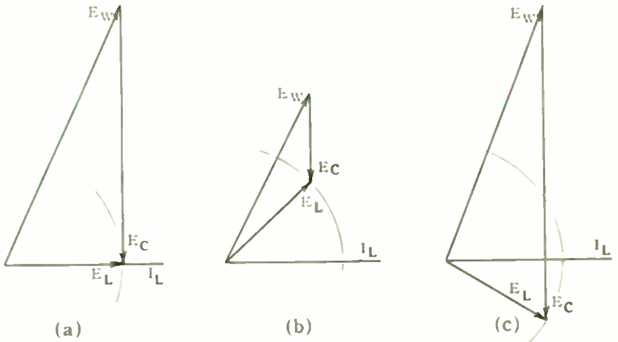


Fig. 1—*When the resistance welder is corrected to unity power factor, the vector relations are pictured as in (a). Correction less than unity, or lagging power factor, is shown in (b). For the condition of leading power factor, or correction greater than unity, the relationship of the vectors takes the form in (c).*

ance weld is made, the frequent and dissimilar current surges cause annoying light flicker. Thus, the application of shunt capacitors to resistance welders with their heavy loads and low power factor tends to aggravate the undesired conditions.

In such cases as these, the charging current of the capacitors becomes important. In fact, this is often greater than the peaks associated with the welding transformer. Without highly complicated controls and additional equipment to prevent wide line-voltage fluctuations and coincidence of welding-transformer peaks with capacitor charging surges, the use of shunt capacitors with resistance welders for power-factor correction is not suitable. This scheme, because of complication of control and economic factors, is not feasible at present.

This problem is not solved by leaving the shunt capacitors connected to the line at all times. The magnitude of the resistance-welding load necessitates large banks of capacitors. Leaving the capacitors on the line continually increases the plant load power factor; in fact, it may even cause it to become leading when the welders are not in operation. In this case, although shunt capacitors reduce the supply-line demand, the power factor of the plant load fluctuates the same as when the capacitors are not used. Any such change in the power factor of the plant load causes a corresponding change in the plant voltage. Care must be exercised that the line voltage is not too greatly increased.

Series Capacitors

Series capacitors do not differ fundamentally from shunt capacitors, except that shunt capacitors, for safety purposes, are normally equipped with resistors across the terminals. Because shunt capacitors are always connected across the power lines, they are constantly charged. Should the lines be de-energized, the shunt capacitors would still retain their charges. The resistor across the capacitor terminals bleeds off this stored energy. These resistors do not interfere with the proper functioning of the capacitors in shunt arrangement because shunt capacitors are not called upon to function after the line voltage is removed. In series applications, resistors cannot be used, as the change must be allowed to remain between welding cycles. A resistor across the terminals of a series capacitor would tend to drain this charge. However, to prevent an unwanted charge from remaining on the capacitor, welders are supplied with safety interlocks that automatically short circuit the capacitors when the welding installation is de-energized.

It is interesting to note the voltage conditions across series capacitors during the intermittent operation of resistance welders. Without a discharge resistor the charge remains on the capacitor during the off period of the welding cycle. The line-current and capacitor-voltage relationship is shown in the oscillogram, Fig. 2.

Properly calculated applications of series capacitors produce the desired results of decreasing the welder demands, approaching a unity load power factor, minimizing lamp flicker and improving power regulation. Series capacitors are applicable with comparable results to seam, projection, spot, and pulsation welding. Stored-energy and flash welding are special cases to which these principles of series-capacitor applications do not apply.

To demonstrate the efficacy of capacitors to resistance welders for correction of line power factor our research laboratory undertook a program of tests to show by means of oscillograms just what occurs in such applications, and to determine the principles governing such applications.

The oscillographic record of welding without capacitors is shown in Fig. 3. By measurement, E_{rms} is found to equal 287 volts, while I_{rms} is equal to 332 amperes. The peak demand is therefore 95.30 kva.

The term power factor is generally defined as the ratio between the kilowatts and the kilovolt amperes. It can also be expressed as the cosine of the angle between the voltage and current. Reference to Fig. 3 shows the displacement or lagging effect of the current trace with respect to the voltage trace. An enlarged view of the voltage and current traces for one cycle is shown in Fig. 4. A calculation of power factor by this method gives 42.9 per cent. The kilowatts are readily obtainable as the product of kva and power factor, or 95.30 × 0.429, or 40.8 kw.

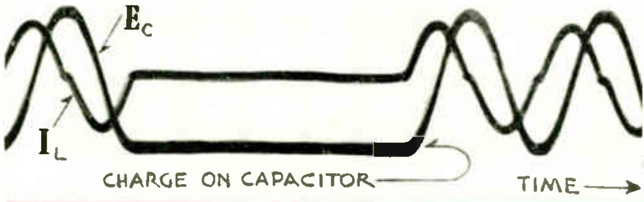


Fig. 2—*The charge on the capacitor is shown to remain at peak value during the off-time when the load current is zero, eliminating the charging current at the next on-time.*

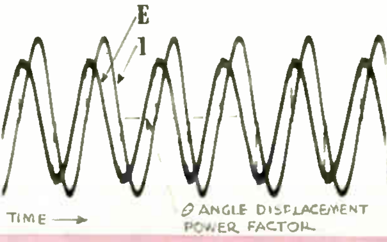


Fig. 3—*The phase displacement of the current when welding without capacitors is shown by the current* I *lagging the voltage* E. *The amount of lag is determined by the magnitude of the angle* θ.

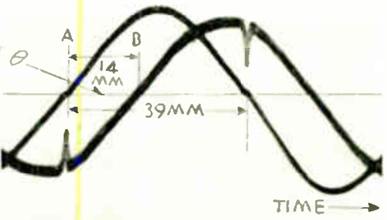


Fig. 4—*Enlarged view of a single cycle of the series in Fig. 3. The phase angle displacement is clearly shown. The per cent power factor from the measurements shown is 42.9.* ($\theta = 14/39 \times 180°$)

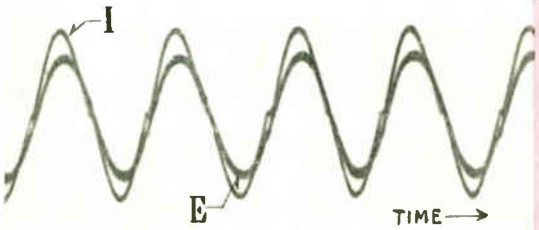
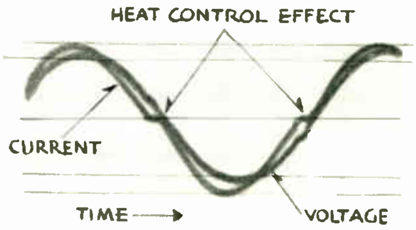


Fig. 5—Oscillogram taken after the application of series capacitors to the welder.

Fig. 6—This enlarged view of a single cycle from Fig. 5 clearly shows the near approach of the line-current trace to the line-voltage trace, indicating the condition of nearly unity power factor.



The oscillogram shown in Fig. 5 was taken during a welding cycle after the circuit was tuned to series resonance. The enlarged view of a portion of this oscillogram, Fig. 6, however, shows more clearly how the current trace is nearly superimposed upon the voltage. This denotes an approximate unity power factor. It also shows the effect on the wave form caused by heat control.

A comparison of Fig. 4 and Fig. 6 shows what actually happens when the power factor is raised from 42.9 per cent to approximately unity. The phase shift is obvious. Not so obvious is the reduction in the power demand from 95.3 kva, as calculated from the first trace, to approximately 48 kva, as computed from the experimental results secured after the installation of the capacitors. Thus, series capacitors have halved the resistance-welder demand.

Data Necessary for Capacitor Selection

The capacitors must be selected to meet the individual needs of each application because the capacity and voltage ratings of the capacitors vary over a wide range. Capacitors are available in standard sizes rated for continuous 60-cycle operation from 230 to 2300 volts with a resistance of 7.5 to 353 ohms. The capacity of standard capacitor units varies from 375 to 7.5 microfarads.

In applying capacitors to existing equipment, it should be recognized that their use with standard welder transformers increases the electrode voltage. The increase in electrode voltage arises from the fact that the voltage drop caused by the inductive reactance of the transformers has been lessened. The improvement in power factor necessitates the lowering of the voltage (the current at the weld remaining constant) to operate at the rated kva and supply the prerequisite heat to the weld. To obtain the proper voltage at the electrode, it is necessary to apply an autotransformer, or to rewind or reconnect the welding transformer. In new equipment, designed for use with capacitors, the transformer is wound to produce the proper voltage.

Another determining factor in capacitor selection is the duty cycle of the application. In resistance welding, the current actually flows for but a portion of the time comprising the welding cycle. The length of the on-time (when current flows), plus the squeeze-time, hold-time, off-time, and other factors that vary with the type of weld, is called the welding cycle. The ratio of the on-time to the welding cycle determines the rating of the capacitor for safe operation in a particular application.

Capacitors are rated as to maximum working voltage and maximum short-circuit voltage. When, as with the installation discussed previously, an overvoltage protective device is used, and the duty cycle is less than 44 per cent, the capacitor can be selected from the maximum working voltage group that satisfied the other specifications needed for this application. Otherwise, the selection must be made from the maximum short-circuit voltage group that has a lower rating per unit and is self-protecting when operated within rated voltage limits.

The calculation of the series capacitors required for the welder used in the foregoing oscillographic analysis will show the principles involved in series-capacitor applications. The problem at hand is to select the correct number of capacitor units so that the power factor can be increased from approximately 42.9 per cent to unity and the demand decreased from 95.3 kva to approximately 48.0 kva.

The selection of the number and size of the capacitor units required to operate the longitudinal seam welder (Fig. 7) at unity power factor can be determined by calculations from data obtained in the tests. The method is applicable to all seam, projection, spot, and pulsation welders. The fundamental schematic circuit and test-connection diagram are shown in Fig. 8. The information required is:

1—The supply-line voltage and frequency.

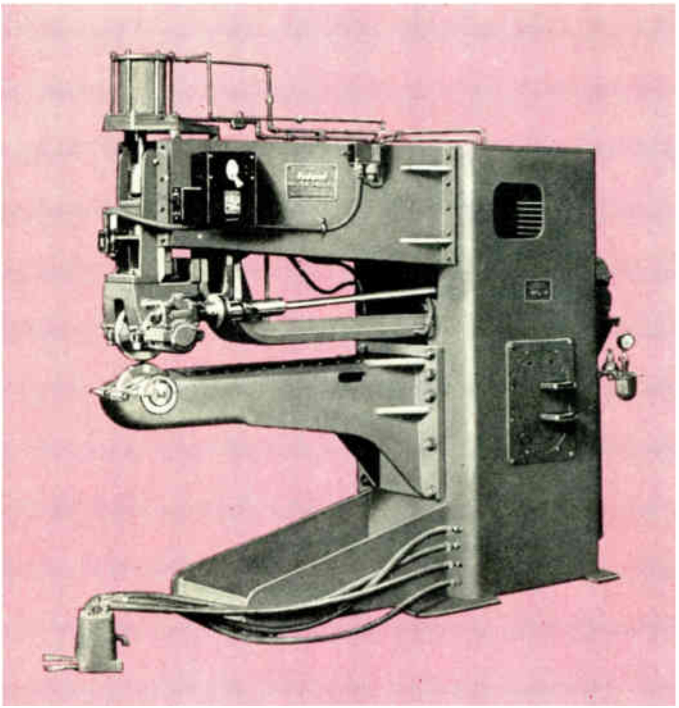
2—Type of control (synchronous—non-synchronous—or mechanical contactor).

3—Welding duty cycle.
  a—Number of welds per minute.
  b—Number of cycles of current flow.
  c—Number of cycles of off-time.
  d—Number of pulsations per weld. (If pulsation welding is used.)

4—Kva and power factor during actual welding condition. If actual readings cannot be obtained, the welder manufacturer can make an estimate from past performances.

5—Kva and power factor during the maximum short-cir-

Fig. 7—This seam welder, together with a synchronous electronic seam-welding panel, two-element oscillograph and a bank of series capacitors, was used in securing the accompanying test oscillograms.



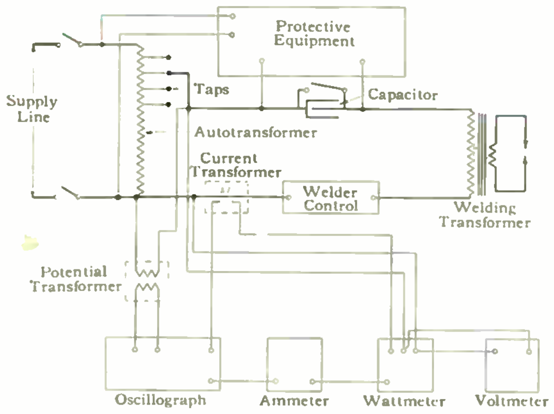


Fig. 8—*This wiring circuit shows the various components used in the tests. Provision was made to short circuit the series capacitors to run tests with and without power-factor correction.*

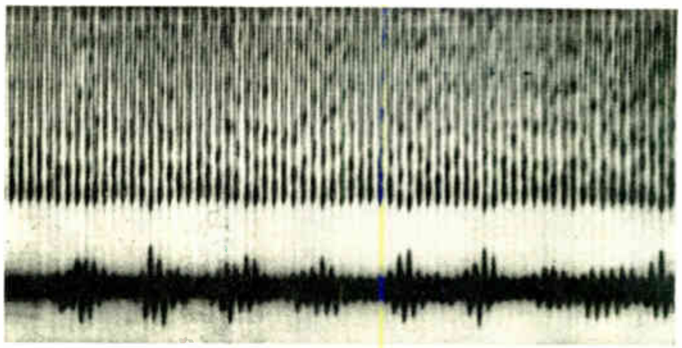


Fig. 9—*Oscillogram taken during the flashing period of a flash-welding operation shows the irregular voltage trace during that time.*

cuit conditions, i.e., with the electrodes in contact with no work between them.

From the known factors and the data secured through tests, the voltage requirements and the amount of the capacitance can be computed for both the welding and short-circuit conditions. It is necessary to know the capacitor requirements under both conditions because the power factor of the welding circuit changes markedly between welding and short-circuit conditions with corresponding change in voltage. There is a relative change in power factor when welding different metals, such as steel and aluminum. The complete step-by-step calculations with attendant formulas are contained in the sample calculations on page 38.

For this particular equipment, with a duty cycle of less than 44 per cent, capacitors were chosen from the manufacturer's maximum working voltage classification rather than the maximum short-circuit voltage rating as the overvoltage protective device was used and the greater safety factor was not required. Continuous-rating 575-volt, 60-cycle capacitors fulfilled the requirements (series-capacitor voltage of 570 volts) computed in the sample calculation, equation (e). As manufactured, each 120-microfarad capacitor unit has a reactance of 22 ohms. The total reactance of the series-capacitor bank is 3.78 ohms—sample calculation, equation (f). Thus, a total of six 120-microfarad capacitor units is required. (22 divided by 3.82 equals 5.76.)

Flash Welders

Flash welders have been thus far specifically excluded from this discussion. They present a peculiarly distinct problem because of the dual nature of the welding operation. The welding cycle comprises two periods, flashing and upset.

During the flashing time, the edges of the two pieces of metal being joined are heated to a plastic state by the arcing of the current as it flows from one piece to the other, the electrode pressure being relatively light. When sufficient heat is stored in the plastic weld region, electrode pressure is suddenly increased, and upset occurs. It is at this time that the pieces are forged together, producing a weld. The flashing period is usually relatively long, compared to the upset period. The flashing current is irregular and intermittent in nature. The upset current is considerably greater than the flashing current and is constant.

An oscillogram of the flash welding of 18-gauge flat stock steel is shown in Fig. 9. Enlarged traces of the flashing and upset conditions, Figs. 10 and 11 show a wide variation in demand and power factor in the flashing and upset periods. The characteristics of the two are such that it is possible to correct the power factor for only one. To do so aggravates undesirable characteristics during the other period.

Applications of Shunt Capacitors

The effect of adding sufficient shunt capacitors to give unity power factor at upset is to raise the general level of welder voltage during welding. This is caused by the line current leading the voltage during flashing and being in phase with the voltage at upset.

Another solution that might prove satisfactory from the standpoint of line-voltage differentials and equipment cost is to add sufficient capacitors to give leading power factor during flashing but not enough to correct the upset condition to unity. This produces a rise in line voltage during flashing. However, there is still about the same relative voltage drop between flashing and upset as when capacitors are not used, but the differential rise at the end of upset is less than before capacitors are added. Hence the light flicker will be less. Furthermore the kva demand in this application, where the upset is not corrected to unity, can be adjusted so as to be approximately constant.

Although the addition of shunt capacitors may somewhat decrease the line kva demand and also diminish light flicker, the current in the shunt capacitors is not constant throughout flashing. It seems to be susceptible to surges induced by changes in flashing. Variations in current should be checked to determine whether they will have any adverse effects on the weld in a given case. If necessary, it might be possible to compensate for these effects by alteration in machine settings.

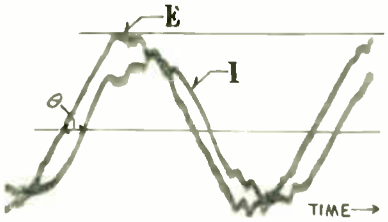


Fig. 10—*An enlargement of a single cycle of Fig. 9. The phase-angle relationship and the irregularities of the voltage and current oscillogram traces are clearly shown.*

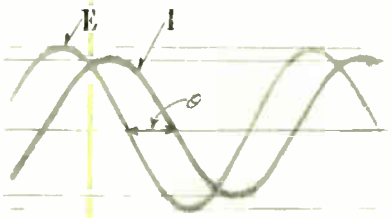


Fig. 11—*This enlarged oscillogram of a single cycle taken during the upset period of a flash-weld operation shows the widely different conditions in the upset period as compared to those in the flashing period* (*Fig. 10*).

Application of Series Capacitors

The current and voltage irregularities of the flashing period are not objectionable from the standpoint of the application of series capacitors for power-factor correction. Actually, series capacitors would tend to suppress rather than increase the surges. Series capacitors usually cannot be used without some sort of switching arrangement because the difference between the flashing and upset conditions is too great.

If the capacitor bank is designed on the basis of the flashing conditions it will not withstand the high voltage obtained during upset. This voltage is similar to that arising from short circuiting the electrodes on a spot or seam welder, except that the voltage rise is probably much greater during the upset of a flash welder.

While the increased voltage during upset can be carried by providing higher voltage capacitors, this increases the installation cost considerably because of the greater number of capacitors required to obtain the same reactance. The cost and size of a capacitor having a fixed reactance increase as the square of the voltage class of the capacitor insulation.

Summary

Investigations and test results show that series-capacitor power-factor correction for resistance welders of highly intermittent or long duration loads is entirely feasible.

The method of application outlined can be applied to all types of spot, projection, and seam welding. The several advantages attendant upon power-factor improvement are entirely applicable to the resistance welder.

On the basis of this investigation and existing equipment, series capacitors instead of shunt capacitors are recommended for power-factor correction. The uncontrolled welding current inherent with the use of shunt capacitors makes consistent welding difficult on spot, projection, and seam welders.

When power-factor correction is necessary on flash welders that have widely different flashing and upset conditions, series capacitors should not be considered without some switching arrangement. Instead the compromise method of shunt capacitors should be substituted.

Sample Calculation

The following data was secured from tests using the equipment described in this article connected as shown in Fig. 8 with the capacitor unit short circuited.

1—Welding kva—95.30 at 42.9 per cent power factor (θ).

2—Short-circuit kva—121 at 31.0 per cent power factor (θ_2).

3—Autotransformer voltage—287 volts at 60 cycles.

4—Synchronous electronic seam timer.

5—Approximately 33⅓ per cent duty cycle.

The following computations were made under welding conditions:

Effective line voltage, E_L, equals line voltage less voltage drop across contactor:

$$E_L = 287 - 15 = 272 \text{ volts} \qquad (a)$$

Line demand in kilowatts at unity power factor equals kva times power factor in per cent:

$$\text{Kw} = \text{Kva} \times \text{P.F.} = 95.30 \times 0.429 = 40.8 \qquad (b)$$

Line current at unity power factor equals kilowatts times 1000 divided by effective line volts:

$$I_L = \frac{\text{Kw} \times 1000}{E_L} = \frac{40.8 \times 1000}{272} = 150 \text{ amperes} \qquad (c)$$

Welder transformer primary volts equals the welder load of 95.3 kva divided by the primary current of 150 amperes or it equals the effective line volts divided by the power factor in per cent:

$$E_T = \frac{E_L}{\text{P.F. } (\cos\theta)} = \frac{272}{0.429} = 635 \text{ volts} \qquad (d)$$

Series capacitor voltage equals the welder primary voltage times sin θ:

$$E_C = E_T \times \sin\theta = 635 \times 0.903 = 573 \text{ volts} \qquad (e)$$

Series-capacitor reactance in ohms equals capacitor voltage divided by the line current:

$$X_C = \frac{E_C}{I_L} = \frac{573}{150} = 3.82 \text{ ohms} \qquad (f)$$

Using data given that is applicable to short-circuit conditions, the following calculations were made.

The welder short-circuit kva was given:

$$\text{Short-circuit kva} = 121 \qquad (g)$$

And also the short-circuit power factor:

$$\text{Short circuit P.F. } (\cos\theta_2) = 0.31 \qquad (h)$$

Welder impedance in ohms equals welder transformer primary volts squared divided by the short-circuit kva times 1000:

$$Z_W = \frac{E_T^2}{\text{kva} \times 1000} = \frac{(635)^2}{121 \times 1000} = 3.33 \text{ ohms} \qquad (i)$$

Welder resistance in ohms equals welder impedance times short-circuit power factor ($\cos\theta_2$):

$$R_W = Z \times \cos\theta_2 = 3.33 \times 0.31 = 1.03 \qquad (j)$$

Welder reactance in ohms equals welder impedance times the sin θ_2:

$$X_W = Z \times \sin\theta_2 = 3.33 \times 0.95 = 3.16 \qquad (k)$$

The net reactance in ohms equals the reactance of the capacitor in ohms, step (*f*), minus the welder reactance:

$$\text{Net } X_T = X_C - X_W = 3.82 - 3.16 = 0.66 \text{ ohm} \qquad (l)$$

The net impedance in ohms is then the square root of the welder resistance squared plus the net reactance squared:

$$\text{Net } Z = \sqrt{(R_W)^2 + (\text{Net } X_T)^2} = \sqrt{(1.03)^2 + (0.66)^2} = 1.22 \text{ ohms} \qquad (m)$$

The line current under short-circuit conditions equals the effective line volts divided by the net impedance:

$$I_{L2} = \frac{E_L}{\text{Net } Z} = \frac{272}{1.22} = 223 \text{ amperes} \qquad (n)$$

Welder primary volts (short circuit) equals the line current (short circuit) times the welder impedance:

$$E_W = I_{L2} \times Z_W = 223 \times 3.33 = 743 \text{ volts} \qquad (o)$$

The welder kva (with capacitors) equals the welder primary voltage times the line current divided by 1000:

$$\text{Welder kva (short circuit)} = \frac{E_W \times I_{L2}}{1000} = \frac{743 \times 223}{1000} = 166 \text{ kva} \qquad (p)$$

The capacitor voltage (short circuit) equals line current times the capacitor reactance in ohms, step (*f*):

$$E_C \text{(short circuit)} = I_{L2} \times X_C = 223 \times 3.82 = 852 \text{ volts} \qquad (q)$$

For operation under these conditions with a 44 per cent duty cycle, a 575-volt, 60-cycle, continuous-rating capacitor was chosen. Having a reactance of 22 ohms each, the number of units required is as follows:

$$\text{Number of units} = \frac{\text{capacitor unit reactance}}{X_C} = \frac{22}{3.82} = 5.76 \qquad (r)$$

As stated in the text, six condenser units having a 575-volt rating and 22 ohms reactance each were used for the test.

The Mototrol and Its Applications

The adjustable-voltage system stands preeminent when accurate control of motor speed over a wide range is required. In many applications, especially in the smaller sizes, the disadvantages of additional rotating equipment and relatively heavy controls limit the use of motor-generator sets for linking d-c motors with the a-c power lines. Electronics comes forward with a scheme known as Mototrol that provides precise and wide-range speed control without the use of the usual motor-generator set, using light-weight controls that can be preset and can tie in automatically with intricate cyclic machine operations.

T. R. Lawson
Electronic Control Section,
Westinghouse Electric & Mfg. Company

The search for a satisfactory motor with exceptionally wide adjustable-speed range to operate from alternating current has continued ever since alternating current itself was first commercially used. Many solutions involving a-c motors—with electrical modification of the motor itself and modifications of the mechanical application of torque—have been proffered. In general, however, it has been the usual practice to use a suitable d-c motor, even though this involved individual a-c and d-c motor-generator sets. Even the standard d-c motor does not completely fulfill all requirements of extremely wide and stable speed range, good speed regulation, and smooth, automatic acceleration. The most satisfactory means of achieving these rigorous characteristics is the Mototrol, an electronically controlled d-c motor, taking power from a-c lines.

Electronic Control System

The heart of the Mototrol is the electronic power supply for the motor drive and its accompanying control system. With it a d-c motor supplied from an a-c line is able to perform the following functions without external regulators, belts, or gearing: wide, stepless speed range with ease of control; automatic speed regulation under varying loads; smooth, fast acceleration to any preset speed within rated limit; automatic current limitation; dynamic braking; and reversal without excessive current peaks.

The electronic system consists of a single-phase or polyphase, grid-controlled thyratron rectifier. The d-c voltage output of the thyratrons is applied to a regular shunt-wound d-c motor (Fig. 1) and can be varied from zero to rated motor voltage (or above) for d-c armature control. Smaller thyratron tubes provide direct current for the motor field. Speeds below the base or full-field speed of the motor are obtained by variation of armature voltage. To provide higher speeds, the field is weakened by reducing the field voltage. In short, the Mototrol accomplishes with electronic rectifiers the same function as the motor-generator set in the conventional adjustable-voltage system of obtaining a wide speed range from a d-c motor starting with a-c power.

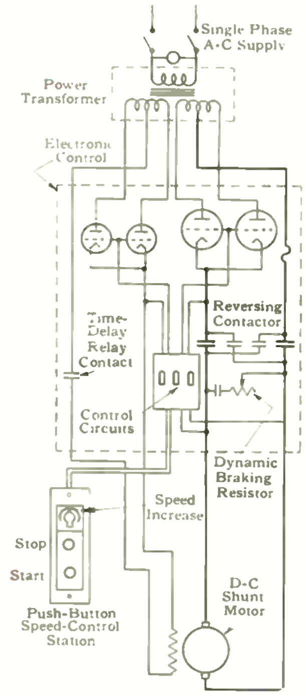
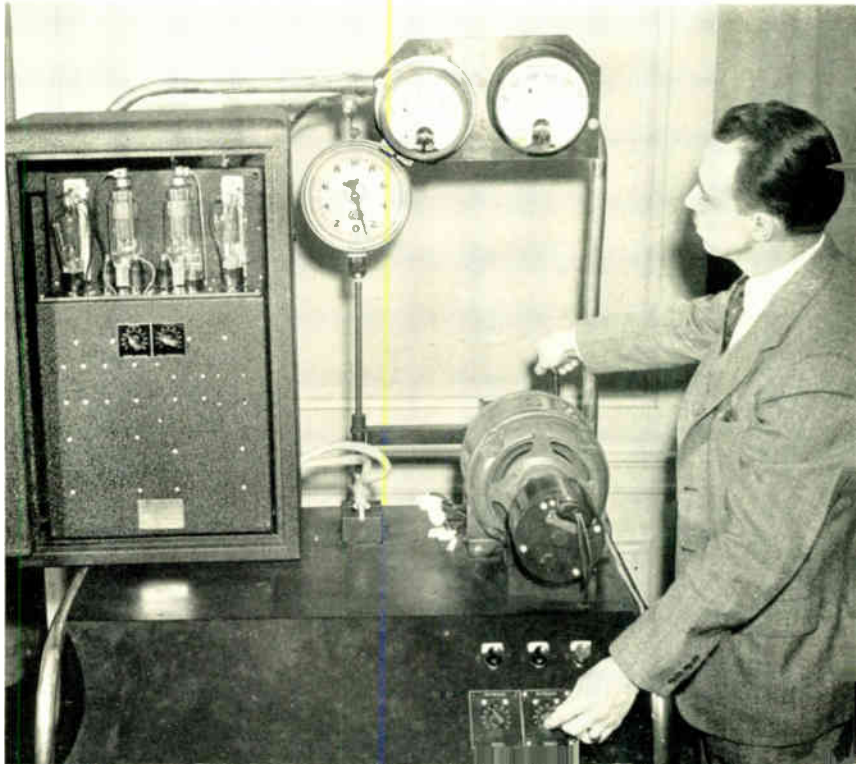


Fig. 1—*The method of controlling the armature and field voltage in the shunt motor by electronic means is shown in this wiring diagram of the component elements of the Mototrol.*

A complete a-c electronic motor-control drive is comprised of four pieces of apparatus: (1) the a-c power transformer, which has the proper number of phase windings and correct secondary voltage to supply the rectifier tubes, (2) the electronic-control cabinet proper including all necessary tubes, resistors, relays, capacitors, etc., (3) the operator's control station (push buttons and speed-adjustment dials), and (4) the d-c motor itself.

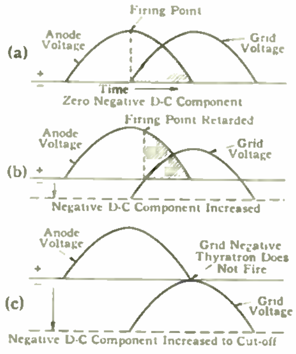
The power-transformer and electronic-control units together are considered as the power supply. The number of rectified phases depends upon the most economical arrangement of available thyratron tubes required to handle the motor rating. On Mototrols of two-horsepower rating and smaller, single-phase full-wave rectification is usually employed. For larger ones, some one of the several polyphase rectifier systems (two-phase full-wave, three-phase half-wave, six-phase, etc.) is employed.



The characteristics of the Mototrol are demonstrated on this test apparatus by the author. The open cabinet at the left contains the electronic tubes and the control circuits. All control is centered in forward, reverse, and stop buttons. Dials are provided for presetting the forward and reverse speeds.

Fig. 2—*An a-c voltage from a small grid transformer is properly phased and applied to the grid of the thyratron control tube.*

A variable negative d-c voltage is applied to the same grid. With a zero negative d-c component (a), the firing point is at the line-voltage peak and maximum voltage is delivered to the motor armature. When the d-c component is increased negatively (b), the firing point is retarded and the voltage delivered to the motor decreased. When the negative grid voltage is increased to cut-off (c), the thyratron does not fire and no voltage is supplied to the motor armature circuit.



How It Works

All of the speed-adjustment functions (exclusive of field weakening) whether manual or automatic, as well as the current limitation, are accomplished by adjusting the motor-armature voltage. This adjusting armature voltage is obtained by advancing or delaying the point on the a-c voltage wave at which the rectifier tubes fire, thus permitting only a part of each a-c voltage wave to be rectified. This firing point (the amount of phase shift of the control-grid voltage with respect to a-c line voltage) can be controlled in several ways. In the Mototrol, an a-c voltage from a small grid transformer is applied to the thyratron grid. This voltage, through the proper adjustment of capacitor and resistor components in the grid-transformer secondary circuit, lags the anode (or line) voltage by 90 degrees. In addition, a variable negative d-c voltage component is applied to the same grid. When the d-c voltage component is zero, the maximum advance in firing angle is obtained, as shown in Fig. 2, and therefore the maximum voltage is supplied to the motor armature. Also, when this d-c component is increased negatively, the firing angle is delayed until the voltage supplied to the armature is reduced to zero.

The a-c grid voltage is chosen 90 degrees out of phase with the a-c supply voltage because this arrangement permits maximum continuous control of the thyratron throughout the range from maximum advance of the firing point to cut-off.

If the a-c grid voltage lags the a-c supply less than 90 degrees, as shown in Fig. 3 (a), the control range of the tube would be only from point (a) to point (b), Fig. 3 (b), and not to cut-off. Also, if the a-c grid voltage lags the supply more than 90 degrees, as in (c) continuous control of the rectifier tube is obtained from maximum advance to cut-off, but in this case the range control would be less than 90 degrees.

Operating Characteristics

Starting—The control is arranged so that the motor is always started with full field regardless of the setting of the speed-control potentiometer. If the desired motor speed is above the base speed (achieved by weakening the field), that portion of the control that weakens the field does not become effective until the motor reaches base speed. To start the motor with weakened field would result in heavy armature currents. After the base speed is reached, the field is weakened until the preset speed is secured.

Current Limitation—Fast, smooth acceleration is automatically obtained through an adjustable current-limiting device, which also controls the negative d-c grid-voltage component of the rectifier tubes when a preset armature current is reached. Thus, the voltage output of the rectifier tubes is always such that the preset current limit is not exceeded. This limitation provides smooth operation of the driven machine through the elimination of shock loads in starting.

Dynamic Braking—The motor is quickly stopped by means of a dynamic-braking resistor inserted across the motor armature. This is done by the closing of back contacts on the motor-armature contactor when the motor-armature contacts are opened. The amount of dynamic-braking resistance is adjustable.

Manual Speed Adjustment—Manual speed adjustments or settings are obtained by a small potentiometer. Changing this resistance alters the negative d-c component to the thyratron grids and thereby varies the rectified voltage to the motor armature from maximum to cut-off. The control can be preset for any desired speed or the speed can be adjusted while the motor is running.

Automatic Speed Regulating—Through other small control tubes and circuits the negative d-c voltage component on the rectifier-tube grids is increased or decreased automatically, as the motor speed changes from the preselected speed, in much the same manner as described above for manual adjustment. The entire system is so balanced that the rectifier tubes furnish an output voltage to the motor armature at the correct value to maintain the preset speed under conditions of varying loads.

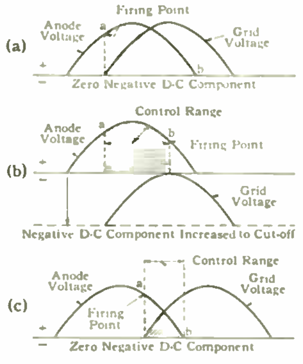
Reversing and Inching—Reversing contactors can be included in the control without increasing the size of control cabinet. Proper relays for inch-forward or inch-reverse service can also be provided and suitable push buttons added to the control station. Inching or reversing can be done at any preset speeds within the speed range of the unit or, if preferred, can be done at one fixed speed. No speed-control dial for inching speed need then be used.

Overloads—On some applications requiring frequent reversing service, such as high-speed planers or shapers, the average motor current may be much higher than the motor current at constant speed. If this overcurrent lasts for considerable periods, as during frequent reversals, the rectifier (power supply) tubes may be seriously overloaded if the Mototrol application is made on the standard basis. The thyratron tubes to supply d-c power to the motor are chosen to handle the full-load current of the motor continuously. However, they have peak-current ratings several times the average-current rating and can, therefore,

(continued on p. 42)

Fig. 3—*If the a-c grid voltage lags the anode voltage by other than 90 degrees, maximum continuous control is not obtained.*

If the a-c grid voltage lags less than this, as in (a), with zero negative d-c component, the firing point is at some point *a* which is less than the peak line voltage. By increasing the d-c negative component to cut-off, (b), the firing point cannot extend beyond the point *b*. Should the a-c grid voltage lag more than 90 degrees (c), the control range of the line voltage is restricted as shown.



Examples of Mototrol Applications

1—A 5-hp drive over a speed range of 2300 to 115 rpm is desired. Usually the horsepower and speed are the first items known. In addition to horsepower, speed, voltage, and frequency of supply, the following information is needed:

(a)—Constant torque range?

(b)—Constant horsepower desired over what range?

(c)—Open or enclosed motor, ball or sleeve bearing, etc., as normally furnished for d-c motor.

Assume (a) constant torque over a speed range of 1750/115 rpm, (b) constant horsepower from 1750 to 2300 rpm, and (c) open, sleeve, etc.

As constant torque is required between 1750 and 115 rpm a motor with a base speed of 1750 rpm is chosen for this drive because constant torque can be had from the base speed down by means of armature control. If a base speed of 2300 rpm at 5 hp were chosen, the frame size would be smaller than for a base speed of 1750 rpm but the motor would not develop 5 hp at 1750 rpm by armature control.

This is shown in rating curve, Fig. 4. If 2300 rpm is base speed, 1750 is about 76 per cent of base speed. From the dotted horsepower curve, at 76 per cent base speed by armature control, we get 76 per cent of rated horsepower or 76 per cent of 5 hp is 3.8 at 1750 rpm. This does not meet the requirements.

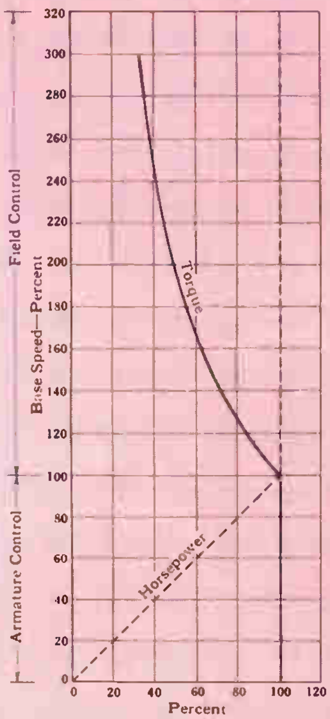


Fig. 4—*With armature control below base speed, torque remains constant while horsepower decreases directly as the speed. With field control above base speed, horsepower remains constant whereas the torque decreases.*

However, if 1750 rpm is used as base speed, constant horsepower can be obtained from 1750 to 2300 rpm by field control, or field weakening. The 2300 rpm is about 132 per cent of base speed and from the dotted curve Fig. 4, standard drives will deliver constant horsepower from base speed on up by field control. At the same time, however, constant torque is not obtained at speeds above base speed resulting from field weakening. This is shown by the solid line curve, in Fig. 4; nor is it needed to satisfy the requirements of this particular example.

2—Assume the same conditions and requirements as in example 1, except that constant torque is desired over the entire speed range of 2300/115 rpm. Then no field control is needed because the speed range is within the 20 to 1 that can be obtained by armature control without field control. Again, from curve, Fig. 4, constant torque can be obtained from base speed down by armature control. Because Mototrols of a given size are less expensive if no field control is required, a 2300-rpm base speed 5-hp motor is chosen equipped with armature control only.

3—If constant torque is required from 1150 rpm to 115 rpm and constant hp from 1150 to 2300 rpm, a base speed of 1150 rpm would be selected. Constant torque from 1150 to 115 rpm (10/1 range) is obtainable by armature control (See solid line curve, Fig. 4) and constant hp is obtained from 1150 to 2300 rpm (2 to 1 range) through field control (See dotted curve, Fig. 4).

Proper selection of the base speed of a motor when constant horsepower is required over a wide speed range can keep the size and cost of the power supply to a minimum, as well as the motor size and cost.

The load or armature current is practically directly proportional to the motor torque; this means that on a constant-torque drive the motor takes approximately constant current from its power supply. Standard controls for a given horsepower, say 5 hp, are designed to handle the full-load current of a 5-hp motor. The full-load current of a 5-hp motor does not materially change for various base speeds, and the power supply for that given horsepower is not affected when different base speeds of the same horsepower are selected, provided only constant torque, i.e., constant current, is required over the range of armature speed control (from base to minimum) and constant horsepower from base speed to maximum speed.

If, however, constant horsepower is required from base speed down to some lower speed, it will be seen from solid line curve, Fig. 5, that the torque must increase as the speed decreases. Motor current varies with the torque; thus, if the motor torque increases, a greater load is imposed on the power supply. Or, on constant horsepower drives below base speeds the size of control or power supply must be increased.

4—A 3-hp drive is needed with speed range from 1750 to 175 rpm and constant horsepower over the entire speed range with safe temperature, etc. What motor base speed would be best, and what size of power supply would be required to satisfy these conditions?

(a)—Because it has the smallest frame, assume a motor with a base speed of 1750 rpm. The Mototrol provides the required speed range below base speed by armature control. By armature control the standard motor and power supply are designed to supply only constant torque (Fig. 4). At 175 rpm the standard 3-hp Mototrol, with base speed of 1750 rpm, delivers 0.3 hp instead of the required 3 hp.

(b)—The motor full-load current does not materially change if the motor is designed for different base speeds. Then why not use a base speed of 175 rpm? This will permit the use of a 3-hp power supply, too. But how can the speed be increased from 175 rpm to 1750? Normally, the Mototrol uses field control, giving constant horsepower above base speed. However, 3 to 1, or possibly 4 to 1 in special cases, is about the maximum adjustment possible by field control or 175 rpm × 3 (or 4) = 525 or 700 rpm maximum.

(c)—The best condition is found between (a) and (b). On a constant-hp drive over the entire range such as this one, start at the highest required speed and see what part of the speed range can be accomplished by field control. Field control gives constant horsepower within the three-to-one range above base speed of the motor. Here 1750/3 rpm = 583 rpm. Using this figure as the base speed, the rest of range down to 175 can be obtained by armature control. It is true the 3-hp motor frame at 583-rpm base speed, designed to give constant horsepower by armature control down to 175 rpm, will be about as large as a 10-hp motor at a base speed of 583 rpm because at 3 hp and 583 rpm, torque equals 27.01 ft lb, and at 3 hp, 175 rpm, torque equals 90 ft lb. As the torque has gone up 3⅓ times the power supply must be equivalent to a 10-hp Mototrol.

carry overloads up to 20 per cent of motor rating for short periods required during starting and normal acceleration.

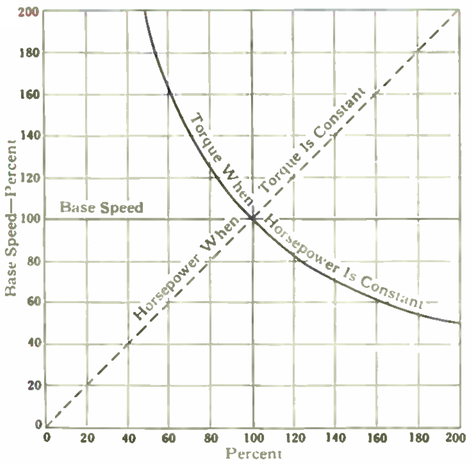


Fig. 5—*Torque-horsepower curves showing that with constant horsepower and reduced speed, torque increases. Also, with a constant-torque component and reduced speed, the horsepower component decreases directly as the speed.*

However, a tube is damaged by overheating (on overloads as heavy as 200 per cent) much quicker than the motor itself. Hence, the Mototrol should not be used for continuous overloads or even for overloads of one half hour without careful check.

To guard against too great an overload on the tubes and also to obtain desirable accelerating torque adjustment, the current-limiting device is standard on all units. The motor current is limited by proper control of the thyratron grids. The range of current adjustment is from less than the full-load motor current to double the full-load current. On standard drives, this is set for a maximum of 200 per cent of rated motor current. In other words, it provides a starting torque of 200 per cent and a pull-out torque of 150 or 160 per cent. Aside from the protective feature, this current-limiting device permits adjustment of the maximum starting torque of the motor. The machine and its accessories are protected by the lessened starting shock load and smoother overall operation.

In addition to this overload protective feature, the standard Mototrol is equipped with regular linestarter overload and low-voltage protection, plus the inclusion of fuses in the armature circuit.

Overall Efficiency—Where single-phase rectification is used the overall efficiency from a-c line to d-c motor output is 45 per cent or more. On units where polyphase rectification is used, the overall efficiency is 60 per cent or more. These efficiencies may seem low, but they are comparable to the overall efficiency of an adjustable-voltage system using a motor-generator set. Considering the a-c to d-c motor-generator set, direct-connected exciters, field rheostats, and d-c motor, the efficiency is of the order of 50 per cent. Also, it should be recognized that where the advantages and features of a Mototrol are desired, exceptional efficiency is usually secondary to functional performance.

Principles of Application

The proper application of a Mototrol drive is no more complicated than the application of an ordinary d-c motor where adjustable armature and field voltages are used. The anode (power) transformers and electronic-control cabinet can be considered as the source of adjustable-voltage d-c power (a motor-generator set would be used for this purpose on standard adjustable-voltage drives) for the shunt-wound d-c motor and should not be considered as complicating the actual application of the Mototrol.

A brief discussion of constant-torque and constant-horsepower drives will clarify the requirements for the application of these drives. Motor horsepower, in terms of speed and torque, can be expressed as follows:

$$\text{Torque (ft-lb)} = \frac{\text{hp} \times 5250}{\text{rpm}}; \text{ or hp} = \frac{\text{torque} \times \text{rpm}}{5250}$$

If the horsepower load is constant and the speed is reduced, it is obvious from the above equation that torque has increased. If the torque is constant and the speed is reduced, the horsepower required is decreased in direct proportion to the speed. The curves in Fig. 5 show these two conditions.

Unless the application dictates otherwise, the frame size of the d-c motors used is selected to furnish constant torque, the required constant current over that speed range being controlled by adjusting the armature voltage. Over this range, the field voltage is held constant. This is usually from the base speed of motor to its minimum operating speed.

The standard power-supply unit is designed to supply safely a continuous, constant current equal to the rated full-load motor current at base speed. It provides smooth, stepless control of motor speed from just a few revolutions per minute (enough to keep the motor rotating uniformly) up to base speed of the motor. However, at extremely low speeds with constant-torque load, the motor temperature will exceed the rise of 40 degrees C allowable at base speed but will still stay within safe operating temperatures.

On motors with base speeds of 500 rpm and higher, speeds from 1/20 to full base speed are obtained with standard units by armature-voltage control only (constant field voltage). A speed range of more than 20 to 1 is easily obtained by armature-controlled motors of higher base speed, but the characteristics of the particular motor in question should be checked so that safe operating conditions are not exceeded.

Where speeds higher than the base speed of the motor are required, the standard control or power supply unit is so designed that the motor field can be weakened after an armature voltage corresponding to base speed has been reached. In this case all speed adjustment over the entire range of both armature and field control is done on one dial of the control station. Approximately half of the dial circumference controls the range from zero to base speed and the other half provides field weakening and therefore provides speeds from base speed to maximum rated speed.

Over the speed range from base speed to maximum speed, the motor develops constant horsepower. This means that the torque characteristic of the motor, at speeds higher than base speed, drops off almost in reverse proportion to the increase in speed. (See equation at left.)

A range of three to one above base speed can be obtained by field weakening if the high speeds thus obtained are within the electrical and mechanical limitation of the motor. The operating range curves of a standard Mototrol drive are shown in Fig. 4.

While the field of application of the motor-generator set and the Mototrol are apparently similar, each has its place where it is economically or functionally the better. A motor-generator set is generally cheaper on less involved controls. Where close control over a wide speed range is necessary, Mototrol is cheaper. The Mototrol also provides closer speed adjustment than standard adjustable-voltage motor-generator controls. By eliminating one rotating element, the generator, overall vibration is minimized and substantially less floor space is required.

The Fame and Fortune of Magnesium*

Magnesium is the number one glamour metal of the day, but it has required two world wars to bring it to a place of importance among the major metals. Now that war's insatiable demands for incendiaries and for airplanes have resulted in a U. S. production capacity of about three hundred thousand tons annually, and with the enormous improvement in magnesium technology that is resulting, the many alloys of magnesium—the lightest of all metals—will be important as postwar structural materials.

Leaders, they say, are developed by crises. Magnesium is like that. In the last war magnesium, previously almost unknown, gave a hint to its future possibilities. But it was too young; it needed much more development before it could take a prominent place in the family of metals. So interest in it lagged until this second war emergency appeared. Because this war is fought so much with planes and with bombs, magnesium has been brought suddenly to the fore and has become co-leader with aluminum among the light metals.

As with anything that skyrockets to fame, much publicity has come to magnesium. Some of it is favorable, some unfavorable, some true, much untrue. Rising swiftly as it has through a welter of economic influences and the exigencies of war, magnesium has become surrounded with uncertainties, disagreements, misunderstandings—even among those who live with it. This, too, is natural, but through it all there is the unmistakable evidence that magnesium has earned a place of deserved leadership in the world of materials.

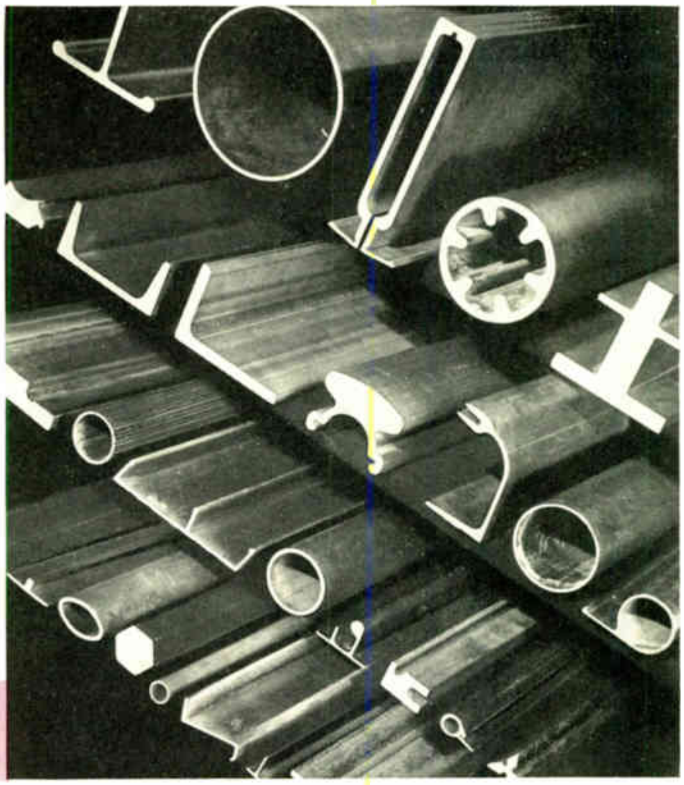
Magnesium experienced a flurry of activity during the last war. Some five companies in the United States went into business of recovering it from ores. Production in 1918 was about 140 tons, which is less than a single day's output now. This trivial quantity was used in magnesium flares and other pyrotechnics of warfare.

Came the armistice, and magnesium production in the United States grew only slowly. By 1928, all but one of the five producers had turned to other, more promising matters. Only the Dow Chemical Company continued to manufacture magnesium, although the American Magnesium Company, one of the original five producers, continued to cast magnesium and now is one of the world's largest producers of magnesium castings. Even as late as 1939 Dow was the only United States producer of magnesium. To Dow must go a great deal of credit. Dow had the foresight, the persistence, and the willingness to spend millions over a lean and unpromising period of nearly 20 years to simplify magnesium production, to reduce its cost, and to help develop it into a practical engineering material. Without all this invaluable production and development work our light-metals program at the outset of the war would have been in an even worse predicament than it was.

Magnesium and aluminum are the twins of the light-metal family. Like many twins, they are similar in many ways, but are far different in others. They look much alike, so much so, in fact, that the average person cannot distinguish between them. On the other hand, aluminum is produced by one process; magnesium by several. Aluminum is attacked by alkalies but resists most acids; magnesium is resistant to alkalies but is attacked by most acids. Aluminum and magnesium are at the same time competitive and mutually dependent. While their lightness in weight makes them competitors for many structural purposes, each is an important alloying constituent of the other. In price, at present, they are comparable. Aluminum sells for 15 cents per pound, while magnesium costs about 20.5 cents per pound. On a volume basis magnesium costs less than aluminum (in the ratio of 23 to 26) because lightness in weight is magnesium's outstanding physical characteristic. Magnesium is the lightest of all structural metals, being one third lighter than aluminum. The specific gravity of magnesium is only 1.74, and a cubic foot of it weighs but 112 pounds, which compares with 175 for aluminum, 450 for cast iron, and 706 for lead.

Magnesium as a Material

Magnesium presents the anomaly of being an old metal, (it was first isolated more than a hundred years ago) but the technology of its use as compared with other metals is in its infancy. Aluminum, by comparison, is old and thoroughly



Magnesium extrudes well, if done hot, and is now available in a wide variety of shapes. (Photo courtesy American Magnesium Co.)

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*In the gathering of material and checking of manuscripts on this and the following article on magnesium, invaluable assistance was rendered by technicians and executives of many organizations, among whom are: The Dow Chemical Co., Kaiser Co., Electro Metallurgical Co., Basic Magnesium, Inc., American Magnesium Co., Aluminum Company of America, War Production Board, and Bureau of Mines, Pullman, Wn.

established. Thorough investigation of the properties of aluminum, its alloys, and their fabrication, has been in progress for 30 years. Magnesium, on the other hand, is not so well known in this country. For one reason or another relatively few design engineers have taken any interest in it as a structural material. This accounts for the many obstacles that have lain in the way of its use, of the wide difference of opinion between metallurgists in aircraft plants but a few miles apart. In discussing magnesium now and in attempting to evaluate its future, the fact that its technology is still so young must be kept in mind. As an example, the tensile strength of the best cast or wrought magnesium alloys available today is 50 per cent higher than the best of 20 years ago.

Magnesium has three major kinds of uses—as a chemical agent, in pyrotechnics, and as a structural material. Magnesium's strong affinity for oxygen is put to good use in many non-ferrous metallurgical processes as a deoxidizer and scavenger. Pure magnesium, for example, helps remove bismuth from lead. Magnesium is also used in many chemical processes as a catalyst in the formation of complex organic chemical compounds.

The wartime demand for magnesium to be used in flares, tracer bullets, incendiary bombs is almost insatiable. Magnesium, when the conditions of surface area and temperature are right, burns with an intense white light and with the release of enormous quantities of heat. The temperature created by a burning magnesium bomb is of the order of 3000 degrees F.

The big peacetime future of magnesium is as a structural material. Preponderant reason for this is its light weight. Its other physical characteristics, however, are equally important for their bearing on the place magnesium is to take in the family of materials. Magnesium melts at 1204 degrees F; aluminum at 1220; lead at 620; iron at 2800. Its thermal conductivity is only 44.4 per cent of the International Annealed Copper Standard, or 79 per cent of that of aluminum. The electrical conductivity of magnesium is low, only 38.6 per cent of copper standard and 65 per cent of aluminum on a volume basis. For the same weight magnesium has nearly twice the electrical resistance (197.7 per cent) of copper and one fourth more (128.6 per cent) than that of aluminum.

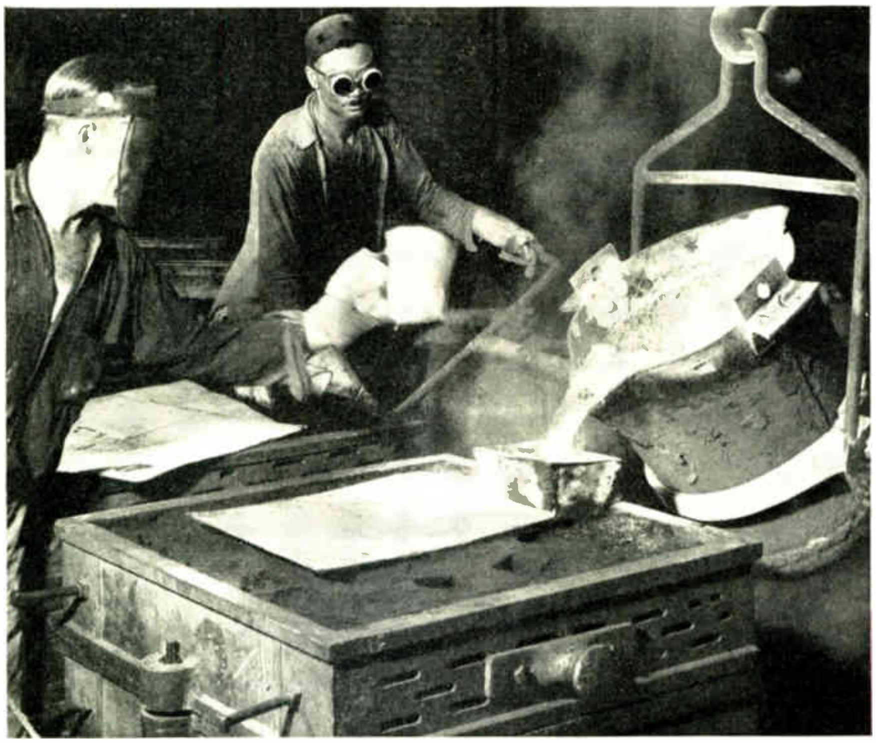
One limitation of magnesium is the adverse effects of notches or sharp corners on its strength. All metals are notch sensitive to some degree, and with magnesium the effect is especially pronounced. Much research work is under way to determine the cause and to eliminate this shortcoming with magnesium alloys. The notch sensitivity of some magnesium alloys has been somewhat improved by heat treatment.

Magnesium is not suitable in a pure form as a structural material; it always appears in an alloy form, of which there are already many thousands. By 1937 patents covering about 3000 compositions had been granted and many more have been issued since. Aluminum is used as a hardener in magnesium castings and to assist in grain refinement. The castability of magnesium-aluminum alloys rises with increasing aluminum content up to about 10 per cent aluminum. Zinc also improves physical properties of magnesium-aluminum alloys, but it is usually limited to not more than three per cent of its total. Small amounts of manganese (½ to 2½ per cent) have a beneficial effect on the corrosion resistance of magnesium and magnesium alloys. One theory of this improvement is that this is due to a purifying effect.

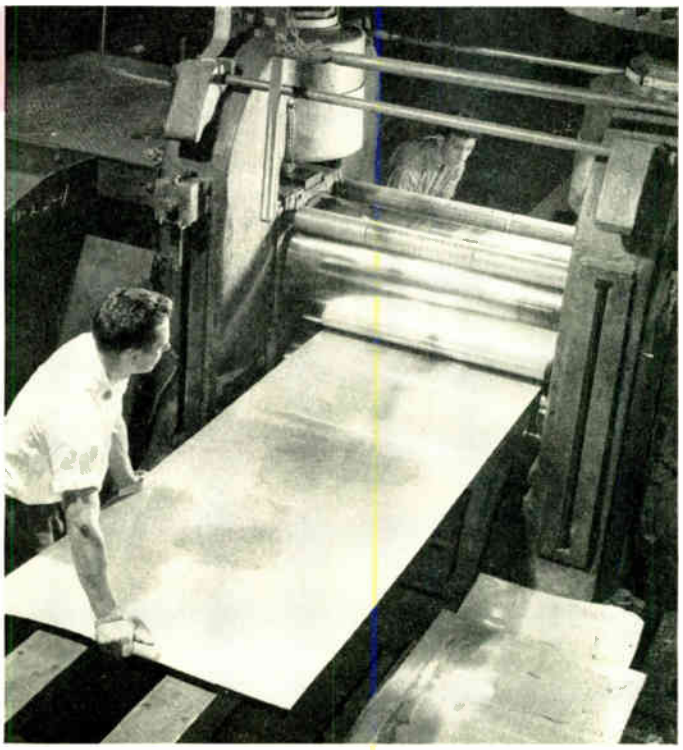
Magnesium alloys are strong. As shown in table I, the ratios of strength to weight of magnesium alloys are equal or superior when determined for tension, yield, and fatigue to aluminum alloy, low-carbon steel, or grey cast iron. If the high-strength alloys of magnesium and aluminum are considered, the yield-strength range would be 30 000 to 50 000 for aluminum and 25 000 to 40 000 for magnesium. Because aluminum is half again as heavy, on the basis of equal weights, magnesium alloys are as good as, and perhaps better than, alloys of aluminum.

Magnesium alloys make superb castings. In fact, about 85 per cent of the magnesium used as a structural material is used in the form of castings. Magnesium alloys require no radically different technique for sand, permanent-mold, or die casting. The extraordinarily good machinability of magnesium-alloy castings—not exceeded by any other metal—is one of their outstanding features. The fire risk is small, provided the cutting tool is kept sharp and heat is not allowed to accumulate. Feeders and risers of magnesium castings must be higher than with other metals. Also, the loss of magnesium resulting from oxidation during melting totals about three per cent even with care, which corresponds to about one-half to one per cent for aluminum.

Magnesium extrudes well, but at necessarily slower rates than other metals. Extruding and forming magnesium alloys are best done hot. Standard bars, rods, and a wide variety of structure and special shapes are available. Magnesium alloys can be forged, preferably with press equipment. The rate at which magnesium can be deformed without injury to its grain structure is much lower than aluminum or steel. As a consequence the technique of wrought magnesium alloys has lagged. Until recently, work in this direction has been severely limited by the lack of



Most structural magnesium goes into castings, which do not require much change in usual foundry practices. **(*American Mag. photo.*)**



Magnesium can be hot rolled into sheets, although relatively little of this has been done to date. (American Magnesium Company photo.)

even small quantities of the metal that could be spared from more urgent war demands for experimental purposes. It is to be expected, however, that satisfactory methods will be developed for working magnesium under the hammer.

Relatively little work has been done in this country with magnesium sheet, although German planes with wing surfaces of magnesium have been shot down. Magnesium sheet can be, and in some cases is being rolled on conventional aluminum rolling mills (at reduced rolling speeds because, again, of the critical limit to the rate of magnesium deformation) and is best done hot. The handicap to the use of magnesium sheet has been its tendency to corrode, particularly in the presence of salts. In 1924 a magnesium casting, unless carefully protected by paint, would be attacked seriously when exposed to tap water for only a few hours. Much improvement has been made, and although some engineers are still pessimistic there is evidence that much of this weakness will be mitigated or eliminated by the use of anodizing or other surface protective processes, or by the application of platings or coatings. Corrosion resistance has been greatly increased by purification from traces of iron and nickel. Some enthusiasts predict, with some foundation, that in airplanes of the future not only will most of the engine and other parts be made of magnesium, but also the fuselage and wings will be comprised of magnesium sheet.

Assuming improvement in corrosion resistance and protective treatments, magnesium offers striking advantages for large surfaces, not so much to save weight as to increase rigidity. For equal weight and stiffness, a sheet made of magnesium alloy is much thicker than if made of any other metal. Because rigidity increases as the cube of the thickness a magnesium panel is two and one half times as rigid as one made of the same weight of aluminum. Thus a magnesium sheet has a high resistance to buckling and bending. Greater rigidity lessens—or perhaps even eliminates—the amount of bracing required and reduces the time, labor, and expense in fabrication. This may become a big factor in airplane manufacture.

Also important in plane fabrication is the weldability of magnesium. A process for the welding of magnesium in a protective atmosphere of helium has been developed by Northrop Aircraft, Inc. Much magnesium welding is being done with safety and with excellent results by gas, arc, and electric-resistance methods.

Magnesium has already been applied to sufficient uses to give it place among major engineering materials, even if metallurgists should not be successful in solving any of its remaining problems—an obviously unwise assumption. In the last analysis, the extent of its use will be determined by its ultimate cost.

TABLE I—COMPARATIVE STRENGTHS OF MAGNESIUM AND OTHER ALLOYS

	Tensile Strength		Yield Strength		Endurance Limit	
	Actual†	Ratio*	Actual†	Ratio*	Actual†	Ratio*
Magnesium Alloy-wrought	45 000	24 800	33 000	18 900	18 000	10 000
Magnesium-Alloy Sand-Castings Heat-treated, Aged	35 000	19 400	18 000	10 000	11 000	6 100
Aluminum Alloy-wrought	62 000	21 000	40 000	14 400	15 000	5 400
Structural Steel	60 000	7 700	38 000	4 900	33 000	4 300
Gray Cast Iron	30 000	4 300	25 000	3 600	15 000	2 100

† These values are typical. In the case of each metal the actual values extend over quite a range, both higher and lower.

* Strength-weight ratio is the actual strength divided by the specific gravity of the metal.

Cost of Magnesium

Its cost history has duplicated that of other materials that once were rare but are now produced in large quantities. In 1915 magnesium cost $5.00 a pound, but the efforts of the Dow Chemical and the four other companies making magnesium during World War I brought the price in 1921 to $1.30. During the twenties and thirties the price dropped steadily; in 1925 a pound of magnesium sold for 86 cents; in 1930, 48 cents; 1939, 27 cents. The price has now leveled off at 20.5 cents per pound, where it will likely remain for the duration.

With our enormous war-born production capacity, what the price will be when and if normal economics resumes control remains to be seen. The cost can reasonably be expected to drop some but probably not much. Which of the several processes and many plants (see the article beginning on p. 46) will hold up in a freely competitive era is a matter of conjecture. Each process has its ardent supporter who can "prove" that his process and his plant is a low-cost, if not the lowest cost, producer. Obviously they can't all be right. Any honest appraisal now is out of the question because the magnesium-production figure is at present a tangled web of private capital, government subsidy, hurriedly built (and sometimes wastefully built and inefficient) plants, and interrelationships with other processes and products.

However, a large element of the cost of magnesium is bound to be the charges for electric power or for fuels. In some processes electric power is an integral part of the reduction. The electrolytic reduction of magnesium chloride, as done by Dow or by Basic requires about 7.5 to 9 kilowatt-hours per pound of magnesium produced. For the Permanente process (carbothermic) a figure of eight kilowatt-hours per pound has been given. The ferrosilicon process requires in the arc furnaces about five kilowatt-hours to

(*Continued on page 56*)

Magnesium Sources and Manufacture

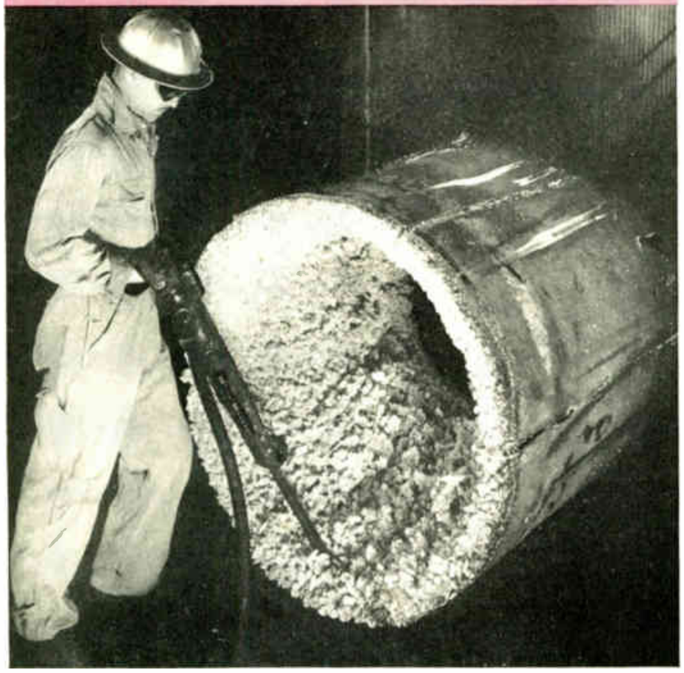
No nation can ever monopolize the sources of magnesium. Among metals it is surpassed in prevalence only by iron and aluminum. It occurs in many ores, profusely scattered in large quantities over the earth. No nation that has a seacoast can be denied a supply of magnesium. Although the magnesium concentration in sea water is but 0.13 per cent, each cubic mile of the ocean contains four and a half million tons; each 100 gallons contains about a pound. About a dozen plants using a variety of processes are producing magnesium in large quantities from several different ores, from brines, and from sea water.

OUR magnesium problems are not concerned with raw-material supply. The task is to induce magnesium to part company with its chemical pals. Magnesium is an extremely friendly element, which is the reason it is never found uncombined in nature. The main problem, and many factors of its cost, lies in its strong chemical ties because a great deal of energy is required for its isolation.

Whereas aluminum is produced at present by a single, universal process from a single ore, i.e., electrolysis, in a cryolite bath of aluminum oxide obtained from bauxite, magnesium is produced by a variety of methods from several of its native forms. No two magnesium plants are alike. Even those using the same general scheme of preparation differ materially both as to important aspects of the chemistry involved and as to the mechanics of the plant. Also, whereas there are no by-products in connection with aluminum manufacture, important by-products are associated with magnesium production, or the process is intimately associated with some other manufacturing process. In some plants the production of magnesium is so contingent on the by-products or associated processes that it would be otherwise too costly.

In general, there are two basic ways now used to produce magnesium. One is by electrolysis of fused magnesium chloride. The other is by thermal reduction of the oxide of magnesium, of which there are two processes, one using carbon as the reducing agent, the other employing silicon.

In the carbothermic process, magnesium is recovered as a crust of beautiful crystals. (Photo courtesy Kaiser Co.)



Magnesium from the Sea, via Electricity

Most publicized and fancy exciting is the recovery of magnesium from the salt of the ocean. Two plants, at Freeport and adjacent Velasco, Texas, operated by Dow, are the largest and best known of this type, but there have been others.

Extraction of magnesium from sea water requires, of course, much more than a convenient strip of beach. It is the possession of the right combination of many factors that makes the Texas site almost ideal. It is so situated that the waste water can be discharged miles from the intake, preventing dilution. The Dow process calls for lime, and to this end oysters of millenniums ago fortunately contribute. In Galveston Bay, only 50 miles to the east, are almost unlimited quantities of oyster shells to be had for the dredging. The nearby petroleum field provides inexpensive fuel; a part of the electric power is purchased from local utilities; the remainder is developed from waste heat.

Oyster shells by the barge load are washed and roasted in an ordinary rotary kiln to produce lime.

$$CaCO_3 + \text{heat} \longrightarrow CaO + CO_2$$

The lime is slacked with water to form a hydroxide

$$CaO + H_2O \longrightarrow Ca(OH)_2$$

which is mixed in huge Dorr settling tanks with raw sea water pumped in from the Gulf. The chlorine and the calcium enter into partnership, leaving the magnesium to join with the hydroxide.

$$MgCl_2 + Ca(OH)_2 \longrightarrow CaCl_2 + Mg(OH)_2$$

The calcium chloride is a worthless liquid that returns to the sea with the waste water. The magnesium hydroxide, an almost insoluble precipitate, is scraped off the bottom of the settling tanks as a dazzling white sludge. Magnesium hydrate sludge is filtered to remove additional $CaCl_2$ solution, and the magnesium hydrate is then neutralized with hydrochloric acid.

Meanwhile, hydrochloric acid has been prepared by burning natural gas to which has been added chlorine from the electrolytic cells. The acid is added to the magnesium hydrate in rubber-lined tanks to form the desired magnesium chloride.

$$Mg(OH)_2 + 2HCl \longrightarrow MgCl_2 + 2H_2O$$

The bulk of the water in this mixture is extracted by passing the milk-like mixture through large canvas filters. Other successive steps in the drying of the magnesium chloride include passage in series through a direct-fired evaporator, shelf dryers, and finally a rotary kiln. Even then the chloride is not completely dry. However, in this form—a whitish, granular substance—it is suitable for charging into the and water vapor which are later reused in converting the hydroxide to the chloride.

Essentially, this is the same process as used at Midland, Michigan, where the Dow Chemical Company spent many years developing the electrolytic process. This Michigan plant was, for many years, the only producer of magnesium in the United States. Instead of sea water and oyster shells as raw materials, the Midland plant uses lime prepared in the usual manner, and brine pumped out of natural salt wells 1100 feet deep. The magnesium concentration of this brine is about five times greater than in sea water.

Electrolytic reduction of magnesium chloride has many variations worked out by individual companies either to suit other processes in which magnesium is only incidental, an important by-product, or to suit some particular source of the metal. The Diamond Alkali Company has a plant in Ohio using the Dow type of cell to produce magnesium from waste liquor and from calcined dolomite. The Mathieson Alkali Works has developed a different type of cell. In it, concentrated chlorine gas—a critically valuable material—is produced from the magnesium cell as a by-product instead of dilute hydrochloric acid and chlorine as in the Dow cell. The Union Potash Company at its Carlsbad, New Mexico, potash-producing plant has a substantial quantity of surplus liquor, carrying 16 to 18 per cent magnesium salts. This waste liquor is converted to magnesium chloride for use in this company's new plant in Texas in conjunction with dolomite mined near by.

Magnesium from the Desert

Before the war the English had an electrolytic plant, Magnesium Elektron, Limited, in operation based on a process developed in Germany, and using Grecian magnesite. When the demand in England for magnesium—particularly for incendiaries—became so great, it was decided to bring this process to the United States. This resulted in the giant plant of Basic Magnesium, Inc., located at Las Vegas, Nevada, which is separated from the Boulder Dam power house by a few miles of desert and barren hills.

In this plant, as in the Dow plants, magnesium is obtained by electrolytic reduction of magnesium chloride. However, the Basic process arrives at the chloride for the electrolytic cells by a totally different route—from ore instead of sea water. At Gabbs, Nevada, three hundred miles from Las Vegas, is a large deposit of magnesite ($MgCO_3$). This is concentrated at the ore site by conventional mining methods (flotation), and then roasted to form magnesia (MgO). This is trucked to Las Vegas where it is mixed with pulverized Utah coal. The mixture in dust form is moistened with magnesium chloride, which is made by neutralizing hydrochloric acid with magnesia, and pressed into small pellets for convenient handling.

The chlorine gas necessary for producing magnesium chloride is manufactured from salt brought in from the beds of prehistoric salt lakes on the desert of California not far from Death Valley. Chlorine is liberated in electrolytic cells with low-cost power from Boulder. Sodium-hydroxide, the other cell product, is a valuable by-product.

$$NaCl+H_2O \longrightarrow Cl+Na(OH)_2$$

The chlorine gas and the pellets meet in an electric-arc furnace and result in the dry (anhydrous) molten magnesium chloride required for the electrolytic cells.

$$4Cl+C+2MgO+heat \longrightarrow 2MgCl_2+CO_2$$

From these cells, as at Freeport, molten magnesium is scooped off at intervals. Chlorine is continuously liberated for reuse in the cycle. Because the magnesium chloride is completely dry the Basic process is performed in a closed circuit.

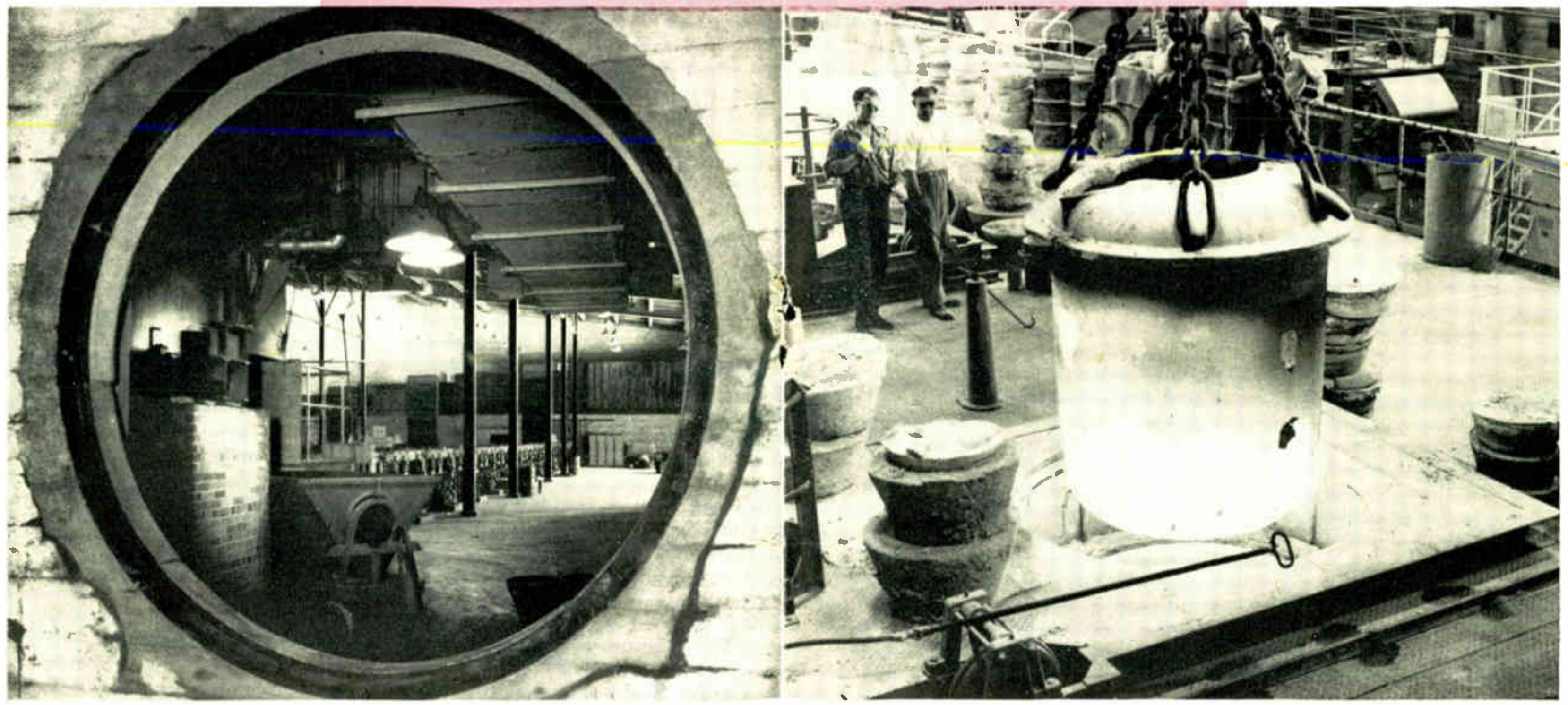
Magnesium from Ore, via Heat

Metallurgists have long been determined to find a method of obtaining magnesium directly from ore by thermal means. The oxide of magnesium (magnesia, MgO) can be obtained fairly readily from either of two ores, magnesite ($MgCO_3$) or dolomite ($MgCO_3 \cdot CaCO_3$), both available in good quantity and quality. The reduction of this oxide requires some element that is more attractive at a high temperature to oxygen than is magnesium. Fundamentally, the problem is to perform this simple reaction.

$$MgO+X \rightleftarrows Mg+XO$$

This reaction proceeds to the right only by the addition of considerable heat. Unless the temperature is maintained or unless the right-hand products are in some way separated, the reaction returns to the left, and with violence.

In some processes magnesium solidifies as beautiful shiny crystals. (Photo by National Research Corp.) Lower left is view of electrolytic-cell room for preparation of chlorine in Basic process. Lower right are magnesium "cheeses" and a two-ton alloying furnace at Basic Magnesium.



Of several possible reducing agents that can be used for X in the equation preceding, two—carbon and ferrosilicon—are the only practical ones.

Two major processes for producing magnesium by the thermal reductions of magnesia are in large-scale use. Both entail large capital investments. One is by the use of carbon and is called the carbothermic or, more popularly, the Hansgirg process. The second method is to use ferrosilicon and is referred to as the Pidgeon process.

Fabulous Permanente

The Hansgirg process was brought to this country at the outbreak of the war by Dr. F. J. Hansgirg, Austrian scientist. In theory his process is simplest of all and potentially should produce low-cost magnesium. The practical execution of the scheme has been fraught with many technical difficulties. Basically, Hansgirg's idea is to heat a mixture of magnesia and carbon in the electric furnace, the carbon divorcing the magnesium from the oxygen, according to the simple equation in which X is carbon

$$MgO+C+heat \longrightarrow Mg+CO$$

At about 1850 degrees C the oxygen abandons the magnesium in favor of the carbon. The problem comes in preventing the above-mentioned explosive reversal of the process. The two reaction products—magnesium and carbon monoxide—of this arc-furnace procedure are gases intimately mixed. Success of the process requires some means of separating magnesium vapor from the monoxide. The Hansgirg idea is to lower the temperature of the mixture with great suddenness—from 1850 to about 200 degrees C in a hundredth of a second by the introduction of large volumes of relatively cool gas. Hansgirg originally proposed hydrogen. The vaporized magnesium is caused to solidify by shock cooling so suddenly that the reaction does not have time to reverse. The magnesium vapor separates as a fine powder, which is recovered by filtration. The cooling agent, hydrogen, can be purified of its carbon monoxide for reuse.

The catch lies in this shock cooling. Obviously it entails a set of conditions of great potential hazard. Magnesium, being of the ultimate fineness (i.e., maximum surface area), burns, if exposed to air, with the fierceness characteristic of incendiaries. The mixture of hydrogen and carbon monoxide, too, clearly is hazardous. And besides, temperatures involved in the process are high.

Henry J. Kaiser believed he could circumvent these hazards by practical controls of the process. He had the faith to build his famous magnesium plant on a gigantic scale at Permanente, a few miles southwest of San Francisco.

The magnesia (MgO) for Permanente could have been prepared by any of several methods. Kaiser elected to do it by a combination ore and sea-water process. Dolomite, mined near by, is reduced to the oxide form in a simple reaction

$$MgCO_3 \cdot CaCO_3+heat \longrightarrow MgO \cdot CaO+2CO_2$$

This is hauled to Kaiser's ocean-side plant at Moss Landing, California, where it is mixed with sea water, resulting in the hydroxide which is heated to form the magnesia

$$MgO \cdot CaO+MgCl_2+2H_2O \longrightarrow 2Mg(OH)_2+CaCl_2$$
$$Mg(OH)_2+heat \longrightarrow MgO+H_2O$$

The water is evaporated, and the white granular magnesia is shipped to Permanente. There it is mixed with carbon obtained from petroleum coke, crushed in ball mills to an intimately mixed powder, and pressed into pellets about the size and shape of peach seeds. These pellets are charged into large arc furnaces where the Hansgirg reaction takes place. However, instead of using hydrogen for shock cooling, enormous quantities of natural gas from the nearby petroleum fields are used. The magnesium vapor, suddenly chilled, is condensed to an exceedingly fine powder, much of which drops to the bottom of the air-tight condenser and is removed by a screw conveyor. Most of the magnesium dust remains in the monoxide stream and is removed by a bag-type dust collector. The magnesium powder—still kept from the air—is compressed to briquets, which are fed into air-tight electrically heated retorts. The magnesium distills into a thick crust of pure and beautiful crystals that can be handled openly without hazard. This, of course, has the disadvantage of being a batch process. The natural gas, enriched by the carbon monoxide, continues to Kaiser's cement plant, a stone's throw away, where it serves as fuel.

Clearly the Permanente variation of the Hansgirg process is not without potential hazard. The final proof always lies not in the theory but in the record. If rumor had its way, Permanente Magnesium would have been a ghost plant long ago. But it isn't. To be sure, accidents, some fatal, have occurred at Permanente. Those closely connected with the Permanente operation insist that the accidents, which rumor has exaggerated in number and scope, have not resulted from the shock-cooling process but were accidents that occur in any industrial plant as large as Permanente. Magnesium is being regularly produced in quantity at Permanente.

Much experimental work is being done in various laboratories to find alternatives for Hansgirg's hydrogen or Permanente's natural-gas shock cooling. Conspicuous is the work of the Bureau of Mines done at the State College of Washington under the direction of Mr. H. A. Doerner. Shock cooling is accomplished by a spray of kerosene instead of gas and most of the oil evaporates in the shock-cooling step. The magnesium dust is collected with a small portion of the liquid oil and is easily separated from the relatively small volume of gas and oil vapor.

Magnesium from Ore, via Silicon

The second candidate for *X* in the thermal-reduction equation is silicon. This process originated years ago in Germany, and has been tried in England, but has been brought to a high state of practicability by Dr. L. M. Pidgeon of Dominion Magnesium, Limited, of Canada, and by the Electro Metallurgical Company of the United States. Upon the recommendation of the National Academy of Sciences, several ferrosilicon plants have been built in this country.

Ferrosilicon is a powerful reducing agent. It is expensive ($135 per ton) and is much in demand in steel making and other work. It, too, is a product of the electric-arc furnace, which is one feature limiting its use in magnesium production. The conventional method of making ferrosilicon is to charge iron ore, silica rock, and coke into an arc furnace where the heat produces ferrosilicon as a liquid, which freezes to lava-like lumps of silvery blue luster. Ferrosilicon is primarily silicon dissolved in the iron, rather than being a chemical combination of the two. The pair is forced into temporary partnership by the electric arc forming a product that is a strong reducing agent.

For the ferrosilicon process, dolomite ($MgCO_3 \cdot CaCO_3$) is preferred to magnesite ($MgCO_3$) because, without calcium, part of the MgO goes to form $MgSiO_3$ from which the magnesium cannot readily be recovered. Advocates of the ferrosilicon process point out that this ability to use $MgCO_3 \cdot CaCO_3$ instead of $MgCO_3$ is a singular advantage because dolomite is more prevalent than magnesite.

TABLE I—THE PRINCIPAL SOURCES OF MAGNESIUM AND THEIR OCCURRENCES

Form	Chemica Formula	Per Cent by Weight	Occurrence and (Amount)*
Magnesium Chloride	$MgCl_2$	0.13 0.6 4.2 2.6 0.8 4.7	Ocean (unlimited) Great Salt Lake (large) Dead Sea (large) Strassfort Salt Beds (very large) Michigan Brine Wells (large) Elton Lake, Russia (large)
Magnesite	$MgCO_3$	28.7	Austria, Greece, California, Washington, Nevada, New Mexico, Russia, Canada, Manchuria (large)
Dolomite	$MgCO_3 \cdot CaCO_3$	13.8	New York, California, and other states (very large) Great Britain (large)
Brucite	$Mg(OH_2)$	41.6	Nevada (large) only important source
Serpentine Kierserite Epsomite	$3MgO \cdot 2SiO_2 \cdot 2H_2O$ $MgSO_4 \cdot H_2O$ $MgSO_4 \cdot 7H_2O$	25.9	Available in large quantities in many areas of the world, but not economically workable at present—known methods
Carnallite	$KCl \cdot MgCl_2 \cdot 6H_2O$		Strassfort Salt Beds (very large). Magnesium obtained as by-product of potassium salt recovery

*These are the only ones of outstanding importance at present. There are many other sources of magnesium in brines and ores both in the United States and elsewhere.

In Dr. Pidgeon's process the ferrosilicon and calcined dolomite are separately pulverized, are then intimately mixed in the proper proportions, and pressed without binder into small pellets. The retort is a furnace, usually fuel fired, through which extends many horizontal stainless-steel tubes, 8 or 10 inches in diameter. A charge of pellets is rammed into these tubes, covers clamped on, and a vacuum of about one hundred thousandth of an atmosphere drawn. At a temperature of about 1200 degrees C the ferrosilicon relieves the magnesia of its oxygen.

$$Si + 2(MgO \cdot CaO) + heat \longrightarrow 2Mg + 2CaO \cdot SiO_2$$

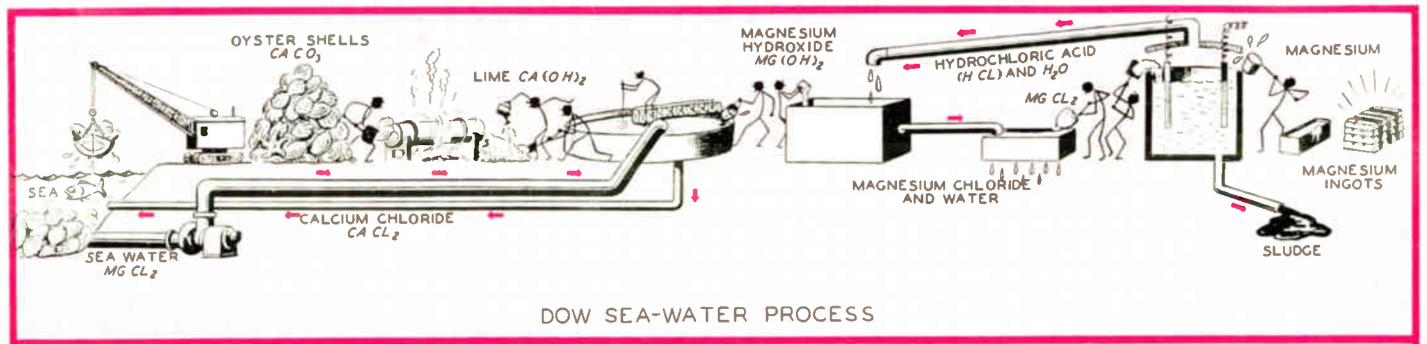
The magnesium leaves as a vapor, which is drawn off and collected at the end of the tube as a crust of beautiful glistening crystals. The remainder of the pellets is calcium silicate, $CaO \cdot SiO_2$, still a solid. The iron remains inert in this procedure. In eight hours the reaction is complete, the vacuum to that particular tube is broken, the exhausted pellets and the iron, which has fluxed with the residue, are removed and discarded. The tube is recharged with fresh pellets and the cycle begins again. While each tube operates on a cycle basis, the furnace operation as a whole is continuous, the heat never having to be shut off.

The ferrosilicon process obviously dodges the potential hazard of the carbothermic process. One of the reaction products (calcium silicate) is always a solid, leaving no opportunity for violent reversal.

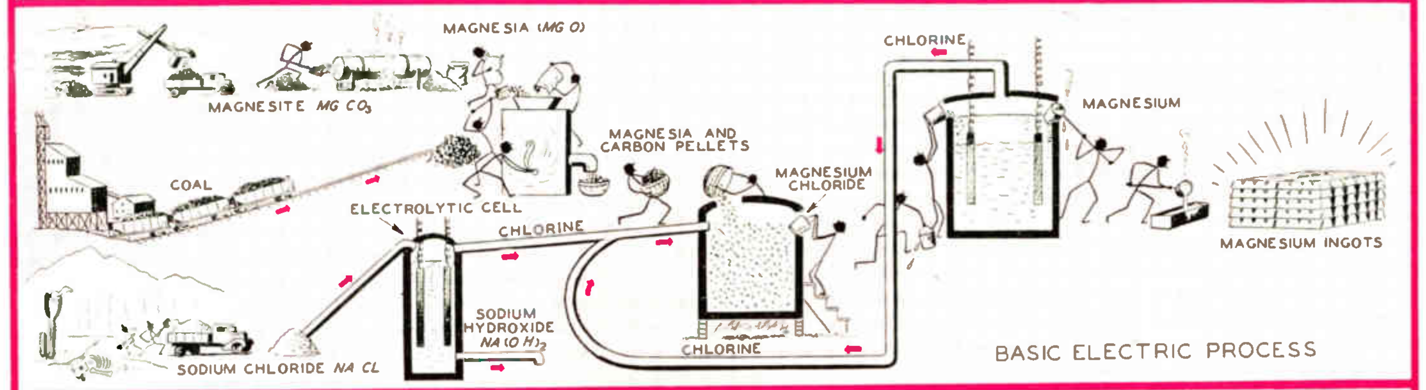
An interesting and important variation of the ferrosilicon process is that developed by the Electro Metallurgical Company, subsidiary of Union Carbide and Chemical Company, and for which it has established a large plant near Spokane, Washington. At this plant ferrosilicon is made in the conventional manner in three-phase arc furnaces of Union Carbide design. Iron ore and quartz, both obtained from near-by

(*Continued on p. 56*)

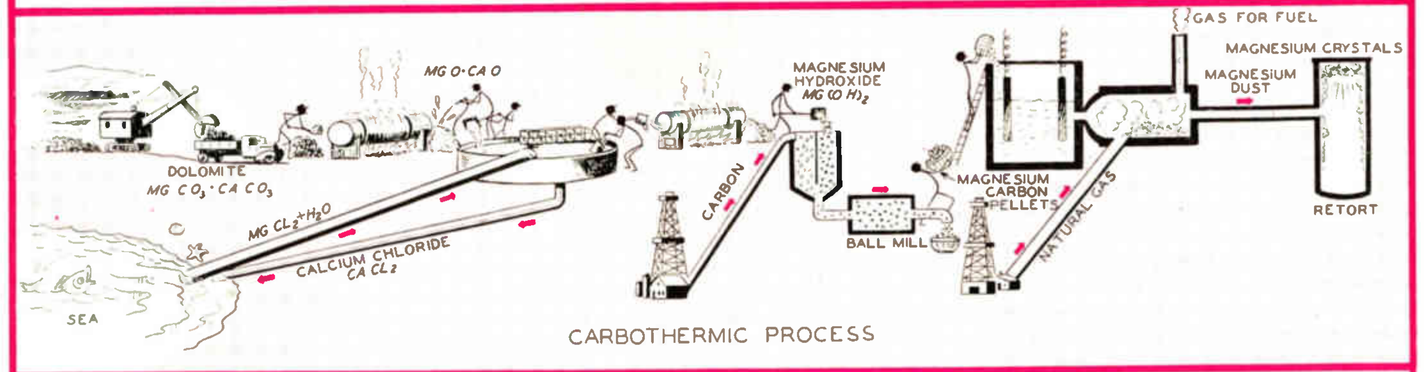
As magnesium is poured into molds for pigs a workman sprinkles the surface with sulfur dust. (American Mag. photo.)



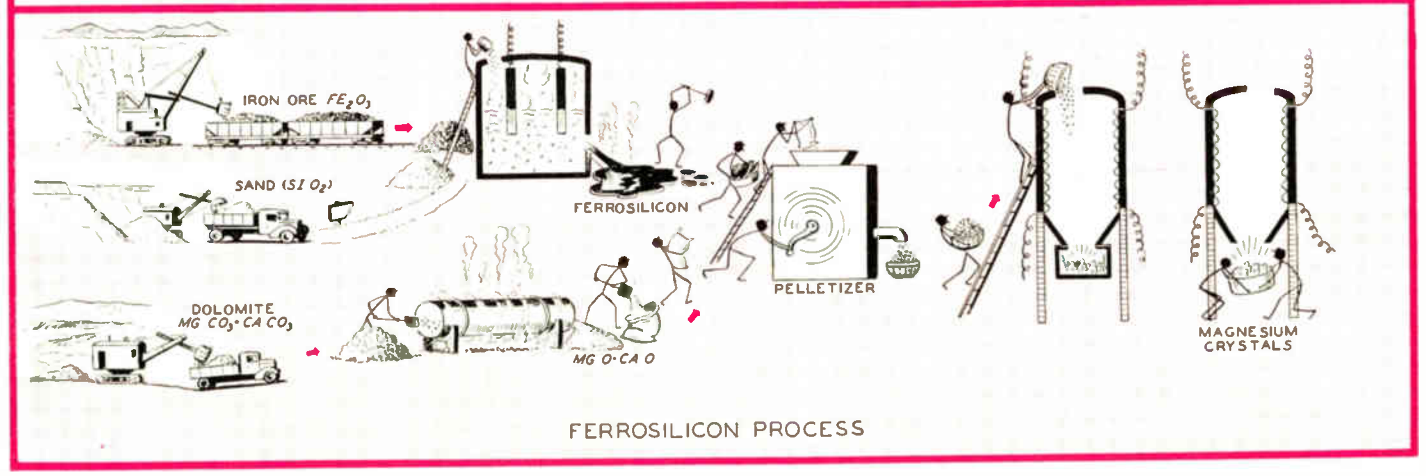
DOW SEA-WATER PROCESS



BASIC ELECTRIC PROCESS



CARBOTHERMIC PROCESS

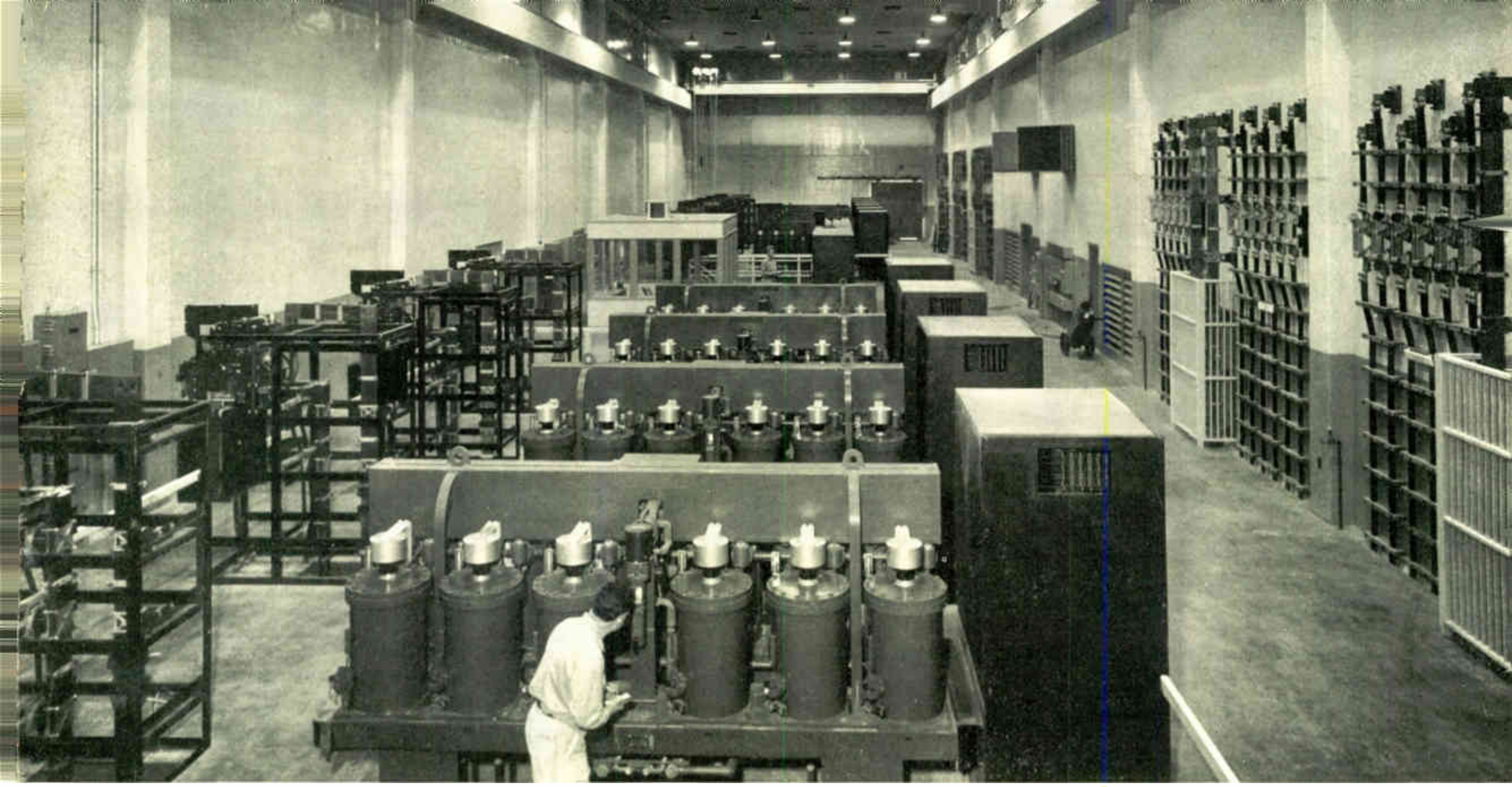


FERROSILICON PROCESS

electrolytic cells—the last step in the devious process of securing free magnesium. Thus the Dow process starts with magnesium chloride and by several chemical sleights of hand arrives at the final stage with magnesium chloride. The reason, of course, is to increase the concentration of magnesium chloride and to free it from the many bromides, iodides of silver, sodium and potassium that also reside in the sea.

The electrolytic cells are rectangular cast-steel pots six by twelve feet set in refractory brick. The steel lining serves as the cathode and graphite anodes are suspended from above. After electrolysis begins the electrolyte is kept molten (670 to 730 degrees C) by the passage of 15 000 to 20 000 amperes at six to nine volts.

The magnesium liberated by heat rises to the top of the electrolyte where it is skimmed off at intervals and cast into pigs. The purity averages 99.9 per cent or better. A fresh charge of chloride is added to the cell at intervals to maintain the process. For each four tons of charge, one ton of magnesium is obtained. Other products of the dissociation in the cells are chlorine gas, a weak mixture of hydrochloric acid,



The Ignitron Mercury-Arc Rectifier
—*War Machine Extraordinary*

J. H. Cox
Head, Mercury Arc Rectifier Section, Westinghouse Electric & Mfg. Company

Machines don't get medals. If they did, the ignitron would have one. The aluminum and magnesium for three of each four airplanes built in the United States and Canada were produced with direct current from ignitrons. Born of a research idea in 1931, the ignitron had reached such a high state of development at the war's beginning that it was selected for the job because of many advantages and because it could be built quicker.

A NOTABLE example of the wartime utilization by industry of a relatively new device is the ignitron mercury-arc rectifier. In the tremendous expansion that was made in the facilities for the production of magnesium and aluminum in the United States and Canada, over 80 per cent of the conversion apparatus installed has been of the ignitron type. Starting from a single 1000-kw experimental installation in 1939, there are now nearly 3 000 000 kw of ignitron rectifiers of the 600-volt class in electrochemical service. This is equivalent to 1000 of the 12-phase, 3000-kw units, the ones almost invariably used for aluminum and magnesium "pot" lines. These figures of installed kilowatts of ignitron rectifiers do not include approximately 175 000 kilowatts supplying power for railway, mining, steel mill and other services.

The reasons for the preference for ignitron rectifiers over other means of conversion are as follows:

1—Higher efficiency.
2—Lower maintenance.
3—Lower installation cost and time.
4—Operations are simple and many are automatic.
5—Less noise and vibration.
6—Availability—The quantity of conversion apparatus desired for the expansion of light-metal production could not have been produced in machinery of the rotating types.

Development of Mercury-Arc Rectifiers

Among the many problems involved in the development of the mercury-arc rectifier, the following three, which are to some extent interrelated, have been the most important:

1—Excitation, or establishment of the arc when needed.
2—Arc-back, or the spontaneous appearance of the arc when not desired during the back-voltage period of the cycle.
3—Vacuum technique, or the provision of pure mercury vapor of the correct density favorable for arc rectification.

In an arc between electrodes in a gas, electrons are emitted from the cathode spot on the negative electrode, are transmitted through the ionized gas, and enter the positive electrode, thus constituting current flow. If a cathode spot is created on one electrode and prevented from forming on the other, the arrangement has unidirectional properties. If alternating voltage is applied, current flows in one direction only, i.e., is rectified. Unfortunately, in any practical arrangement, occasionally a cathode spot spontaneously appears on the electrode bearing negative voltage, permitting current to flow in the reverse direction. This action is called "arc-back." In a practical rectifier an arc-back requires that the connecting breakers be opened to clear the reverse-current arc, resulting in a momentary interruption of service from at least that rectifying element.

The prevention of too frequent occurrence of arc-backs has always been the most difficult problem in rectifier design. Because ionized gas in the presence of an electrode negatively energized greatly increases the probability of breakdown, practically all efforts to eliminate arc-backs have included some arrangement of surfaces, or grids, near the anode to de-ionize the gas in this region promptly at the end of the conduction period. A detailed discussion of the various methods of reducing arc-back frequency cannot be attempted here.

Formation of a glow discharge between electrodes in a gas occurs at a definite voltage, which depends upon the geometry of the space and the gas pressure, but transfer from glow to arc is highly erratic at low gas pressures. Thus, starting the arc by the application of high voltage is not feasible. The only method known prior to the invention of the ignitron was the "drawing of the arc," i.e., the separation of electrodes with voltage applied between them. Once the arc is started, it persists as long as current is kept flowing but stops almost instantaneously if the current falls to zero.

The method of excitation used in the early mercury-arc rectifier consisted of depressing a starting rod into the mercury of the cathode by a solenoid-operated plunger, and withdrawing it by spring action. Obviously such a procedure is not feasible for synchronous application, that is, each cycle. So a "holding," or excitation, anode was provided to which a continuous excitation current was established to maintain the arc over no-load periods.

With a continuous arc maintained, the cathode spot is free to move over the cathode. If this cathode consists of a simple mercury pool in an iron tank, the cathode spot or spots eventually wander off the mercury and up the tank's walls. Because of the high concentration of energy at the cathode spot, holes would be melted through the walls. Therefore, it was necessary to insulate the cathode from the tank walls, and this involved a rather large vacuum-tight bushing.

In most power-rectifier circuits the cathodes are connected together. Therefore, economy of cathode insulation, and of starting and excitation equipment is achieved by placing several anodes in a single tank with a single cathode; hence, the multianode rectifier. Placing several anodes in a single tank naturally increases the size of the tank and the anode-cathode space. This increased electrode spacing aggravates the problem of adequate de-ionization and increases the probability of arc-back. To correct this, large multianode rectifiers required more shielding and grids than small and simple rectifiers. Increased arc length and increased shielding raised the arc drop and lowered the efficiency. The sacrifice was large. The arc drops of typical multianode rectifiers are of the order of 50 per cent higher than those of ignitrons of comparable rating. Because arc drop is practically constant with load it can be directly related to output voltage, and the influence on efficiency is apparent.

The problem of manufacturing evacuated vessels with vacuum-tight electrical bushings no longer presents difficulty although it did handicap early efforts to make a metal-tank rectifier. Many developments have contributed to the solution. The most important are improvements in steel and welding, development of several types of vacuum-tight insulating seals, and improvements in vacuum pumps. As a result, modern pumped rectifiers have a reliability of the same order as other well-developed electrical apparatus. The preservation of vacuum is a nominal maintenance item.

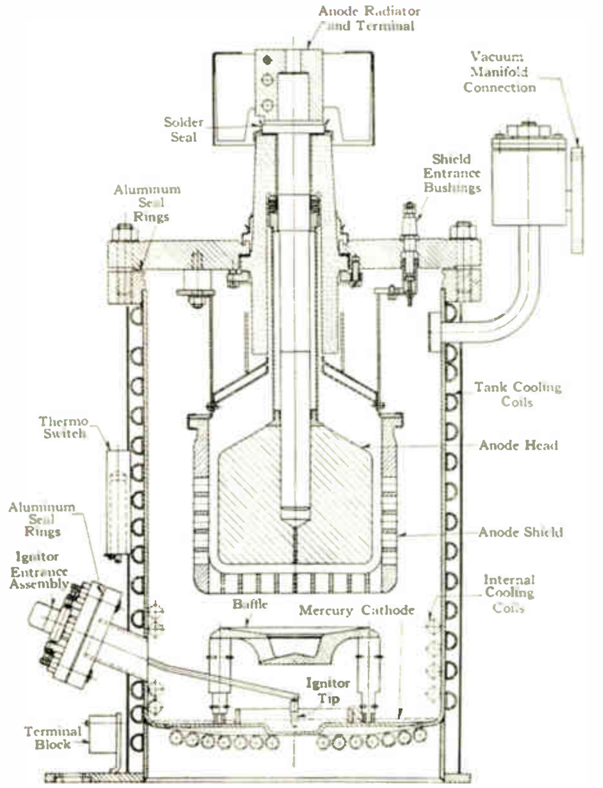


Fig. 1—*This is a sectional view of a continuously pumped ignitron used extensively for heavy-duty rectification.*

The Ignitron—Its Fundamentals

In 1931 Dr. Joseph Slepian found that if a rod of a poorly conducting material is partly immersed in a pool of better conducting material and a current passed from the rod to the pool, a field is set up at the first point of contact. At some value of current this field reaches a stress at which a cathode spot of an arc is created. He found that with a rod of silicon-carbide or boron-carbide in mercury a cathode spot forms at about 10 amperes and 150 volts. It is apparent that the synchronous application of impulses of power of this magnitude is entirely practical. This exact control of cathode-spot formations constitutes the basic feature of the ignitron.

With a system of synchronous excitation available, the arc can be started at the center of the cathode pool at the beginning of each conducting period of the cycle and permitted to go out at the end of the conducting period. Thus, there is not time during the life of any cathode spot for it to travel from the mercury so the cathode insulator can be omitted. The ignitron consists of an anode in a simple vacuum-tight cylindrical tank with a mercury pool in the bottom, together with an auxiliary entrance bushing through which power can be delivered to the ignitor (see Fig. 1). Because the power arc does not exist in the tank during the back-voltage period, the grid around the anode is reduced in size to that required to de-ionize quickly the region immediately adjacent to the anode following its own conducting action and to resist the residual ionization in the remainder of the tank.

Pumped ignitron units are now built in sizes from 300 kw in the 250-volt class, to 6000 kw in the 600-volt class. Larger installations are made up of the required total number of tubes, but for flexibility of both installation and operation individual assemblies are limited to not more than 12 tubes. Most installations of ignitrons are made at 850 volts or less. None has been made at 3000 volts. However, tubes have been built and installed for 12 000 d-c. Unquestionably the ignitron lends itself more readily to 1500 and 3000 volts than do the earlier multianode rectifiers.

The problem of vacuum has evolved into that of permanently sealing rectifier tubes and eliminating the pumping equipment from the installed apparatus. At present sealed-off ignitron tubes are built in the smaller sizes.

How large the tubes can be that utilize sealed construction is a question of the economic balance between (a) the average life of the tube and the cost of replacement, and (b) the cost of purchase and maintenance of vacuum-pumping equipment. The question of life can be answered only by time. Sealed tubes have demonstrated an average life of more than three years. This experience justifies going to the next larger size, and that step is being taken now. As further experience is gained it is probable that sealed construction will be used for still larger tubes.

At the present time sealed-tube ignitrons are built for rectifier application in ratings of from 75 to 500 kw in the 250-volt class and 100 to 1000 kw in the 600-volt class.

How the Ignitron Gets Its Excitation

The basic difference between an ignitron and a continuously excited rectifier lies in the excitation system. The excitation systems of continuously excited rectifiers are well known and will not be discussed.

The three basic forms of ignitron excitation are shown in Fig. 2 and their impulse characteristics in Fig. 3. Figure 2 (a) shows the "anode firing" excitation system. In this system the ignitor receives its power from the main anode circuit. A thyratron in series with the ignitor prevents reverse current through the ignitor. Phase control of ignition is obtained by controlling the grid of the thyratron.

This system of excitation has the advantages of simplicity and high efficiency. Because the main anode short circuits the ignitor as soon as the arc is formed, only the amount of power required to ignite the cathode spot is used each cycle. Anode firing has the disadvantages of less flexibility, inasmuch as it depends on load current for ignitor current; less positive firing, which adversely affects the paralleling of several ignitrons; and it utilizes a replaceable thyratron tube. The sum of these disadvantages has caused this system to be abandoned for the present.

The "capacitor-thyratron" system of separate excitation is shown in Fig. 2 (b). The firing capacitor is charged through a Rectox and is discharged at the desired instant through a thyratron and the ignitor. Phase control is secured by control of the grids of the thyratron.

This system is positive and flexible. As in any system of separate excitation, every cycle must be supplied with an amount of power equal to the maximum required under the most adverse conditions. As in anode firing, thyratron tubes are required, and the current and voltage are such that this tube is one of the more expensive sizes. The life of existing thyratrons in this service has been about 18 months, which involves appreciable expense, and the random failure of a tube constitutes a nuisance factor. The great flexibility of any thyratron type of circuit is most attractive, and in the event of a large reduction in ignitor power requirement or a major improvement in thyratron tubes a thyratron circuit will again be favored for ignitor excitation.

A saturating-reactor excitation circuit is shown in Fig. 2 (c). A capacitor is charged through a reactor with linear characteristics to a voltage at which a reactor in series with the ignitor saturates. At this point the capacitor is discharged as an impulse through the saturated reactor and the ignitor. Because the reactor discharges equally well in either direction it produces impulses of opposite polarity at 180-degree intervals, and one circuit is utilized for two ignitors (in separate rectifiers) by the use of a pair of Rectox units to guide the impulses to the proper ignitor.

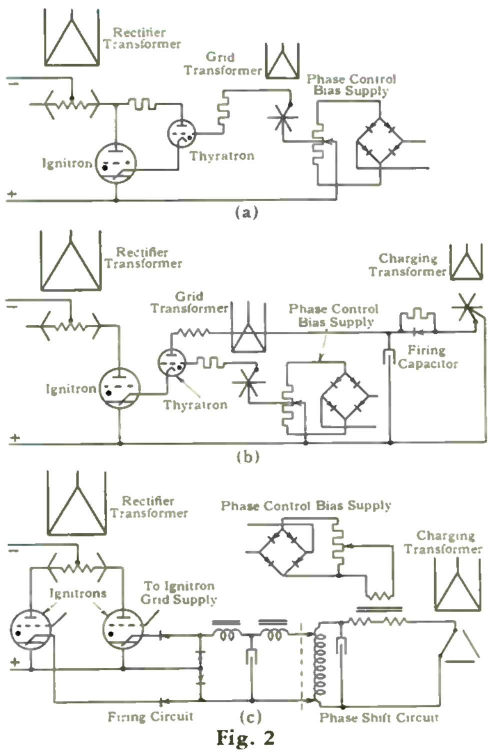


Fig. 2

Fig. 2 (Left)—The anode-firing excitation system in (a) provides high efficiency and simplicity of circuit. In (b) is an excitation system using a firing capacitor charged through a Rectox. It is discharged through the ignitor at the desired instant by a thyratron. The saturating-reactor excitation system (c) is slower in response and less flexible than the systems in (a) and (b) but is permanent, and is widely favored.

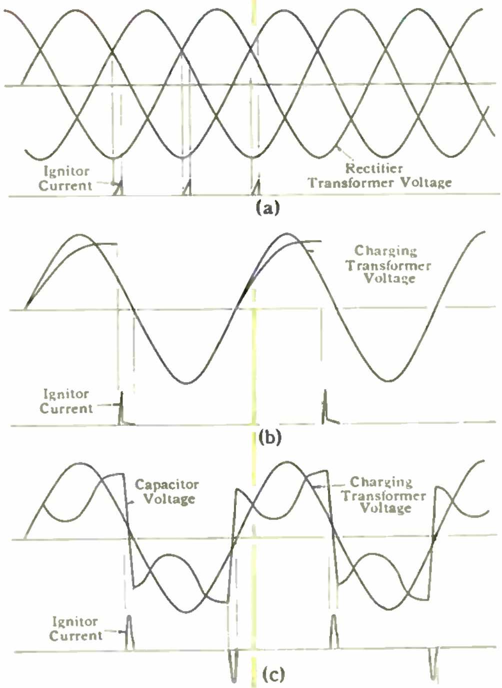


Fig. 3

Fig. 3 (Right)—Impulse characteristics of the three ignitron-excitation systems in Fig. 2 are here shown as (a) anode firing, (b) capacitor-thyratron firing, and (c) saturating-reactor firing.

The firing circuit proper is shown in the left-hand portion of Fig. 2 (c). Such a circuit, of course, produces impulses in a definite phase relationship to the supply voltage. Phase control can be obtained by the use of a mechanical phase shifter. This involves a rather large piece of equipment and is relatively slow in response. A system more favored for general application is some form of phase-shifting network, one being shown in the right-hand portion of Fig. 2 (c). In this circuit, a resonant network is supplied through a series reactor. By varying the inductance of this series reactor with direct current in a saturating winding, the phase position of the voltage supplied to the firing network is altered.

The saturating-reactor excitation circuit with phase-shifting network is heavier and bulkier than either of the thyratron systems. It is also slower in response and less flexible. However, because it is static, rugged, and permanent, and provides positive and reliable excitation with adequate speed of response for most applications, it is in almost universal service on ignitron equipments today.

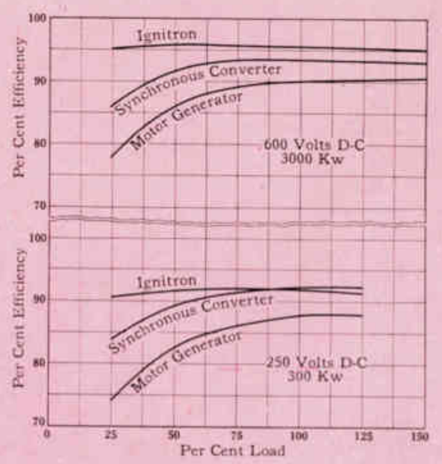


Fig. 4—*A comparison of conversion-apparatus efficiencies.*

How the Ignitron Performs

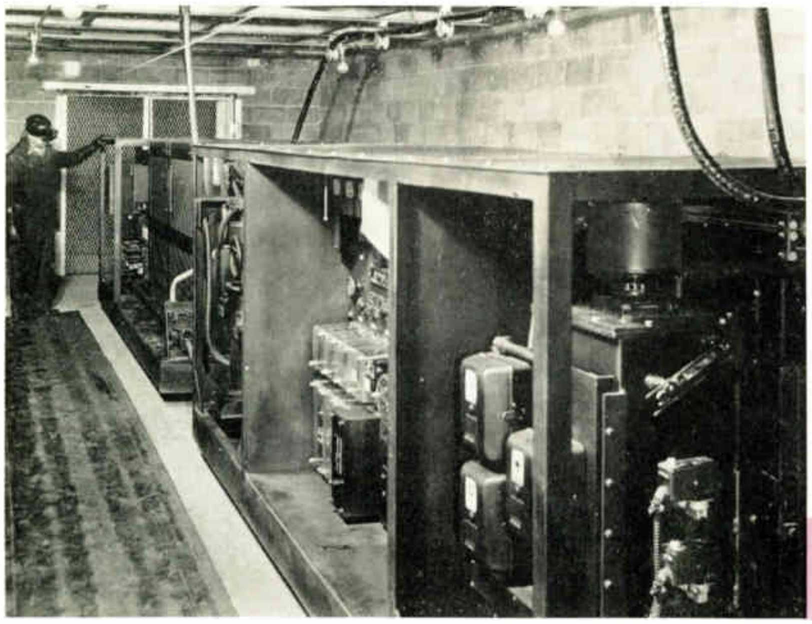
The important rectifier characteristics include efficiency (Fig. 4), flexibility, reliability, power factor, harmonics, and protection required. The normal load-voltage characteristic of any arc rectifier is determined by the supply circuits and transformers, and has approximately five per cent drop from light load to full load. With a simple voltage regulator operating on phase control of the excitation, the voltage characteristic can be made substantially flat. Over-compounding can be applied if desired, but this complicates the control if parallel operation is required. Such compounding is practically never required.

Modern ignitron rectifiers have a reliability comparing favorably with other types of electrical apparatus. In general, causes of shut-down, other than arc-backs, are such that the time of shut-down can be chosen. Although arc-backs have been reduced to an infrequent occurrence, they still happen at unpredictable times and cause trip-outs of at least the arcing-back element. However, to clear an arc-back it is necessary only that the breakers be opened and they can be immediately reclosed. Single-anode tube construction contributes to reliability because in the event of a tube failure, operation can be continued with part of the tubes out of service with only a small decrease in capacity. Should short-time outages of arc-backs be serious, even these can be eliminated by the use of anode breakers so connected that only the offending anode is disconnected, which reduces capacity only momentarily.

The normal power factor of a rectifier operating without phase control is about 94 per cent with a six-phase circuit and 96 per cent with a twelve-phase circuit. Reduction of output voltage by phase control reduces the input power factor, each per cent reduction of voltage reducing the power factor approximately one per cent.

Rectifiers cause harmonics on both the a-c and d-c circuits, and therefore cause telephone interference where the power circuits are exposed to communication circuits. The two principal ways of eliminating interference are to use filters on the rectifier circuits involved, and to increase the number of phases of the rectifier circuit. Modern telephone installations are much less subject to influence than the older types. In practice it has been found that the magnitude of the influence is rarely great enough to require either filters or an inconvenient number of phases. Where filters are required their size is not prohibitive. In the case of large electrochemical installations the d-c circuits are so concentrated that no d-c exposures are involved. On the a-c circuits the magnitude of the usual electrochemical load is so large that serious interference is encountered with six- to twelve-phase circuits. However, in these cases the number of anodes involved is so large that, as shown in Fig. 5, the number of phases can be increased without important inconvenience and with ample reduction in interference.

In rectifier applications the most important protective feature is that necessitated by arc-backs. In the event of a failure of the rectifying action of any anode, reverse current is fed into that anode both from any other counter-voltage apparatus on the d-c bus and from the other anodes in the same rectifier. Therefore, both the d-c and a-c circuits must be disconnected. The magnitudes of the re-



Many ignitron installations, such as this, are made under ground to supply d-c power for mining equipment.

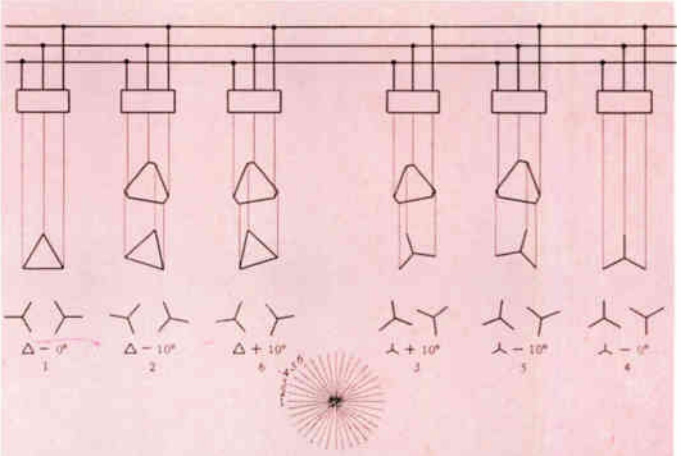


Fig. 5—*In large rectifier installations the number of phases can be greatly increased, which decreases interference.*

verse current contributions from the a-c and d-c circuits are determined by the characteristics of the d-c bus and the rectifier transformer respectively. In the smaller installations both circuits can be interrupted by breakers of normal speed, that is, semi-high speed d-c breakers having a clearing time of 2–3 cycles and a-c breakers having a clearing time of 8–10 cycles, on a 60-cycle basis. In the larger installations, if the d-c contribution is permitted to reach its ultimate magnitude, it becomes so great that it endangers both the transformer and the interrupting breaker. To prevent this, advantage is taken of the inductance of the circuit, and high-speed breakers are used that open the d-c circuit before the d-c reverse current increases above about 40 000 amperes. This requires breakers with sufficient speed to limit the current in about 0.5 cycle and clears in less than one cycle, on a 60-cycle basis. Experience shows that high-speed breakers are required on rectifiers connected to a bus having a total installed capacity of more than 9000 amperes in the 600-volt class, or 12 000 amperes in the 300-volt class.

Representative circuit-breaker arrangements are shown in Fig. 6. Because a breaker in the anode circuit clears both the a-c and the d-c connections and because the d-c breakers are all rapid compared to the 8–10 cycles of the conventional a-c oil breaker, the use of anode breakers minimizes the stresses on all items of equipment. Anode breakers are high speed or semi-high speed, as dictated by the considerations specified for cathode breakers. Anode breakers have the disadvantage of a larger number of poles to purchase and maintain. However, the advantages of anode breakers so far outweigh the disadvantages, particularly for the larger installations, that they have become standard where high-speed breakers are required. Frequently semi-high speed cathode breakers in addition to high-speed anode breakers are desired to facilitate multiple-unit operating procedures. Whether or not an a-c breaker is also used is determined by such factors as voltage and capacity of the a-c system, and the station layout.

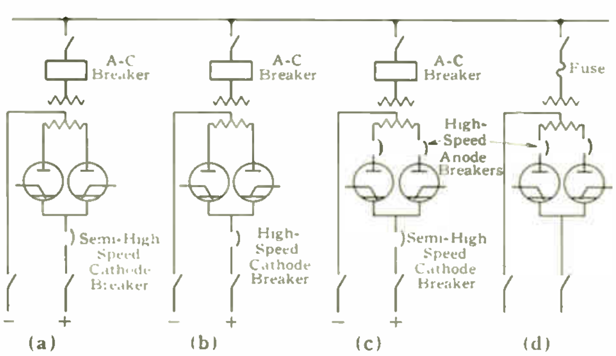


Fig. 6—*In these typical rectifier breaker arrangements, (a) and (b) illustrate the use of cathode breakers. High-speed anode breakers are employed in (c) and (d), while (c) uses breakers in both the anode and cathode circuits.*

Applications of Ignitrons

Ignitron rectification constitutes the preferred method of obtaining d-c power at voltages of 250 to 3000, except in small amounts such as desired for control purposes. Under certain conditions they are used at 125 volts or below, but the relatively fixed arc-voltage drop results in objectionably low efficiency at output voltages below 250. Also, for the higher power requirements, ignitrons have proved attractive at d-c voltages up to 20 000.

The first commercial application of a 300-kw, 275-volt rectifier was in 1937, in a coal mine. Several mining installations followed, and the ignitron has continued to be popular for mines because of its compact size, the ease with which it is made fully automatic and in small portable units so that it can be installed under ground and moved with shift in load center. Its reliability and low maintenance record are also important. A 4800-ampere, 280-volt electrochemical installation was made early in 1939. The first 600-volt ignitron was a 3000-kw installation in railway service in 1938.

However, it is in the 600-volt class electrochemical field where the ignitron has been installed in truly large capacities that it has contributed most to the war effort. At the present time over 65 per cent of the aluminum and magnesium produced in North America is reduced with ignitrons, even including the total capacity installed prior to 1940.

The first 600-volt ignitron in electrochemical service was a 1000-kw unit placed in trial service in the Massena Plant of the Aluminum Company of America in January, 1939. Except for the considerable extent to which the defense needs for aluminum plants had been anticipated and already installed, the really large demand started late in 1939. This coincided with the development of newer and superior methods of making magnesium, which also initiated plans for expansion. Because of the performance of the small Massena trial installation, 275 000 kw of ignitron rectifiers was ordered for aluminum and magnesium reduction before the first large unit was placed in operation—a truly large-scale demonstration of faith in test data. The first aluminum-reduction unit of ignitrons, 60 000 amperes at 675 volts, was started on August 25, 1940. In no case has an electrolytic cell frozen for lack of power.

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Magnesium as a Material

(Continued from page 45)

produce one pound of ferrosilicon, of which about one pound is needed for each pound of magnesium produced. To be sure, the final reduction of magnesium by silicon does not necessarily require electric power, although the Electro Metallurgical Corporation, at Spokane, does prefer to use low-cost power from Grand Coulee Dam. The total power consumption at Spokane is probably eight to ten kilowatt-hours per pound of magnesium. Pidgeon-type reduction furnaces are usually fuel fired, and hence the economics of this process depend on the local price of fuel instead of electric power.

Magnesium Is Not Hazardous

Magnesium has a reputation of being a hazardous metal. This is understandable, for are not incendiary bombs simply shells of solid magnesium set afire by Thermit? Are not tracer bullets, flares, and other pyrotechnics of warfare simply finely divided magnesium powder that burns in air? So they are, but magnesium, when properly handled, is as safe as aluminum, or iron, or wood.

Whether a metal burns in air—be it magnesium, aluminum, iron, or any other—depends mainly on two factors, temperature and amount of surface exposed to the air. The more finely divided the particles of a particular metal, the lower the temperature to which it must be heated in order to support combustion. As an incendiary bomb a solid piece of magnesium is brought to about 2000 degrees F before it continues to combine with oxygen without the addition of heat. This is far higher than any temperature achieved in processing it. In producing magnesium or making castings workmen pour it, as a liquid at between 1400 and 1500 degrees F, from ladles to molds as if it were babbitt and with but little more precaution. Sulfur dust is kept handy to toss on the surface of the liquid magnesium (forming a protective layer of sulfur dioxide to shut out the oxygen) to prevent magnesium fires and to reduce the loss caused by oxidation. Magnesium can be turned, planed, milled, ground or forged with safety, although the smaller the particles of metal that are removed the greater the care with which it must be handled. Adequate handling techniques have been developed for all phases of magnesium production and fabrication. If these are observed magnesium can be handled without undue risk.

The Future of Magnesium

It is risky business to set down with any degree of finality statements that rigidly define the future costs, limitations, advantages, or uses of magnesium. But some things are clear. Our postwar production capacity for magnesium will be enormous. The United States and almost every other nation can expect to be virtually self-sufficient as to this new metal. Magnesium can be produced from a variety of sources by an equal variety of practical processes. Aside from its uses in pyrotechnics and in industrial chemistry, it will unquestionably be a major structural material. Particularly where light weight is a factor—which includes all modes of transportation (airplanes, trains, automobiles, perhaps even bicycles), portable tools and machines, possibly in postwar furniture, as a building material—magnesium will have much to offer. Clearly it is not a panacea for all structural ills; it doubtless will not displace any of its present competitors—be they aluminum, stainless steel, wood, plastic, or steel itself. Instead we should look upon magnesium as an enormously valuable addition to our growing family of materials. Though created largely by the war, magnesium provides another solid foundation stone on which a better postwar world will be built.

How Magnesium Is Made

(Continued from page 50)

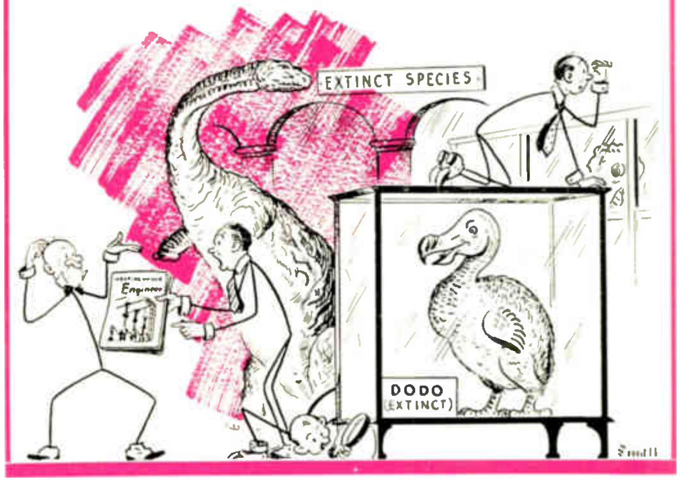
mines, are the raw materials. Power comes from Grand Coulee Dam on the Columbia River.

The Electro Metallurgical version of the ferrosilicon process has to do only with the kind of retort used, not with the chemistry of the reaction. The Electro Metallurgical retort, instead of being a fuel-fired furnace with small tubes, is a tall silo-like steel cylinder lined with electric-resistance heaters. An annular basket loaded with the pellets is lowered into the retort and the cover tightly sealed. A vacuum of about 400 microns pressure is established by jet-type pumps. Meanwhile the electric heaters have brought the temperature up to about 1200 degrees C at which the oxygen switches from the magnesium to the silicon. The magnesium vapor passes through the meshes of the basket and into a tub-shaped steel condenser below where it solidifies as shiny crystals. When the reaction is complete the current is turned off and the vacuum broken. When the tub is opened the magnesium breaks loose from the steel walls by differential expansion. The calcium-silicate sinter remains in the basket and is dumped as waste. The Electro Metallurgical cycle, instead of completing in about eight hours, requires about four days, and does necessitate heating and cooling the furnace once each cycle.

Altogether, we have arrived in the United States by many different routes to magnesium production of about 300 000 tons a year. This production capacity is roughly one hundred times greater than our 1939 output. Of this production roughly 70 per cent will be by electrolysis of magnesium chloride; 20 per cent by the ferrosilicon method; about seven per cent by the carbothermic process; and the remaining three per cent by various semi-experimental methods.

Calling Back Issues

Our shelves labeled August 1941, August 1942, and February 1943 are as bare of copies of Westinghouse *ENGINEER as Mother Hubbard's cupboard. If you have any copies of these three issues that you can spare you will be doing us—and engineers who are trying to complete their files—a great favor by returning them to us.*



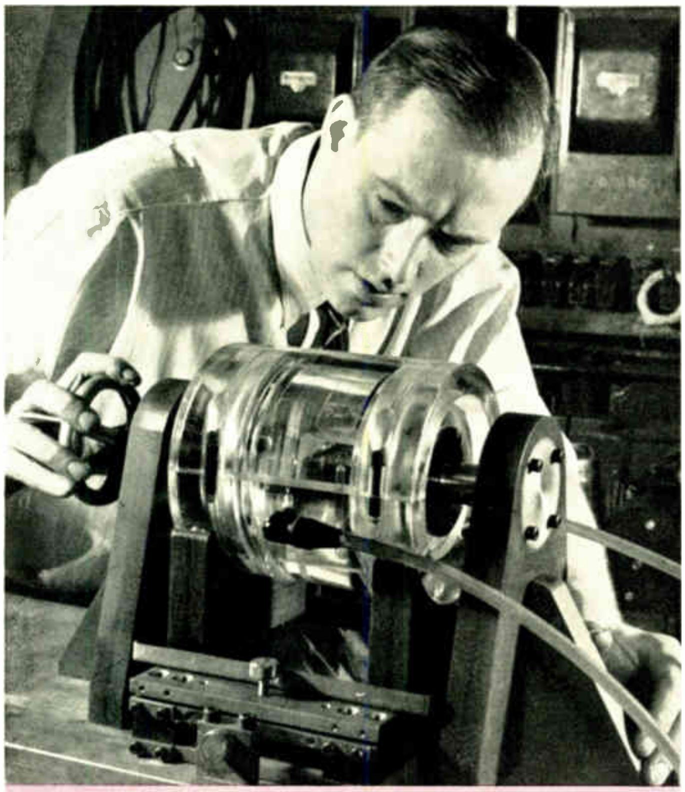
Stories of Research

Insight to a Bearing Problem

Slapping black grease on the axle of an oxcart whenever it squeaked or groaned solved that bearing problem to the satisfaction of the driver, if not the oxen. This technique is disappearing, just as the oxcart itself, in this day of 60 000-rpm motors and water wheels that weigh 500 tons. Bearings must be right and lubrication adequate or all the other engineering involved is of no avail.

In a journal bearing, many questions are posed. Should the lubricant be fed from one side or opposite sides; how deep the grooves and at what angle; what clearance at the top and what pressure the lubricant? Heretofore, engineers have been hampered by not being able literally to see the components of a bearing in operation. But now Mr. J. Boyd, of the Westinghouse Research Laboratories, is able to visualize the results of computed or empirical details of bearing design through the use of the bearing and journal made of Lucite, which is transparent.

This plastic is machined to close tolerances comparable to the metal parts of a bearing. The rotating element is operated by a hand crank for slow speeds and is motor driven for high speeds. Oil that has a red pigment added for more definite perception is fed to the bearing in any one of a number of ways. The resulting film of oil is easily seen and the changes in lubrication effectiveness incurred through each change in bearing design is apparent. One peek is worth many mathematical deductions.



Accurately machined translucent Lucite bearings allow Mr. Boyd to see the results of lubrication design changes, and immediately. Red pigmented oil is used for clear perception.

Aiding Mr. R. E. Marbury (left) in checking this new porcelain-encased capacitor in the Capacitor Laboratory is Mr. C. V. Fields. The flat plate at the end of the capacitor is for electrical contact and shows how the capacitors can be stacked or bolted to bus bars. The hose connections are made below the end plate.

High-Frequency Capacitors

Intricate devices require different heat treatment for different portions of the same part. The technological answer to these and other requirements is induction heating. Such induction-heating devices have an inherently low power factor and therefore require a large reactive kva in addition to the useful power component. If this reactive kva is supplied by the generator, the latter becomes inordinately large and costly. It is common practice, therefore, to supply this reactive component with capacitors. A new type of porcelain-encased water-cooled capacitor construction is particularly applicable to certain ranges of frequency and kva requirements.

Water cooling of all the foil electrodes of one polarity in the capacitor has been used in the past for frequencies in the range below 10 000 cycles to make it possible to handle a large kva per unit of volume. In the higher frequency range, hysteresis losses set up in the conventional metal cases and losses in current-carrying parts have prevented taking full advantage of the increase in kva rating, which is possible through more effective water cooling.

In the experimental porcelain-encased capacitor developed by R. E. Marbury in the Westinghouse Capacitor Laboratory here described, there is no metal case in the high-frequency field and all current-carrying parts can be effectively cooled. The foil structure consists of two coils of opposite polarity separated by suitable working insulation. The foil is bonded directly to the cooling arrangement that forms the closures and terminals. This makes a non-inductive assembly and one that permits transferring more than 95 per cent of the heat generated in the dielectric to the cooling water, since heat flows out in both directions from the center. Because the caps, or terminals, are also the cooling points of the capacitor, partial cooling of the bus bars leading to the capacitors is also accomplished.

The bond between the metal end structures and the tubular porcelain body is made liquid tight and sealed against the entrance of moisture by the use of the Westinghouse solder-seal process of soldering to porcelain.

A capacitor assembly, comprised of units comparable to the one shown above, is connected in series parallel for laboratory research studies of high-frequency heating. The unit structure makes possible a wide variation in overall ratings and a total capacity of 1800 kva.

Single units have been rated at 500 kva, even for relatively low voltage, which results in ratings that involve very large currents through the terminals.

This apparatus is still in the laboratory stages but is available in certain ratings for special high-frequency applications out of the range of the steel-case type of construction.

Throwing Light on Arc Welding

ELECTRIC-ARC welders are still playing blind-man's buff at the start of each weld. To protect their eyes from the injurious arc rays, the glass in their helmet is opaque to light rays of ordinary intensity. The dark window in the helmet permits the welder to see the work in the intense light of the arc, but through it no normally lighted objects can be seen.

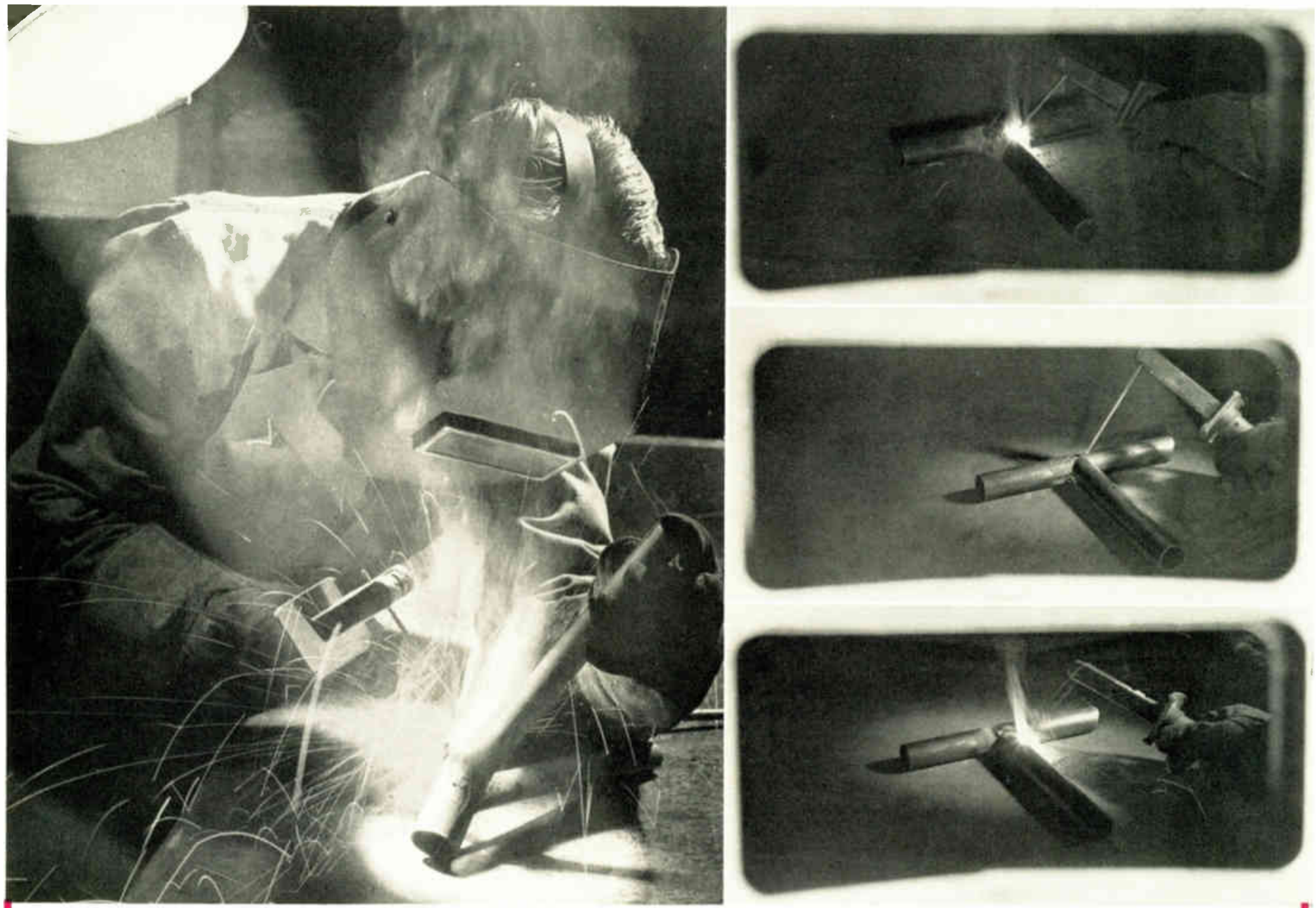
Consider how a welder must operate: first, with welding-helmet raised he carefully poises the welding rod over the work. He then snaps down his helmet, and from memory tries to touch the rod at a predetermined spot. Try it with a pencil with the eyes covered. Stop to consider that in many cases, if the arc is struck at an incorrect spot, the piece is ruined. At the Westinghouse Research Laboratories, this blindfold has been removed, especially for short, repetitious welding, by installing a foot-pedal operated high-power system of concentrated light beams, which flood the work with light. This light is of such brilliance that the work is perceptible even through the dark protective glass of the arc welder's hood.

These light sources are of two types: One is a specially designed lamp of high wattage with self-contained reflector that concentrates the beam. It is similar to a sealed-beam auto headlight. The other lamp has a mirror-finish interior and is operated from a special transformer at one and one half voltage, which, like a photographic photoflood lamp, gives light of great brilliance but with shortened lamp life.

A laboratory development, this equipment is not available commercially at this time.

Iron Bar Doth a Stove Make

SHOULD you ask Mr. Newton Foster, of the Westinghouse Research Laboratories, "What's cookin'?" he will not only be able to tell you what, but also how—and at a glance. A new nine-in-one stove gives uniform gradations of heat for testing specimens of a material simultaneously at nine different equally spaced temperatures.



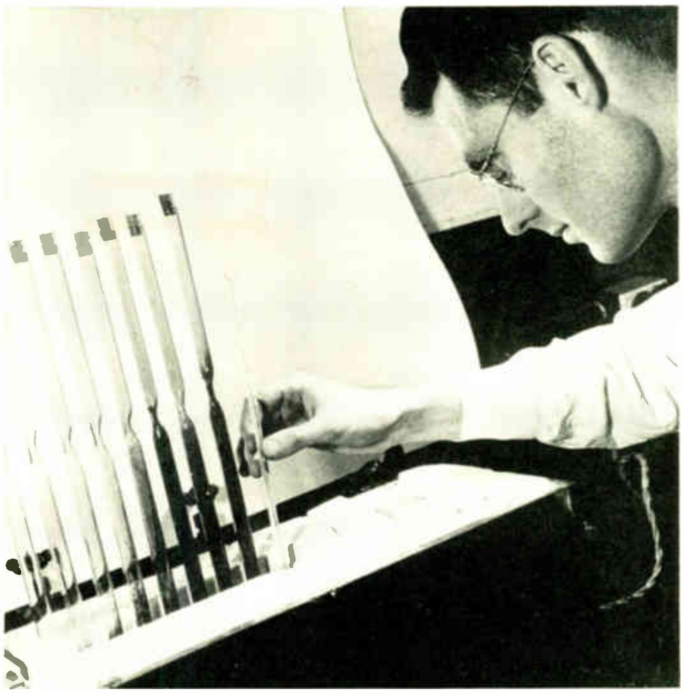
The brilliance of the light that floods the work position enables the operator to see clearly the parts to be welded and the progress of the weld itself. Heretofore, the visibility of the work position through the welder's hood has been poor, even after the arc had been struck as shown by the top inset. The middle inset shows the clarity with which the work can be seen and the arc struck at precisely the proper point. The bottom inset was taken during the welding operation and it makes a striking contrast with the top inset.

Necessity has forced the loading of motors and transformers to higher temperatures so that the resistance of the components of electrical equipment to high temperatures is under careful scrutiny. Plasticizers in insulation make it tough but pliable. However, should the plasticizers boil off, the insulation becomes brittle with attendant danger of electrical breakdown. At what temperature does a given plasticizer become volatile? What is the effect on other insulation constituents at various temperatures? The new cookstove for chemists comes up with all the answers at one time.

An iron bar, about a foot and a half long, three inches wide, and two inches thick, is heated at one end with an electric heater. A coil of pipe, in which cooling water is circulated, is soldered to the other end. Nine deep holes, in which are placed test tubes, are drilled at uniformly separated intervals in the bar. The gradation of heat along the bar is linear so that the test-tube temperatures increase from the cold end in equal increments. The temperature range here used is for 40 to 230 degrees C.

Determination of the temperatures of the several tubes is simple. When the stove has reached equilibrium, the temperature at the test tubes is measured at each end and the difference divided by nine. This gives the difference in temperature between each successive test tube.

Thus, if equivalent samples of a material are placed in the nine tubes, the reaction of the material can be observed at nine different temperatures simultaneously under identical conditions. The results achieved are uniform and are obtained quickly.

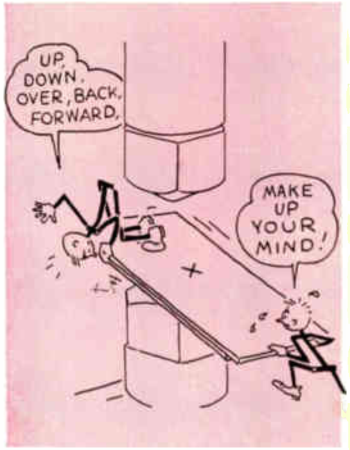


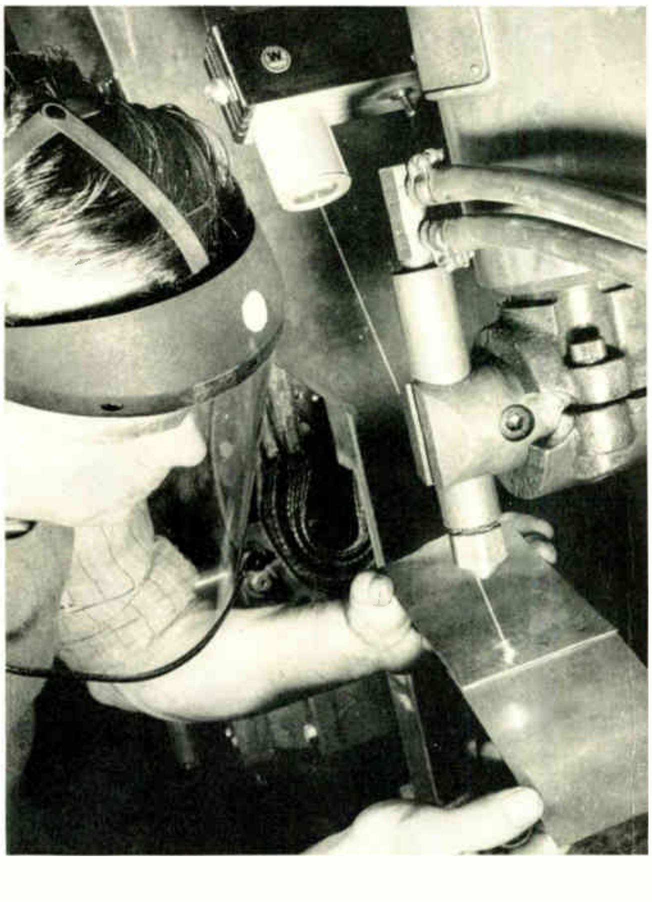
Mr. Foster checks the temperature of the hot end of the nine-in-one stove preparatory to calibrating this unusual laboratory apparatus.

Spot Welds—Right on the Beam*

A simple game that amuses children consists in placing a finger against the hidden underside of a board and trying to place a finger of the other hand directly over the hidden finger. The same problem—not so amusing—is posed in spot-welding sheet material. The lower electrode is hidden by the part to be welded. When the metal is not positioned by a jig, large variations in locating the weld point result because, with the sheet resting on the lower electrode, the welder cannot accurately determine where the electrodes will join the material. Mr. A. B. White, of the Westinghouse Research Laboratories, has thrown some light on the problem, thereby solving it.

A small light source throws from above a concentrated beam (about one-eighth inch in diameter) on the work. This spot of light is located on the work by two vernier adjusting screws that move it laterally and longitudinally. In practice, a sample spot weld is made and held in position on the lower electrode. The spot of light is focused on to the weld. The spot of light shows exactly where the subsequent welds will be made for metal of that thickness and for that electrode adjustment. For any variation of these factors, the light source is quickly readjusted for the new conditions.





After focusing the light on the trial spot weld, all subsequent welds can be located quickly and with accuracy. Mr. White shows the ease with which the spotlight spots the exact position where the electrodes will contact the work.

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*Note: This device is purely a research development and is not now commercially available.

Lightning Protection for Rotating Machines

Lightning, like a fox, has devious ways. No single combination of protective traps will catch it on all kinds of systems with various apparatus arrangements. But, for a given set of conditions, an adequate protective system can be provided. Recommendations, the result of long study, are here listed. These rules are reduced to their simplest form, and are necessarily conservative.

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The high monetary value and low insulation levels of rotating machines make it necessary that special protection be employed. A rotating machine can be conceived as a transmission line with distributed constants, the essential difference being that the machine winding is wound back on itself in the form of turns, which may permit high voltage across the turn-to-turn insulation. The installation of special arresters with low and consistent sparkover characteristics satisfactorily limit the maximum voltage that can appear across the terminals. However, capacitors are also required, which, in conjunction with the inductance in the line, slope the front of the wave. In this manner, voltage is prevented from piling up across the turns of the machine winding.

While the protection required at the machine and on the line are mutually interdependent, it is possible to resolve the suggestions for surge protection into four broad categories.

1—Protection at the rotating machine terminal or bus.

2—Line protection for rotating machines that are connected directly to overhead lines.

3—Line protection for rotating machines that are connected to overhead lines through cables.

4—Protection of rotating machines that are connected to lines through transformers.

Protection at the Machine Terminal or Bus

The ratings of valve-type arresters and capacitors recommended for each voltage class of machine are listed in Fig. 1 along with their method of application. It is important that the arresters at the machine be valve-type, and they should always be applied with capacitors that are located either reasonably close to the arresters or between the arresters and machine. This combination, Fig. 6, prevents the occurrence of steep-front surges resulting from a sudden voltage drop when the arrester discharges.

When more than one grounded machine is connected to a bus through short feeders, good lightning protection is provided with a single set of capacitors and arresters at the bus, provided all exposed incoming lines are connected to the bus and there is no exposed line section between the bus and a machine. If more than 500 feet of line connects a machine to the bus, it is best to provide a set of capacitors and arresters at the machine. In some cases machine protective apparatus may be desirable for protection against switching surges. It should then be placed on the machine side of the machine circuit breakers.

The present practice of applying the same amount of capacitance to ungrounded machines as for grounded machines up to 6900 volts, and using double capacitance for 11 500 to 13 800 volts, has in general provided satisfactory protection. Recent study, however, indicates that for certain conditions more positive protection of the neutral is desirable and can be obtained by the addition of a capacitor and arrester in the neutral with arresters and the same capacitance as used for grounded machines at the machine terminals. The neutral arrester prevents overshooting of voltage at the neutral from reflections. The capacitor prevents a steep neutral-voltage rise and a sudden drop when the neutral arrester discharges. This method of protection can be justified economically for machines of 11 500 to 13 800 volts where the neutral is brought out, mounting space is available, and where protection is applied to each machine.

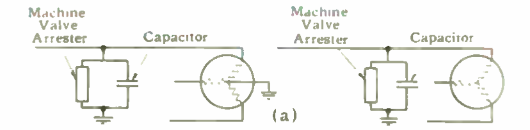
Where more than one ungrounded machine is connected to the bus, one set of arresters and two sets of capacitors can be applied to each phase at the bus. Better still is to connect one set of capacitors and arresters on each phase at the bus and one set at the neutral of each machine.

In general, ungrounded machines require different machine protective equipment than grounded machines only when they are connected to overhead lines directly or through cables, as subsequently discussed.

Machines Connected Directly to Overhead Lines

In protecting machines of this class, line-type arresters must be placed far enough out on the line that sufficient equivalent inductance is present to produce, in conjunction with the machine capacitors, the required wave sloping. Five hundred feet of line for 650-volt machines, and 1500 feet for all higher voltage classes have commonly been used. A detailed study has been made of the machine-voltage conditions. These were made both analytically and through the use of equivalent circuits to represent sections of overhead lines, cables, and terminal apparatus. The surge-current and voltage conditions were produced with a surge generator and measurements made with a cathode-ray oscillograph. The lightning-current investigations indicate that line-arrester discharge currents of 20 000 amperes provide a conservative basis for such a study. One set of valve-type line arresters, 1500 feet out on the line, permits machine-voltage wave fronts that are too steep for ground resistances of more than two or three ohms when overhead ground wires are not used. A De-ion arrester (type A) with an unlimited fault-current rating, obtained without the use of a series resistance, has been found more effective for use as the line arrester because of its low discharge voltage. However, even with one set of these the grounding resistance should be limited to three to five ohms.

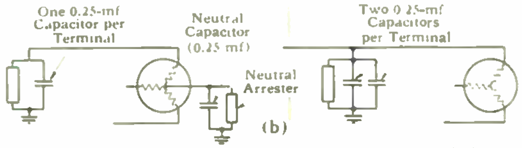
The two methods of line protection shown in Fig. 2 are recommended as providing the most effective and economical schemes for general application. The scheme of Fig. 2 (a) is recommended where the section of line between the line arresters is exposed to lightning. The multiple arrester grounds provided by the overhead ground wire permit a minimum length of 500 feet for the ground wire when the listed pole grounding resistances can be obtained. For this



(a) FOR ALL GROUNDED MACHINES AND FOR UNGROUNDED MACHINES UP TO AND INCLUDING 6.9 KV.

Machine Voltage Class	Surge Capacitors		Machine Valve Arrester Ratings RMS Kv	
	Microfarads	Voltage Rating RMS-Kv	Grounded	Ungrounded
For Grounded and Ungrounded Machines				
650	2.0	0.65	0.75	0.75
2400	0.5	2.4	3.0	3.0
4160	0.5	4.16	3.0	4.5
4800	0.5	4.8	4.5	6.0
6900	0.5	6.9	6.0	7.5
For Grounded Machines				
11 500	0.25	11.5	9.0	...
13 800	0.25	13.8	12.0	

Arrester rating is determined by machine grounding conditions when mounted at machine, but upon system grounding when mounted at bus.



Where neutral is readily available and space permits.

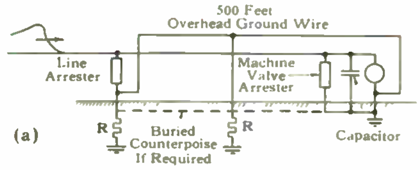
Where neutral is not available or neutral protection not economical

(b) FOR 11 500–13 800-VOLT MACHINES WITH NEUTRAL FLOATING, GROUNDED THROUGH RESISTANCE OR REACTANCE EXCEEDING 50 OR 0.2 OHMS, RESP., PER 100 OHMS OF WINDING SURGE IMPEDANCE.

Machine Voltage Class	Terminal Equipment Voltage Rating in RMS-Kv		Neutral Equipment Voltage Rating in RMS-Kv	
	Capacitors	Arresters	Capacitors	Arresters
11 500	11.5	12	6.9	7.5
13 800	13.8	15	11.5	9.0

Minimum surge impedance can be taken as 100 ohms. If grounding impedance at 60 cycles is low enough that machine can be considered grounded from normal fault voltage standpoint, the arresters (a) may be used at terminals and (b) at the neutral.

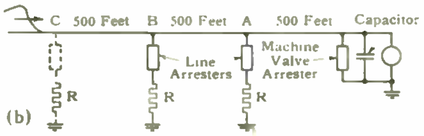
Fig. 1—*Apparatus for surge protection of machines.*



(a) CASES WHERE OVERHEAD GROUND WIRE IS REQUIRED FOR ADEQUATE SHIELDING.

Maximum Permissible Pole Grounding Resistance, R in Ohms		
Spacing of Pole Grounds	250 ft.	125 ft
Type of Line Arrester		
De-ion Valve	5–10 2–5	10–20 4–10

If these resistances cannot conveniently be obtained with driven ground rods, buried counterpoise connecting line arresters to machine ground should be used.



(b) CASES WHERE OVERHEAD GROUND WIRE IS NOT USED (STROKES TO LINE WITHIN 1000 FEET MAY ENDANGER MACHINE).

Type of Line Arrester	Maximum Permissible Line Arrester Grounding Resistance, R in Ohms	
	Two Sets of Arresters at A and B	Three Sets of Arresters at A, B, and C
De-ion Valve	10–20 5–10	20–40 10–20

Fig. 2—*Line protection for machines connected directly to overhead lines. Machine valve arresters and capacitors should be applied as described in Fig. 1.*

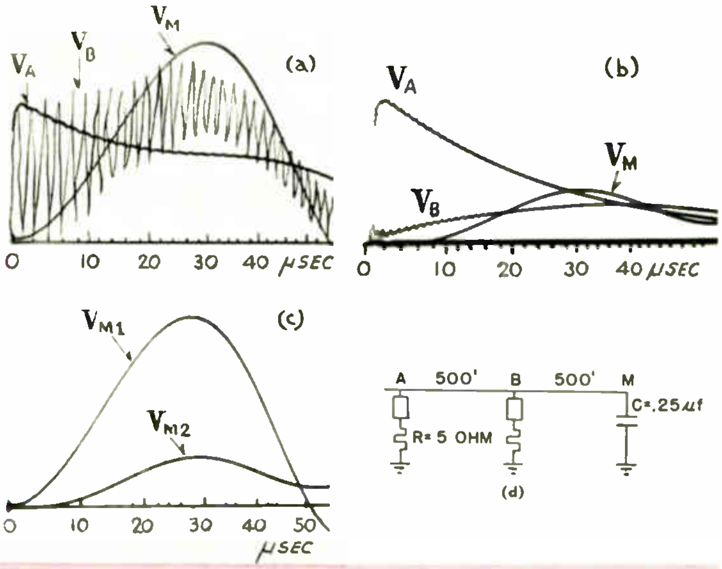


Fig. 3—*Showing the reduction in machine terminal voltage,* V_M *provided by extra set of De-ion arresters at the point B of (d). No overhead ground wire. (a)-Arresters at A only; (b)-Arresters at A and B; (c)-*V_{M1}*, arresters at A only,* V_{M2}*, arresters at both A and B.*

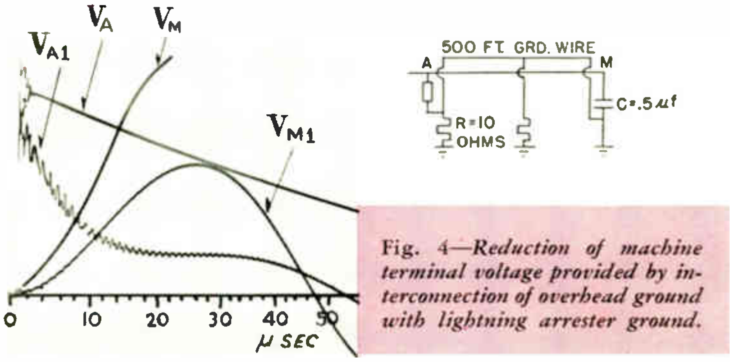
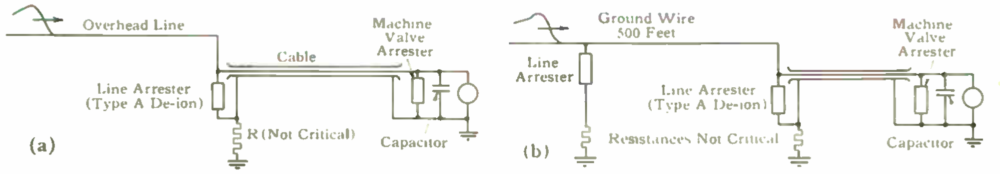


Fig. 4—*Reduction of machine terminal voltage provided by interconnection of overhead ground with lightning arrester ground.*

length of ground wire, sufficient direct-stroke protection is obtained with a line insulation level of 250 kv. If these ground resistances cannot be obtained with driven rods, a buried counterpoise can be used. The line construction is usually more economical even with the counterpoise than a longer section of ground wire with higher pole-ground resistances, because an increase in line-insulation level would also be required. Where an overhead ground wire is not used, Fig. 2 (b), the benefit of multiple sets of line arresters arises from the fact that for incoming surges the farthest set of arresters discharges most of the surge current permitting a much lower line-to-ground voltage at the inner sets. The actual benefit provided by the ground wire interconnections and the use of multiple De-ion lightning arresters is shown by the oscillograms of Figs. 3 and 4.

Machines Connected to Overhead Lines Through Cables

The line protection recommended when cables are connected between the line and machine is given in Fig. 5. When line arresters are connected directly to the cable sheath through short leads, the voltage that can be transferred through the cable is only the arrester discharge voltage plus the drop across the short grounding lead. The much lower discharge voltage of De-ion arresters permits considerable simplification in the line protection. These schemes of protection should be used only when De-ion arresters are applied at the cable pothead.



(a) For cables sufficiently long that section of line is not required for wave sloping.

Cable Surge Impedance in Ohms	5	10	25	50
Minimum Cable Length in Feet	2000	1000	500	300

(b) For cables longer than 200 feet, but not long enough to be classified with (a). An overhead ground wire is preferred but not essential.

Fig. 5—For protection of machines connected to overhead lines through cables, machine valve arresters and capacitors should be applied as in Fig. 1.

Machines Connected to Lines Through Transformers

Inasmuch as the transformer leakage inductance is always sufficient for wave-sloping purposes, it is not necessary to provide arresters out on the line when machines are connected through transformer banks. However, consideration must be given to the surges that can be transferred both electrostatically and electromagnetically through the transformers. The following steps provide a method of determining the lightning protection required under these conditions:

1—Station-type arresters should be provided on the line side of the transformer bank.

2—Both capacitors and machine valve arresters should be used when the need for either is indicated.

3—When machine protection is required, only one set of standard capacitors and machine valve arresters is required at the machine terminals regardless of whether the machine is grounded or ungrounded.

4—Machine surge protective apparatus should be applied to protect against surges transferred electrostatically through transformers unless 50 to 100 feet of cable, providing an effective capacitance of 0.005 microfarad or more per phase, is connected to the machine terminals. The data on cable capacitance given in table I can be used. The capacitance of the machine windings is not effective in suppressing this component. The winding acts only as a surge impedance during the first few microseconds.

5—Machine-protection apparatus should also be used to protect against surges transferred electromagnetically unless both of the following conditions are satisfied:

a—To assure adequate wave sloping. C_1 is equal to or greater than $15/L$.
where C_1 = positive-sequence, line-to-neutral capacitance of cable in microfarads.
L = Leakage inductance of transformer bank in microhenries on line-to-neutral base referred to machine side.

b—To limit the magnitude of the induced surge. C_1 is less than $(AL)\,10^{-6}$,
where A has the values given in the table below.

Transformer-Bank Connections	Waterwheel Generators and other slower speed machines. Machine Kv class 2.4	4.16	4.8-6.9	11.5-13.8	Turbo-generators and machines 1800 rpm and above. Machine Kv class 2.4	4.16	4.8-6.9	11.5-13.8
a-Wye to Delta on Machine side								
Grounded Systems 80% arresters*	60	15	8	4	200	70	30	15
Ungrounded Systems 100% arresters	12	4	2	1	45	20	10	5
b-Machine protective equipment is recommended with wye-wye banks having both neutrals grounded.								
c-All other bank connections								
Grounded systems	20	6	4	2	70	30	15	7
Ungrounded systems	6	1.4	0.8	0.3	25	8	3	1

*Station arresters on line terminals of transformers.

6—This means of determining the use of protective apparatus is conservative. For example, it indicates that most large and therefore important machines should be protected. A more detailed method of calculation is given elsewhere.[1] Because of the conservative values used, more accurate calculation or experience may show that protection is not required for some cases where this summary indicates it to be necessary. The authors are of the opinion that in any doubtful cases protection should be applied since the expense is small compared to the investment in machines.

TABLE I—EFFECTIVE SURGE IMPEDANCE (OHMS) AND POSITIVE-SEQUENCE CAPACITANCE (MICROFARADS) OF PAPER INSULATED CABLES*

Three-Conductor Belted Cables

Cond. Size Circular Mils	Voltage Classes-Kv 0-1 Imp.	0-1 Cap.	2-3 Imp.	2-3 Cap.	4-5 Imp.	4-5 Cap.	7-8 Imp.	7-8 Cap.	14-15 Imp.	14-15 Cap.	Type H Cables 14-15 Imp.	14-15 Cap.
4	29	0.010	31	0.008	34	0.007	36	0.006	42	0.005	22	0.006
1	22	0.012	25	0.010	30	0.009	30	0.008	36	0.007	17	0.008
00	14	0.020	17	0.015	22	0.012	23	0.011	29	0.009	15	0.009
250 000	11	0.023	13	0.021	15	0.017	19	0.015	23	0.012	11	0.012
500 000	8	0.036	9	0.030	12	0.024	13	0.021	17	0.015	9	0.015
750 000	5	0.049	7	0.040	9	0.030	10	0.026	13	0.019	8	0.018

Single-Conductor Cables

Cond. Size Circular Mils	Voltage Classes-Kv 0-1 Imp.	0-1 Cap.	2-3 Imp.	2-3 Cap.	4-5 Imp.	4-5 Cap.	7-8 Imp.	7-8 Cap.	14-15 Imp.	14-15 Cap.
4	14	0.014	16	0.012	19	0.011	24	0.008	33	0.006
1	11	0.019	12	0.016	14	0.014	20	0.010	24	0.008
00	8	0.024	10	0.019	12	0.017	16	0.012	22	0.009
250 000	6	0.032	8	0.027	9	0.022	13	0.016	17	0.012
500 000	4	0.044	6	0.034	7	0.029	10	0.021	13	0.016
750 000	5	0.040	6	0.035	6	0.035	8	0.025	11	0.018
1 000 000	4	0.048	5	0.038	5	0.038	7	0.027	10	0.020
1 500 000	4	0.018	4.5	0.043	4.5	0.043	6	0.032	8	0.023

Specific inductive capacity $k = 3.7$
Velocity of propagation $v = 512$ ft per microsecond

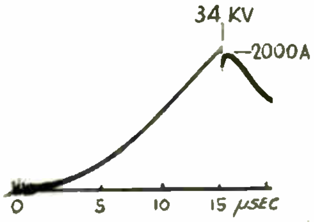
*Effective surge impedance for surge propagation on only one phase. This is the most severe condition. For single conductor and type H cables this is the positive-sequence surge impedance. For belted three conductor cables, it is equal to 4/3 the positive-sequence surge impedance.

If machine protection apparatus is not required for lightning surges, it may still be desirable for protection against switching surges. However, it is usually preferable to limit such surges by proper grounding methods.

REFERENCE

1—Technical Paper No. 44-17, by G. D. McCann, E. Beck, and L. A. Finzi, presented at Mid-Winter Convention, A. I. E. E., January, 1944.

Fig. 6—Discharge voltage of actual 12-kv machine lightning arrester with a 0.25-microfarad capacitor placed in parallel with the de-ion lightning arrester.



What's New!

Performance—Right on the Nose

Nothing is more disheartening (except to the enemy) than to expend the time, trouble, and expense of getting a fragmentation bomb to the war-area supply depot and then brave the ack-ack flak and enemy fighter planes just to drop, with great precision, a dud.

Simplest way to prevent duds, of course, would be to arm the bombs (ready them to explode on impact) before they are shipped to the fighting fronts. Safety requires, however, that these bombs explode only after they are released from the plane. This necessitates the use of a fuze* that detonates the bomb on impact yet provides safety during handling and shipping.

To make sure these arming devices, called bomb-nose fuzes, are both safe and effective, Westinghouse engineers designed a new-type wind tunnel. This wind tunnel not only tests bomb-fuze assemblies now in production, but also was used in the development of fuze refinements to cut down duds and permit the setting of the fuzes to a degree of precision heretofore impossible.

This wind tunnel, Lilliputian in comparison to the wind tunnels for planes, uses a blast of compressed air against the fuze propeller blade to simulate air speeds as high as 800 miles per hour instead of using high-speed fans to produce this hurricane in miniature. The tunnel is some three feet long and about five inches in diameter. The compressed air is supplied from a large cylindrical storage tank. At various speeds—250, 500, and 800 miles per hour—the bomb must be armed within a stated period. Incorporated in the wind tunnel is a light source and a photoelectric-cell timing device which records exactly the performance of fuze assemblies sampled from daily production.

This wind tunnel automatically checks the arming time to one one-hundred-twentieth of a second. The tunnel was used in the design of a new fuze of improved uniformity and reliability. Most important, since production started on the new fuze, not a single fuze has failed to meet the stringent test requirements.

*Note—In military parlance, the word is spelled fuze. However, in electrical parlance, the protective device is spelled fuse.

Simplicity the Keynote of New Gearmotors

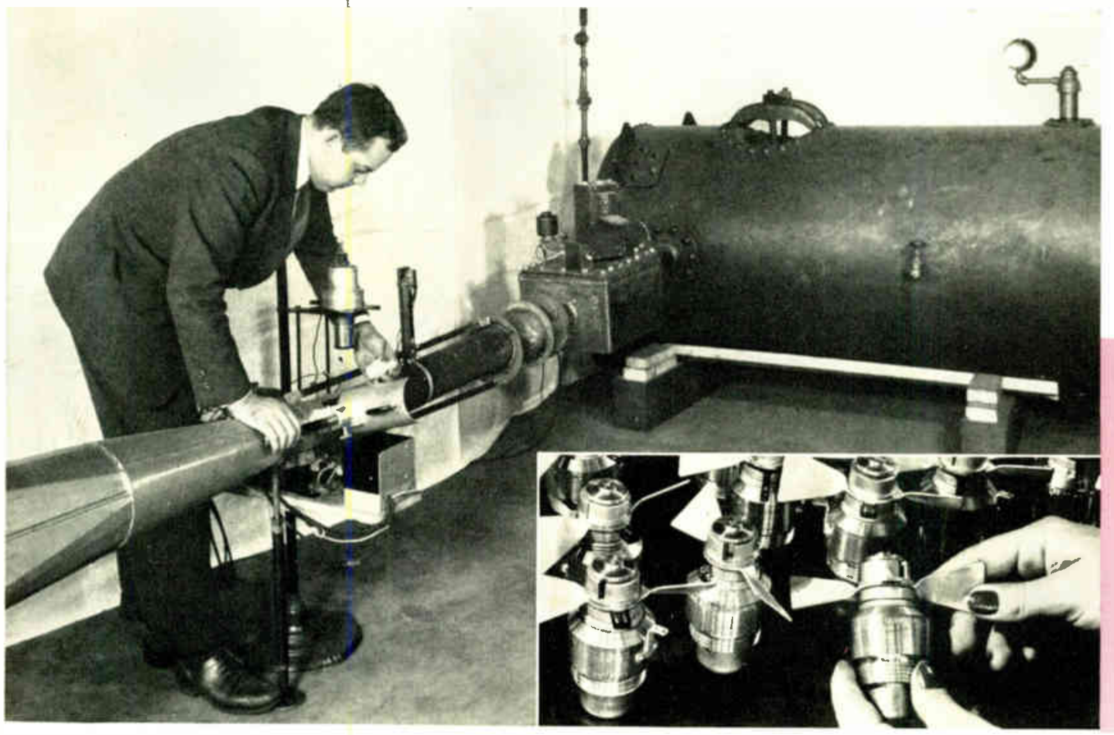
When a good golfer drives, he keeps his eye on the ball, but he also keeps his second shot in mind and plans his drive accordingly. The users of drives for industrial equipment may well keep in mind the peacetime shot after the present war drive. The new line of Westinghouse gearmotors offers not only advantageous interchangeability of parts between units of a given horsepower, but also the interchangeability of all Westinghouse standard-type NEMA frame motors on the three styles of gear units used to cover the speed range. This permits the rapid application of the drives to new duties without delay.

This new line of gearmotors was the first to be specifically designed and manufactured in accordance with the recommended practice of the American Gear Manufacturers Association for parallel-shaft type units.

These gearmotors meet the speed-reduction requirements for a wide variety of industrial applications in a range of 1 to 75 horsepower. Each of the three gearmotor units is supplied with AGMA standard output speeds within their respective gear-ratio capacity.

The use of 1750-rpm, four-pole motors wherever possible provides the minimum size of motor for a given gear combination and thereby improves the overall efficiency. The use of adapter castings standardized for each type of motor enclosure provides easy interchanging of motor types. The renewal-parts inventory required for unit types of the same size is minimized by the interchangeability of parts.

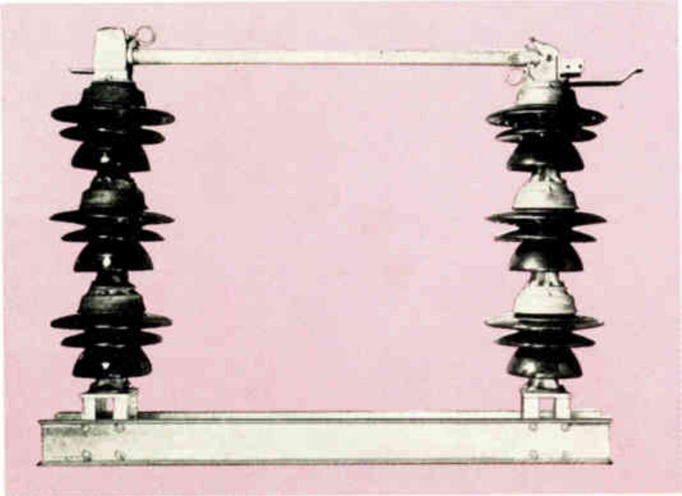
Equipped with anti-friction bearings of ball and roller type, the gearmotors are lubricated by the simple but effective splash method. The gears and pinions are given a special heat treatment before hobbing, which produces a tapering hardness from surface to core. This results in tough impact-resisting teeth. The sturdy, compact housing has an exterior rib at each mounting hole providing maximum foundation stability. The three unit styles, one single reduction, and two units of double reduction are designed to accommodate gear-ratio ranges of from 1.22 to 58 and 3 to 1. These provide output speeds of from 30 to 1430 rpm, the horsepower, output speed, and gear ratio depending on the standards governing the application. Occupying less space than other drives, requiring less maintenance and having a greater efficiency, the new line of gearmotors presents a distinct advance in motor-gearing engineering.



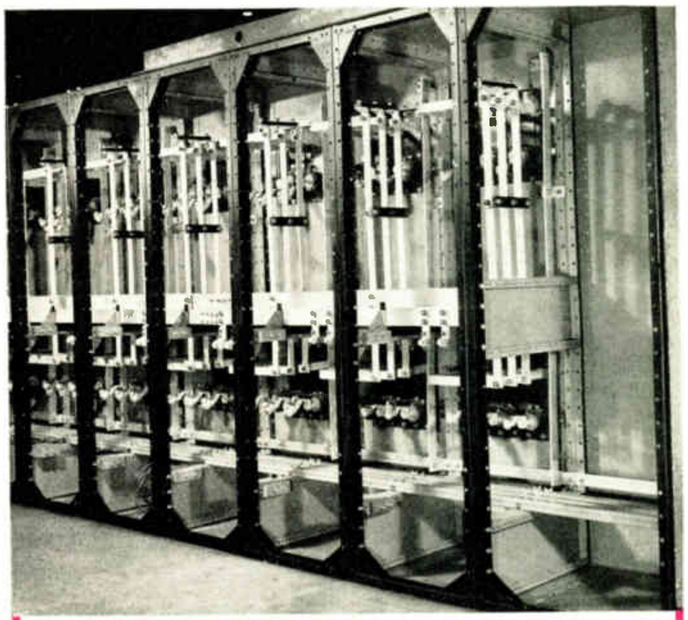
This miniature wind tunnel provides the "proving air" to test bomb fuzes under all air-speed conditions up to 800 miles per hour. In addition to routine testing of production samples, such as shown in the insert, here also are born the innovations that improve the deadliness of our aerial bombs. Through the efficacy of this wind tunnel, no duds are made.

New Fuse for the Higher Voltages

A newly designed fuse utilizing some of the standard features of the successful boric acid fuse has been developed to interrupt circuits as high as 138 kv. These high-voltage fuses, which in the 138-kv size are six feet long, have an interrupting capacity approximating 1 000 000 kva. The maximum voltage rating previously attained by the boric acid fuse was 34.5 kv in a design that made use of a renewable interrupting element in a porcelain tube and which could not be carried to higher voltages because of size and weight considerations. In the new fuse, the design is modified to the point where the equivalent of the renewable element only is required. This makes the design of the renewable element, now the entire fuse, more costly; however, it is economically sound since the first cost and operating cost of the old renewable type are balanced against the cost of the new design for the normal life expectancy of a high-voltage fuse installation. In the new design, the porcelain tube is replaced by Micarta. A sliding contact is substituted for the current-carrying shunt and the operating spring is placed inside the sliding contact. When the newly developed fuse was tested, it was found that interrupting the high voltages caused a voltage field disturbance, with the possibility of a flashover on the outside of the insulated tube. At these voltages additional length is not the answer, so that the fuse tube is designed to graduate the interrupting voltage stress by means of interwound foil, giving a distributed-capacity effect in the tube, comparable to that achieved in the condenser bushing. This distributed capacity enables the insulation to cope with the voltage surges met on interruption. These fuses are available in voltage ratings from 7.5 kv through 138 kv. When used to connect equipment or feeder circuits to important systems, the reliability of the complete system is increased by the rapid isolation of faults. The fuse incorporates a construction whereby it is dropped out of the circuit after the current is interrupted. This complete air break in the circuit removes the possibility of leakage currents causing a flashover.



This new type of fuse, rated at 115 kv, is similar to the six-foot long unit that has an interrupting capacity of 1 000 000 kv.



Adaptable for all types of metal-enclosed low-voltage switchgear, the universal frame eliminates many parts and much welding.

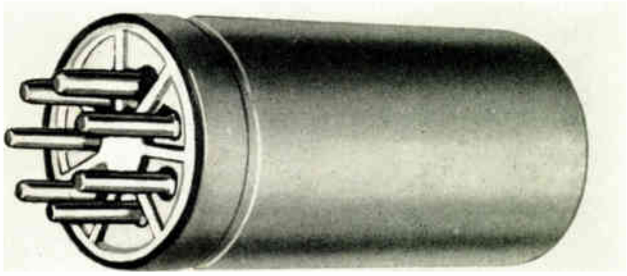
Unit Metal-Enclosed Switchgear—To Order

Toys ofttimes follow closely the engineering of full-size operations, as model railroad and airplane enthusiasts can well attest. The new Westinghouse metal-enclosed low-voltage switchgear reverses this order and borrows from the Erector model builder the idea of perforated angles, and stock-size parts that can be bolted and fitted together to form units that precisely fit the individual needs of the job at hand.

Originally strictly custom-built, the metal-enclosed switchgear picture was changed several years ago by the Westinghouse unitized design whereby thirteen basic units in various combinations met practically any requirements for 600-volt switching equipment. The development has been carried a step further and to standardization of units has been added the wider use of a smaller variety of parts. The universal frame idea has been applied to low-voltage switchgear and quantity-made parts are carried in stock so that a number of combinations of breakers and associated equipment can be swiftly assembled without cutting steel members and with a minimum of welding.

This assembly method affords a maximum of materials conservation in addition to allowing the utmost in flexibility for matching the equipment to the needs peculiar to a given job. Parts have been simplified and so designed as to lend themselves to several applications. Changes can easily be made in the field to increase the current capacity of an assembly or new units can be added to an installation by merely bolting in new members and new electrical components.

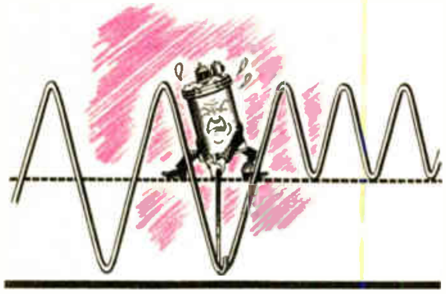
The various steel parts carried in stock are prime coated and need only to have applied the specified final finish. Assembled from stock parts, a unit exactly fitting the specification of the job is shipped more quickly than heretofore possible.



You can't readily boil an egg at 40 000 feet, but contacts on a conventional radio vibrator will "boil" away in ten hours. Thus, the supply of radio power is assured for one flight, maybe. As a result, vibrators have not been used on military-plane applications. Bonding porcelain to metal, using Westinghouse solder-seal technique, now has the vibrator situation well in hand. The destructive elements, corona and arcing, are greatly enhanced in the rarefied atmosphere at high altitudes. The insulating base of Prestite, upon which is mounted the vibrating unit, is now soldered to the enclosing metal case and the connecting pins, making the entire unit hermetically sealed. Filled with an inert gas under pressure, the life expectancy of the vibrator is now equal to that of the plane.

PERSONALITY PROFILES

Many Army and Navy reserve officers have been deferred from active duty at the request of their employers. Few have been deferred because of the vigorous insistence of their employer's customers. *J. H. Cox* is one of these. He has the rank of Lieutenant-Commander in the U. S. Navy Reserve, having maintained active interest in the Navy Reserve since the last war from which he "graduated" as a Lieutenant (j.g.). When this war broke out he all but packed his bag to go when word came from Washington that he was deferred at the urgent request of the nation's producers of aluminum and magnesium on the basis that in providing them with ignitron rectifiers his services were absolutely indispensable.



The fact that Cox didn't attend high school did not prevent him from getting his B.S. in electrical engineering from M.I.T. in only three years, graduating in 1923. He joined Westinghouse that same year and continued to make up time lost as a result of the war by hurdling the usual training courses, and entered the Service Department. In 1924, as a protege of Dr. Fortescue, he went to California to study flashover characteristics and surge phenomena on the famous 220-kv transmission line, then just completed. After several years of work in making field studies of lightning, he transferred his activities to the Mercury-Arc Rectifier Section, of which he soon became the head, the position he now holds—and which has been so important in the battle of light-metals production.

* * *

Old saws to the contrary, all work and no play in the case of *J. E. Ponkow* and *N. A. Smith* resulted in sharpening their wits for the production of a greater number of war-needed welders. It is particularly fitting that Ponkow's name should appear here as an author as it betokens somewhat the return of a native. Before graduating from Johns Hopkins University he worked summers with Westinghouse, both at East Pittsburgh and Baltimore. Upon graduating in 1937, with the degree of Bachelor of Engineering, Ponkow became a full-time employe in the Westinghouse East Pittsburgh plant, later going into application work in the Pittsburgh office. In 1941 he became chief electrical engineer for the Federal Machine and Welder Company at Warren, Ohio. His responsibilities allow little time for his usual sports activities, bowling, ping-pong, and swimming, and the film drought curtails his photographic indulgences for the duration.

Neal Smith was graduated from the Ohio State University ('41) with the degree of Bachelor of Electrical Engineering. He immediately entered the employ of the Federal Machine and Welder Company. A member of the honorary engineering fraternities, Eta Kappa Nu and Tau Beta Pi, he is also an associate member of the A.I.E.E. Both Ponkow and Smith are teaching electronic classes several nights a week, training large groups, to take over additional responsibilities, one answer to the manpower shortage.

* * *

A man of many facets is *T. R. Lawson*. Upon graduating with a degree of Bachelor of Science in Electrical Engineering from Johns Hopkins University in 1928, he embarked upon the student course of Westinghouse in the same year. Showing a predilection for trouble shooting in the motor, generator, and welding sections, he hit his stride in 1937 as an a-c motor and control specialist. Calling upon his store of practical experience, Lawson has been more and more active in liaison work, smoothing the path of negotiations, insuring the procurement of needed apparatus and just plain getting materials that are impossible to obtain. Seeing a great need for an engineering discussion of resistance welders written in layman's language, Lawson wrote such a brochure nearly two years ago. It has had wide acceptance and has paved the way for other publications written in simple language to explain intricate operations clearly. The duck blinds of the Eastern shore know him but seldom now. Lecturer extraordinary, when the industrial Chautauqua circuit knows him not he is active in his other role as a gentleman farmer. And come November first each year, he roams his rolling acres, gun in arm, with his springer. "Saves ration points," says he.

* * *

The credit side of the ledger of war is not entirely a blank page. One credit entry is the bringing to this country men of technical talent, such as *Dr. Leo A. Finzi*, who has in the four years since arriving from Italy become as enthusiastic an American as our native born, or more so. Dr. Finzi, born and raised in Italy, obtained the foundation of his technical training at the Naples Royal University, from which he graduated in 1926 as Master Electrical Engineer. From 1927 to 1931 he worked at Cologne, Germany for a well-known manufacturer of high-voltage apparatus. Dr. Finzi returned to Italy in 1931, working with the Volturno Electric Power Company, in charge of the erection and operation of new power stations on the Volturno River, a name now seared into the memory of Americans. His alma mater beckoned him, and he returned to the Naples Royal School of Engineering as associate professor. Late in 1938—as Dr. Finzi so succinctly and in characteristic American fashion sums it up—he became fed up with Italy. He started for the United States, stopping en route for a time in England. He joined the Westinghouse Company and is now in charge of the impulse laboratory at East Pittsburgh. His hobby is learning about things American. "I am," he says with a twinkle, "an ardent Li'l Abner fan."

IGNITRON RECTIFIERS

are supplying the direct current for three fourths of the aluminum and magnesium being produced. Aside from many intrinsic merits, the ignitron was first choice for nearly all new reduction plants because they could be built in much shorter time.