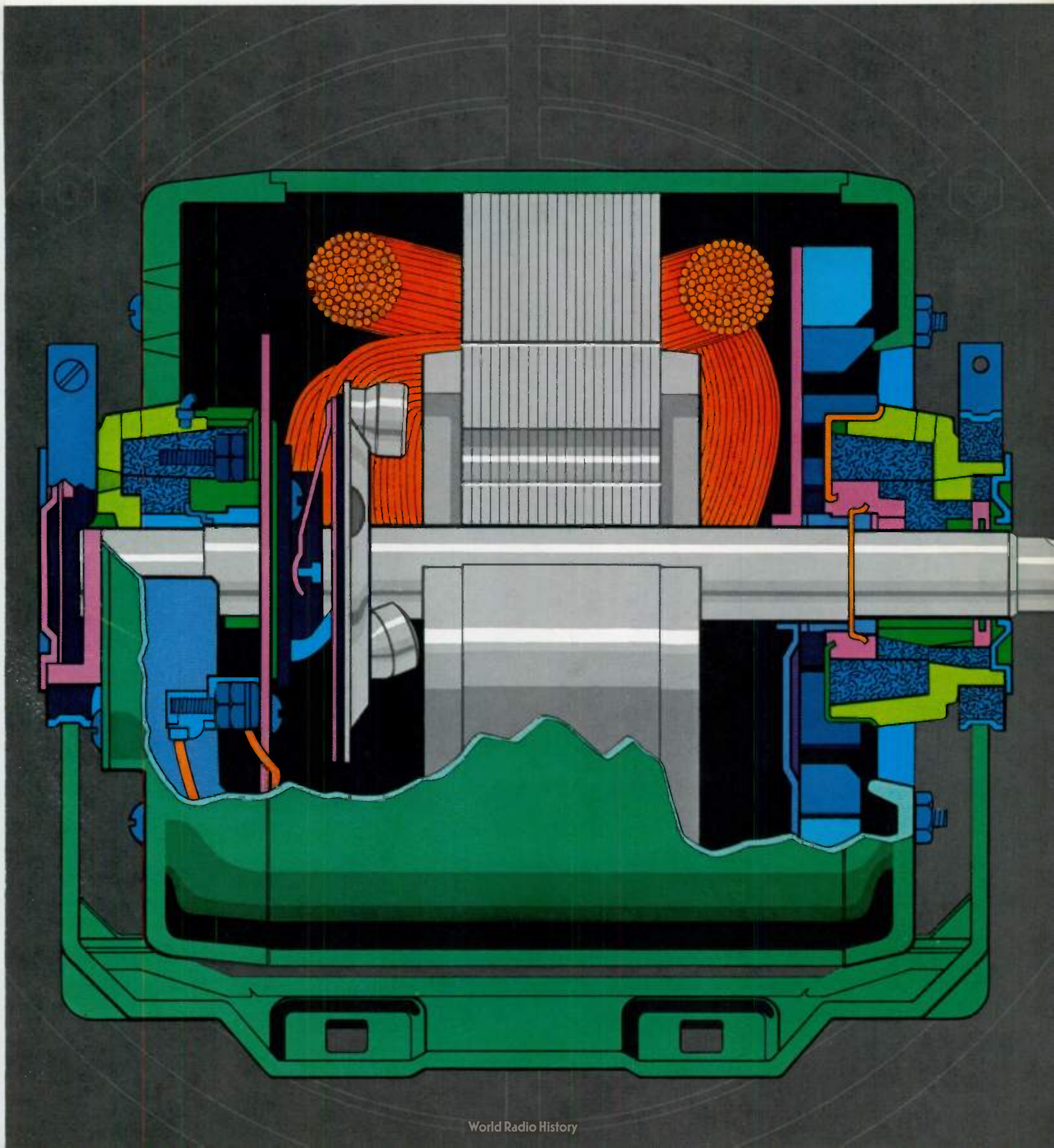
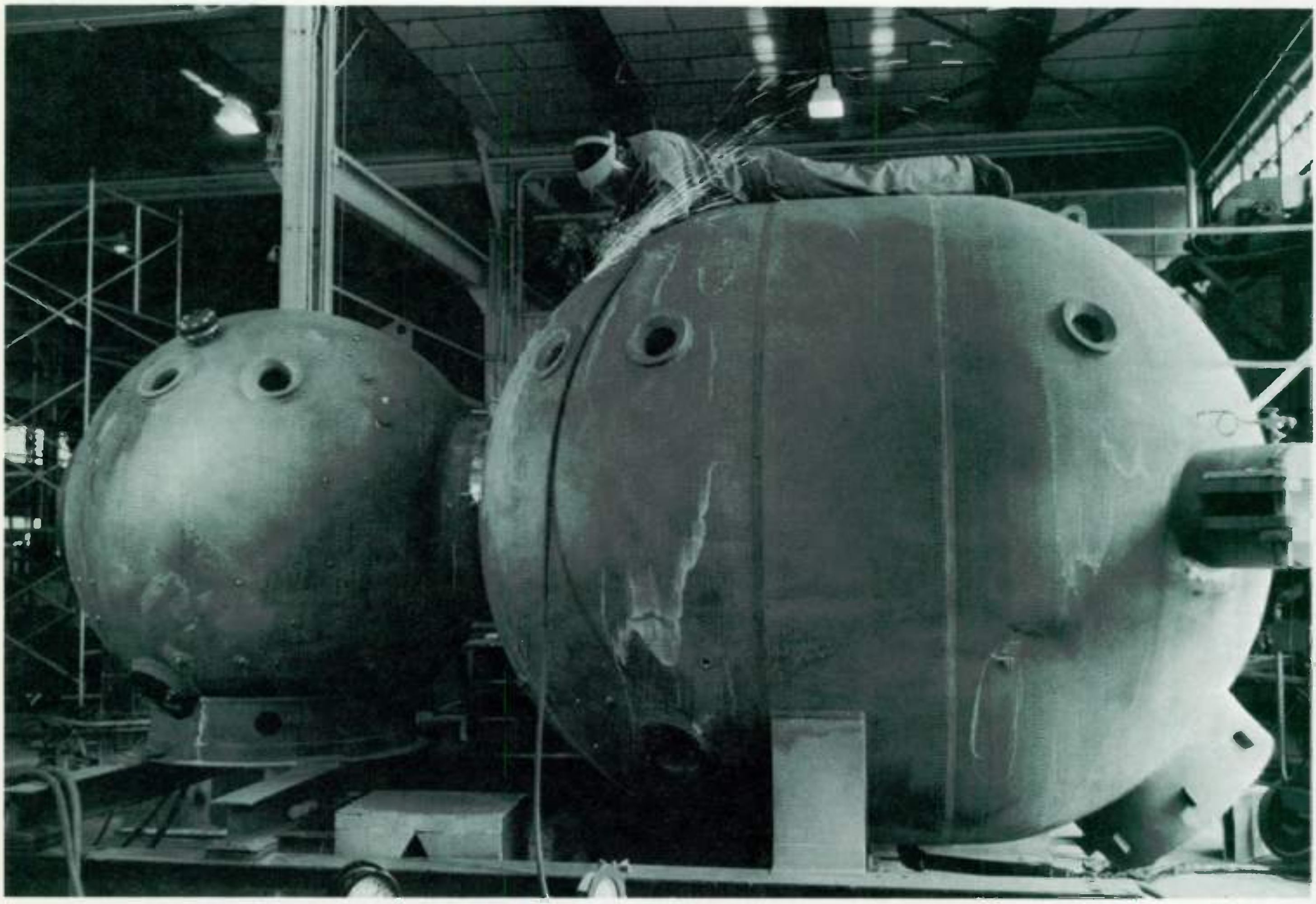
Westinghouse ENGINEER

November 1967





Pressure Vessels Readied for Diving Research Facility

Finishing touches are being applied here to two of the three steel pressure vessels for a new deep-diving research facility. The sphere on the left is an entry chamber where research workers will enter the system through an air lock. They will live in the larger chamber for days or weeks, and a third chamber partly filled with water will permit testing of equipment and techniques under realistic conditions. The three chambers can subject men and equipment to pressures up to that produced by 1500 feet of water. They will be connected by pressure-tight hatches. Research in diving physiology and improvement of diving equipment and techniques will be the major areas of work in the new facility. (For more information, see article on page 188.)

Westinghouse ENGINEER
November 1967, Volume 27, Number 6

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Subscriptions: United States and possessions, $2.50 per year; all other countries, $3.00 per year. Single copies, 50¢ each.

Mailing address: Westinghouse ENGINEER,
P. O. Box 2278, 3 Gateway Center,
Pittsburgh, Pennsylvania 15230.

Published bimonthly by the Westinghouse Electric Corporation, Pittsburgh, Pennsylvania. Printed in the United States by The Lakeside Press, Lancaster, Pennsylvania. Reproductions of the magazine by years are available on positive microfilm from University Microfilms, Inc., 300 North Zeeb Road, Ann Arbor, Michigan 48106.

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Cover design: A typical fractional-horsepower motor symbolizes those versatile power sources in the cover design by Tom Ruddy. An article on the motors and their uses begins on page 175.

Peaking Plants Can Provide System Cost Reductions

M. J. Boho

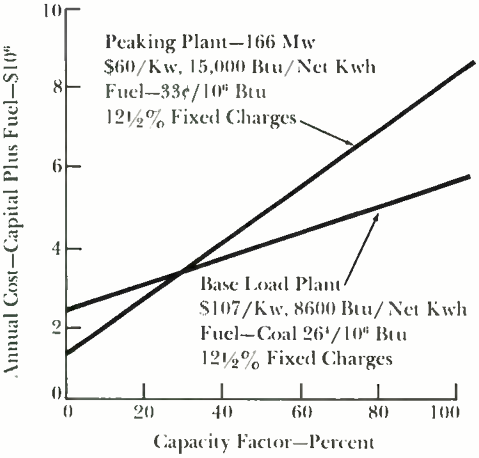
Peaking planned as an integral part of a utility's system expansion program now bids to follow previous movements to more efficient turbine designs, larger generating units, integrated power pools, and nuclear fuel.

Recent utility system simulations indicate that investor-owned utilities have the opportunity to effect substantial cost reductions in the years ahead through an approach to system generation based on an economic trade-off between capital investment costs and production costs—on a scale considerably greater than has been practiced before.

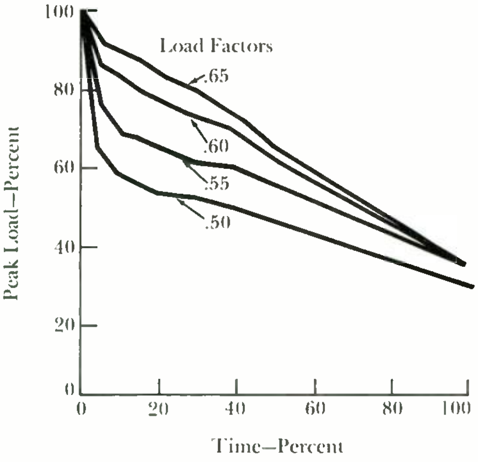
Utilities have always calculated the value of a Btu to optimize cost against value and arrive at the most economical combination for their situation. But these calculations have generally assumed that only base-load units would be used, and have been carried out within restricted ranges around some base point with departures of perhaps 0.7 percent in plant efficiency. The approach now proposed uses plant concepts in which efficiency and cost may vary as much as 70 percent from present base-load values. Operating efficiency is deliberately and substantially sacrificed to gain lower \$/kw investment costs. These low-cost plants would be used principally to provide reserve capacity and to supply only part of a utility system's peak-load requirements.

The system studies indicate that cost reductions up to four percent of the utility's total minimum revenue requirements may be possible. The approach applies to fossil or nuclear expansions and to pooled or nonpooled systems, and it represents additional savings not now realized.

For example, an investor-owned utility system in a 25-cent per million Btu fossil-fuel cost area might expect a potential savings of eight percent to result from conversion from fossil to nuclear base-load plants. The four percent cost reduction that can be effected with a peaking plant program is not in lieu of these savings, but rather, an *additional* source of savings.



1—Annual cost of generation at low capacity factor is less for peaking plant than for base-load plant.



2—Annual load duration curves for four utilities show that system base load is approximately the same percentage of system peak load although load factors vary considerably.

Need for Economic Evaluation

The history of technical development in generation plant and equipment has been one of a continuing struggle to lower operating and equipment costs without jeopardizing system reliability. The principal mechanism for assuring generation reliability has been and probably will continue to be the maintenance of reserve generation capacity. Because reserve does not increase revenues, but does increase investment costs, any move designed to lower the cost of owning and operating generating equipment must take into account the reserve generating capacity requirement.

For example, the more efficient high-pressure, high-temperature fossil units of the late 50's and early 60's had boiler and turbine designs that more closely approached the frontiers of metals technology. The resulting increased risk of forced outage required a corresponding increase in reserve capacity.

Again, the recent move to larger individual generating units lowered \$/kw capital investment, but also increased reserve requirement in many instances because of the risk of losing generation in larger increments. Interconnections, which transfer the reliability responsibility in part to a transmission line, may bring about a wave of even larger generating units than might otherwise be economically justified and actually force a further increase in reserve requirement, rather than a decrease as had been anticipated. Certainly, the situation is not clear at this time.

Now, nuclear power raises the question not only of unit size and its effect on reserve requirements, but also of the most economic future role of existing single- and double-reheat fossil units. The future operation of existing base-load units and new unit additions (both fossil and nuclear) to the system will be affected by each succeeding unit addition.

The proposed peaking plant approach would have a major effect on the future operation of existing base-load units and

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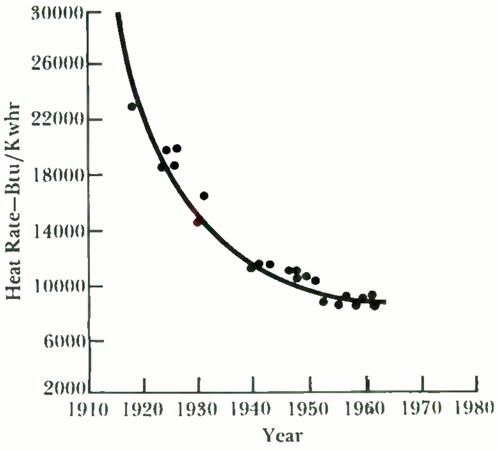
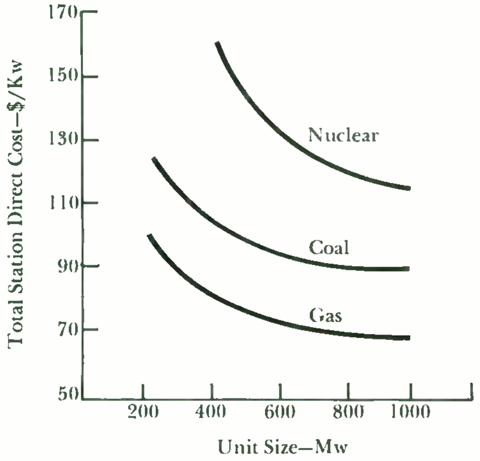


3—Historical heat rate improvement for one utility illustrates the declining rate of improvement with present efficient generating units.



4—Generation unit costs for equipment and installation show a diminishing rate of reduction for all types of plants as generating units get larger.

new base-load additions. Low capital cost peaking plants, with special-purpose generating equipment specifically designed to be most economical for intermittent and low-usage utility service, could defer large blocks of capital investment in base-load generation plant and increase the capacity factor of existing and future base-load units. Thus, system expansion would consist of an optimum mix of these special-purpose plants and base-load plants. An economic evaluation of this approach requires that all known financial effects of the peaking plant be combined with the existing situation to provide a close assessment of most probable results. At present, the most satisfactory way to assess the overall net economic value of the proposal is to simulate system operation with digital computer techniques.

Basic Considerations

A full appreciation of the potential benefits of a mixed pattern of low-investment-cost peaking units and low-production-cost base-load units in a utility system expansion plan comes from recognition of several basic ideas:

The cost of capital and the cost of fuel are equivalent—a cost dollar spent annually in either area has the same effect on net return. The relationship between annual costs of both base-load units and peaking units as affected by capacity factor (or unit usage) is shown in Fig. 1. The essential point is that for low capacity factor operation, the peaking unit can be cheaper to own and operate than the more efficient but more expensive base-load generating unit.

Another basic consideration is that kilowatts and kilowatt hours are not necessarily directly related. For example, a utility's summer peak load may increase 1000 mw for an atmospheric temperature increase from 80 to 90 degrees F for just a few hours each day for two weeks of the year without materially increasing annual kwhr sales. Capital cost requirements for generation equipment increase because these costs are closely related to kilowatt peak; but the utility's revenue does not increase because it is more nearly related to kilowatt hours.

The annual load-duration curves of four different utilities with annual load factors ranging from 50 to 65 percent are shown in Fig. 2. The base-load portion for all four utilities is approximately the same percentage of peak load—30 to 40 percent of peak. The main differences are found in the relatively short duration loads closer to the system's annual peak. Thus, the utility system with a 65 percent load factor can afford to spend more money for higher efficiency in generating kwhrs than can the utility with 50 percent load factor where the need is greater for short-time kw capacity.

A third consideration is that gains from technological improvement are subject to the law of diminishing return. Somewhere along the line, the value of technological gains is offset by added costs in other areas—forcing further cost reduction activity into more productive channels. This is illustrated by one utility's historical experience with heat-rate improvement (Fig. 3), which is typical of the industry. New units are now not much more efficient than their immediate predecessors; consequently, their effect on reduction of overall system heat rate is growing smaller, a trend that is verified in the FPC's *Annual Plant Statistics.* In fact, present developments in thermal pollution controls, which in effect limit permissible

Table I—Minimum Percent Installed Reserve Requirements to Provide Reliability—Ten Years per Day

	Forced Outage Rate		
New Unit Sizes	*1.5%*	*3%*	*6%*
4%	10%	14%	21%
7%	15%	21%	30%
10%	19%	26%	37%

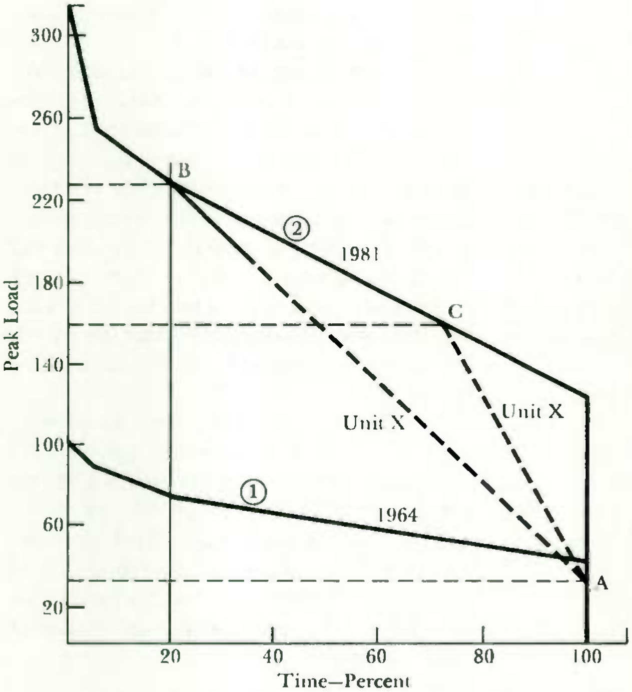
temperature rise through condensers, may cause the trend to reverse and rise in the near future.

Although new units reduce fuel consumption if they are more efficient than existing units, this fuel cost reduction gets smaller as more and more of a utility's generation capacity approaches today's relatively fixed upper efficiency limits. That explains why utility interest has changed over the years from improving thermal efficiency to reducing capital cost by the use of larger units, then to reduction in reserve requirements through interconnections, and now to reduction in fuel cost through use of nuclear units. However, in all of these areas, the law of diminishing returns must be recognized.

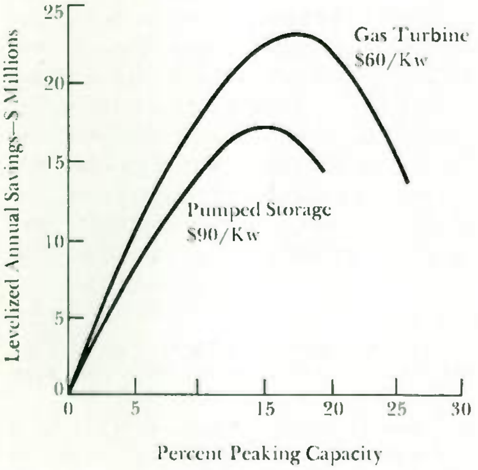
The $/kw relationship to unit size under equivalent, consistent, favorable conditions is shown in Fig. 4. These estimates, based in part on engineering studies of the type an interested utility might make, show clearly the diminishing rate of cost reduction in terms of $/kw as units get larger.

Another cost that must be considered when considering unit size is the generation reserve requirement. The relationship between unit size, outage rate, and required reserve margin for a minimum given level of system reliability is shown in Table I. (Unit size is expressed as percent of installed capacity.) Since the generation reserve requirement increases as either outage rate or unit size or both increase, the annual costs related to generation reserve requirement place economic limits on the type and size of generating unit.

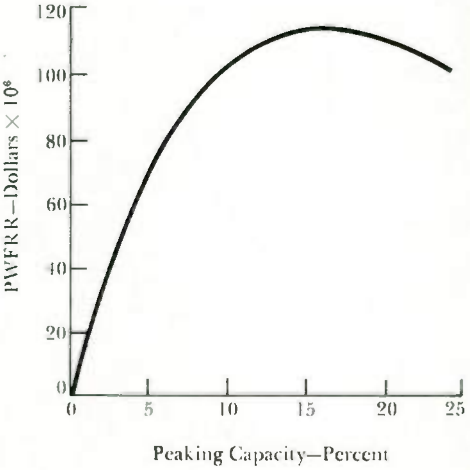
The future operating history of both existing base-load units and new unit additions are affected by succeeding units, as demonstrated in Fig. 5. Annual load duration curves are shown for a utility system as it existed in 1964 (curve 1) and as projected to 1981 (curve 2). If all base-load type units—each even only slightly more efficient than its predecessor—are chosen, a unit X that had a 100 percent capacity factor (A) in 1964 will operate at low capacity factor (B) by 1981. If instead of an all base-load plant expansion plan, a mixed pattern of base-load units and peaking units are installed, then unit



5—System load duration curves for a utility with a 60-percent load factor illustrate the effect of a system's generation expansion plan on existing unit X. In 1964, new unit X operates 100 percent of the time. By 1981, unit X will operate only 20 percent of the time if all new plants are base-load units; unit X can be operated about 75 percent of the time if new plant capacity is a mix of peaking and base-load units.



6—Levelized annual savings to a utility pool can be optimized with peaking plants, compared to expansion with base-load only plants.



7—The savings in present worth of future revenue requirements (PWFRR) with peaking capacity as compared to all-nuclear base-load expansion over a 20-year period (1970-1989) can be optimized with about 15 percent peaking capacity.

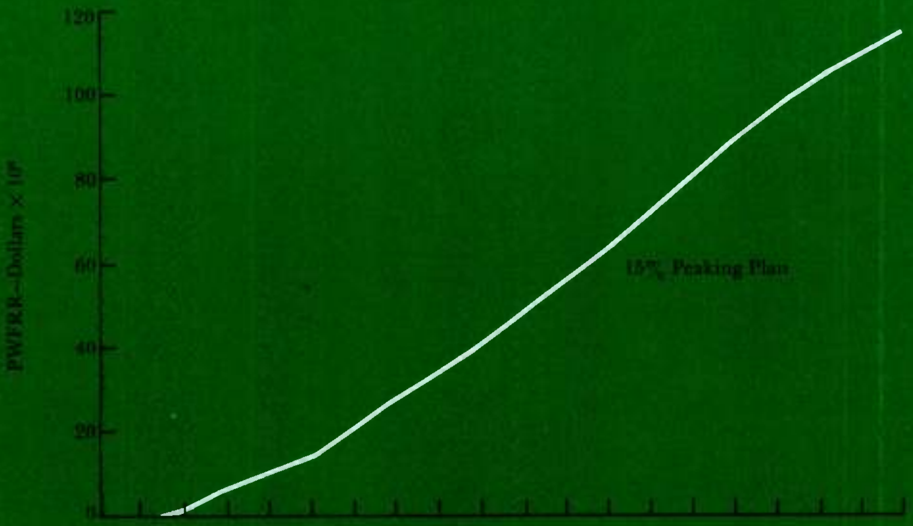
X can be operated in 1981 at a capacity factor three times better (C).

The significance of the higher capacity factor is that the original capital investment in unit X is more intensively utilized because the fixed charge portion of its cost can be spread over three times as many kilowatt hours. On the other hand, if unit X must be operated at low capacity factor, it will be relegated over about half its useful life to a type of service for which this unit was not designed, and for which less costly alternatives could have been used.

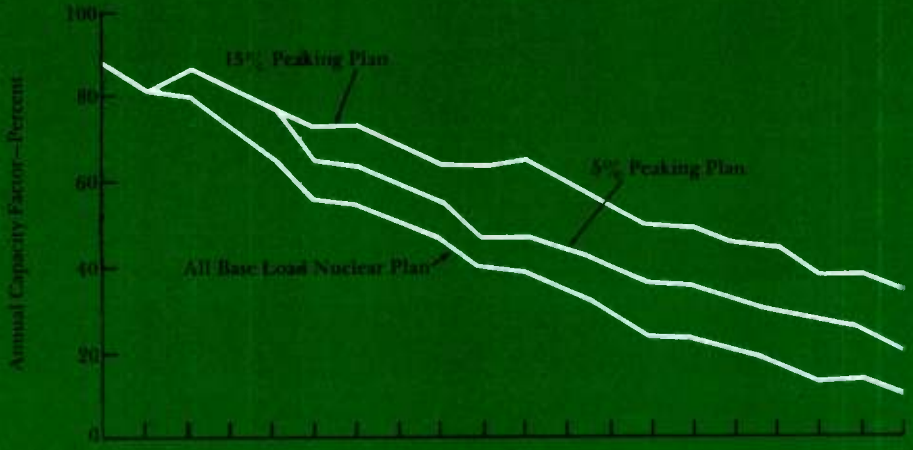
In this example (Fig. 5), the use of peaking plants can also permit deferral of large blocks of capital investment in base-load generating plant for one or more years. Thus, generation capital requirements can be reduced by as much as $30 million per 1000 mw of present peak over the 17-year operating period between 1964 and 1981.

Digital Simulation of Utility Expansion Plans

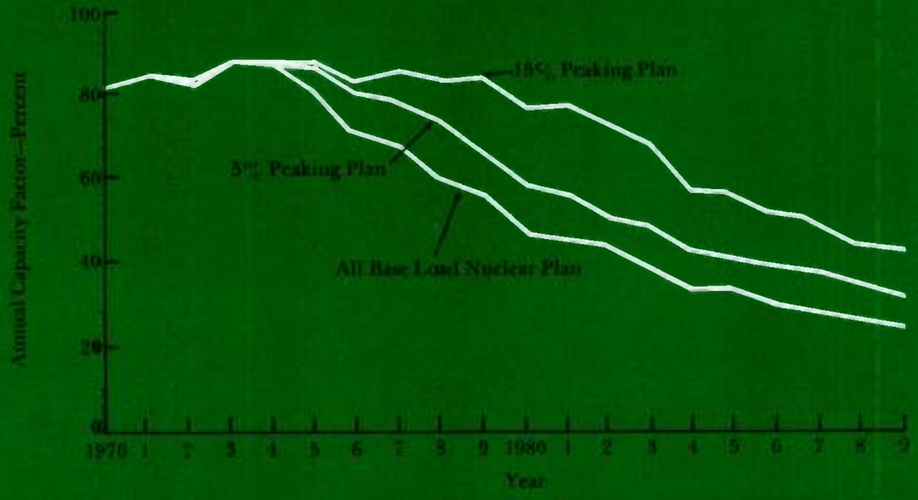
The desirability of including peaking equipment in a specific utility's future generation expansion program is complex and cannot be satisfactorily resolved by a simple mills-per-kwhr comparison for each new unit. However, the question can be handled satisfactorily by simulation on a digital computer. In a computer analysis, alternate types of generation addition patterns—with various amounts of peaking capacity—are compared by simulating system operation for each pattern. The simulation considers reliability risk, the system's historical and expected experience in fuel cost, outage rates, system load growth, interconnections, and financial



8—*(Top)* Cumulative PWFRR savings possible with a 15-percent peaking plan rather than an all base-load nuclear plan.



9—*(Center)* The annual capacity factor for a new 600-mw mine-mouth fossil unit can be improved considerably with a 15-percent peaking plan.



10—*(Bottom)* The annual capacity factor for a new 800-mw nuclear unit is improved by the 15-percent peaking plan, once the system has sufficient nuclear capacity installed to carry base load.

requirements. Production costs for each pattern are calculated week-by-week for a period of 20 years or more, and capital requirements determined to arrive at system revenue requirement for minimum acceptable return. The resulting amounts are converted to present-worth amounts so that the alternative patterns can be compared.

Study System Parameters—The basic mechanism for reducing revenue requirements with a peaking plant program is a favorable trade-off between capital cost and production cost. Therefore, the most important single requirement of a satisfactory peaking unit is that it cost less, in total $/kw, than the base-load unit it would defer—the greater the cost differential, the larger the optimum fraction of a utility's generation in peaking units and the greater the capital savings. For purposes of digital simulation, peaking gas turbines were assumed to cost $60-$70/kw, base-load fossil units were $30/kw higher, and nuclear units were $40-$50/kw higher. Pumped-storage hydro units were assumed to cost $80-$90/kw.

In all of the studies, the fuel efficiency of the peaking unit and its fuel cost were not important factors because peaking units delivered no more than one or two percent of the system's energy requirements and therefore did not significantly affect the utility system's total production cost.

Of much greater importance in the evaluation of production cost is an accurate assessment of the cost reduction potential of installing new base-load plant. For example, if the new base-load unit is much more efficient than existing units, the net fuel savings to the system can be substantial; however, if the new base-load unit is not significantly more efficient than the older units, system fuel saving with new base capacity becomes smaller and the capital saving with peaking capacity becomes more advantageous.

Study Results—Computer analyses were made for both simulated and actual utility systems. Typical study results, shown in Fig. 6, demonstrate the effect of added pumped hydro or gas turbine peaking units to a 4300-mw pool of fossil-fueled utility systems. The peaking pattern using gas turbines shows a potential $22 million levelized annual saving when about 18 percent of system capacity is peaking generation. Pumped-storage hydro also shows significant savings of $18 million for 15 percent peaking capacity. For single systems with only summer or winter peaks, the optimum peaking percentage would be about five percent greater, the curve much sharper around its optimum value, and the savings proportionately higher. The conclusion to be drawn is that the effects of pooling electric utility systems to gain peak-load diversity reduce, but do not remove, the economic desirability of the peaking plant approach.

Since present trends are directed toward nuclear plant additions, the effect of a peaking approach on such systems is of particular interest. The savings as a function of peaking capacity are shown in Fig. 7. Note the nature of the curve and its relatively broad characteristic around the optimum 15 percent value, in contrast with the sharper optimum curve for fossil systems. This is a consequence of the greater capital cost per kilowatt differential between gas turbine peaking plants and nuclear plants compared with the differential between gas turbines and fossil plants.

The savings that accumulate with time for a 15-percent peaking plan are shown in Fig. 8. Savings in this case begin after the second year of the program and continue to mount throughout and beyond the study period.

The improvement in the annual capacity factor of a fossil unit installed at the beginning of the nuclear addition study period is shown in Fig. 9. Note that if only base-load units are installed, usage of a fossil unit (as shown by the lowest curve) drops from 88 percent capacity factor at the start of the period to less than 40 percent in 10 years, and to less than 10 percent in 20 years. This drop is the result of buildup of lower fuel cost nuclear capacity on the system. On the other hand, if 15 percent of the system is added in peaking units, usage is much higher (as represented by the upper curve); even as little as 5 percent peaking capacity provides significant improvement.

The operating history of a nuclear unit installed at the beginning of the period is shown in Fig. 10. No effect can be observed on unit usage as a result of peaking additions for about five years, the result of building up sufficient nuclear capacity in the initial period. Nuclear units, because of their lower fuel costs, displace fossil units in base-load operation until enough nuclear capacity is installed and the earlier nuclear units also must be unloaded. Beyond this point, the effect of peaking on unit usage is similar to that for a fossil unit. Thus, the 15-percent peaking plan (as shown by the upper curve) makes possible significant increases in nuclear unit usage.

The substantial savings possible with a peaking approach to a utility embarking on an all-nuclear program are summarized in Table II. The $10 million annual savings that can result from the addition of 15 percent of total capacity in the form of low-cost peaking type units represents a reduction of 4 percent in revenue requirements from the all-nuclear base-load pattern.

With savings of this magnitude available to utilities, it seems reasonable to expect that peaking as an integral part of a utility's system expansion program will follow previous campaigns of increasing steam pressure and temperature, larger generating units, integrated power pools, and nuclear fueled plants, in the continuing drive to provide reliable power at lower cost.

*Table II—Annual Levelized Savings from Base-Load All Nuclear Plan**

Pattern	*Saving*
5% Peaking	$ 7,319,000
10% Peaking	$ 9,203,000
15% Peaking	$10,583,000

**Twenty year study period. 1970-1989.*

Capacitors and Induction Motors...
The Factors in Trouble-Free Application

R. J. Alke

Capacitors are useful for correcting plant power factor, but they must be applied correctly to avoid motor damage from overvoltages and high transient torques.

Poor power factor in an industrial plant is usually caused by induction motors, especially when the motors have been applied without sufficient attention to application practices that make for good plant power factor. Since it is not usually feasible to replace motors, capacitors are commonly used in motor circuits to correct the plant power factor.

Connecting capacitors in parallel with induction motors (or other apparatus having a low lagging power factor) reduces the current required from the line, thus releasing line capacity. In addition, power-factor correction often brings a substantial saving in power billing by reducing maximum kva demand. Capacitors also improve voltage level. While tables are available for selecting the proper capacitor ratings, background information is helpful in applying the tables, understanding the limitations of capacitor applications, and evaluating the problems that can arise.

Before going into this correction information, however, a word about prevention—applying motors for best plant power factor.

First, the correct size motor for the driven load should be used, because induction-motor power factor varies with load (Fig. 1). The newer designs and rerate programs that put more horsepower into a given frame size work both iron and copper at higher values, making it even more desirable to apply motors for maximum efficiency. Second, applied voltage should be kept close to motor nameplate values. Third, higher-speed motors (except two-pole) give better power factor than those of lower speed, and they are smaller and less expensive. Fourth, the synchronous motor should be considered for larger drives (over about 1000 horsepower) because it gives better power factor and also can be used as a power-factor corrective device.

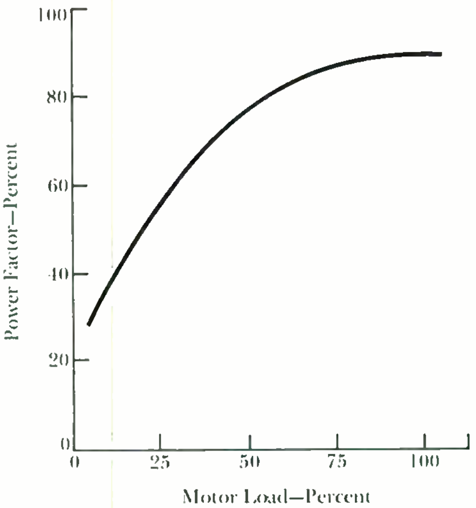
Applying Capacitors

When plant loads fluctuate widely, the capacitors connected to the motors must be switched automatically to avoid excessive voltage rise during light-load periods. Often the simplest and most economical way to do so is to connect the capacitor directly across the motor terminals so that the motor and capacitor are switched as a unit. This method varies capacitor kvar simultaneously with changes in motor loads, and it also saves money since a separate capacitor switch is not required. The method results in trouble-free operation if the capacitor size is properly chosen.

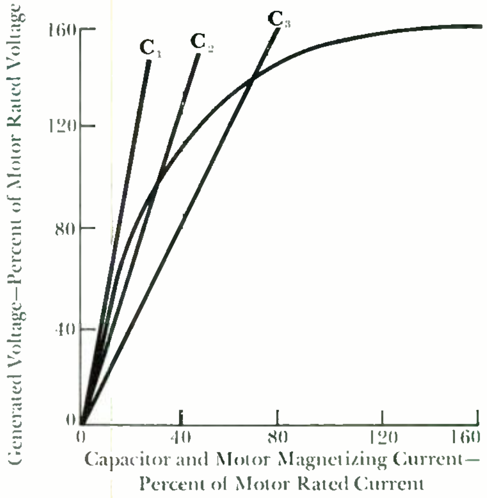
However, if the capacitor used on a motor is too large, self-excitation may cause a motor-damaging overvoltage when the motor and capacitor combination is disconnected from the line. In addition, high transient torques capable of damaging the motor shaft or coupling can occur if the motor is placed back on the line while rotating and still generating a voltage of self-excitation.

Overvoltages—An induction motor operates as an induction generator if it is driven by some means and a sufficiently large capacitor is connected across its terminals to supply the magnetizing kvar. That is what can happen when a motor with a permanently connected capacitor is disconnected from the line: the motor's inertia keeps it rotating long enough for the motor and capacitor combination to build up a voltage of self-excitation.

A given capacitor and motor combination has a critical capacitive reactance, similar to the critical resistance in the field of a dc generator, which must be less than a certain value for the motor to act as an induction generator and build up voltage (Fig. 2). Thus, for a given motor, no self-magnetization occurs with a direct-connected capacitor below a certain rating in kvar. If the capacitor volt-ampere curve does not cross the motor magnetization curve, there can be no voltage of self-excitation. This condition is represented in Fig. 2 by capacitor C_1. Self-excitation occurs only if the capacitive



1—Power factor of a typical induction motor increases with load. Consequently, the correct size motors for the driven loads should be used for best plant power factor.



2—Excessive capacitance permanently connected to a motor to correct power factor can cause the motor to generate a damaging voltage of self-excitation as inertia keeps it rotating after it is disconnected from the line. Voltages of self-excitation are shown by the intersections of the capacitors' volt-ampere curves (at rated frequency) and the no-load saturation curve of a typical induction motor. Of the three capacitors of different sizes illustrated here, only C_1 would produce no voltage of self-excitation.

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reactance is equal to or less than the inductive reactance of the motor. The capacitor of curve C_2 is approximately of the size required to correct no-load power factor of the motor to 100 percent; the voltage generated when this motor-capacitor combination is disconnected from the line rises to 100 percent of its rated value (assuming no speed change). Capacitor C_3 is approximately large enough to correct full-load motor power factor to 100 percent, and voltage of self-excitation is 140 percent.

The values vary widely for different motors. They may be much higher than in this example because motor power factor depends on so many design factors, such as speed, voltage, and type.

This graphical determination of the voltage of self-excitation assumes that the motor remains near rated speed long enough after the switch has been opened to permit the generated voltage to build up to full magnitude. Since voltage build-up is extremely rapid, the maximum voltage actually generated is very nearly that determined by this method. It can be measured by placing a voltmeter across the motor terminals when the motor is disconnected from the line. The voltage of self-excitation usually collapses in a few seconds as the motor slows down quickly; however, it may be sustained for several minutes if the motor is connected to a high-inertia load.

Transient Torques—Even though the capacitor has been chosen properly from the standpoint of avoiding overvoltages, it may still be large enough to produce excessive torques in certain motor applications with high-inertia loads (such as induced-draft fans, large compressors, and large air conditioners) or where open-transition starting is used. High stresses may be applied to the shaft and couplings either when the motor is transferred to the line from the reduced-voltage tap of an autotransformer starter or when the motor is disconnected from the line and reenergized while still rotating and generating a voltage of self-excitation.

The electrical torque produced is large only if the generated voltage is appreciable and out of phase with the line voltage,

Maximum Recommended Capacitor Ratings to be Applied with Induction Motors, when Capacitors are Switched with Motors[1]

	Nominal Motor Speed (rpm)											
	3600		*1800*		*1200*		*900*		*720*		*600*	
Motor Rating[2] *(hp)*	*Capacitor Rating (kvar)*	*Reduction in Line Current (percent)*	*Capacitor Rating (kvar)*	*Reduction in Line Current (percent)*	*Capacitor Rating (kvar)*	*Reduction in Line Current (percent)*	*Capacitor Rating (kvar)*	*Reduction in Line Current (percent)*	*Capacitor Rating (kvar)*	*Reduction in Line Current (percent)*	*Capacitor Rating (kvar)*	*Reduction in Line Current (percent)*
2	1	16	1	20	1	22	1	24	—	—	—	—
3	1	10	1	16	1	21	2	24	—	—	—	—
5	1	9	2	16	2	21	2	21	—	—	—	—
7½	1	8	2	13	2	15	4	21	5	29	—	—
10	2	8	2	13	4	15	5	21	5	25	5	30
15	4	8	4	13	5	15	5	13	5	25	5	25
20	4	7	5	9	5	12	5	13	10	25	10	25
25	4	7	5	9	5	11	5	11	10	25	10	25
30	5	7	5	7	5	11	10	11	10	15	10	19
40	5	5	5	7	10	11	10	11	10	15	10	19
50	5	5	10	7	10	9	15	11	20	15	25	19
60	5	5	10	7	10	9	15	11	20	15	30	19
75	10	5	10	7	15	9	15	9	30	15	40	19
100	15	5	20	7	25	9	30	9	40	15	45	17
125	15	5	20	7	30	9	30	9	45	15	50	17
150	15	5	25	6	30	9	40	9	50	13	60	17
200	40	5	40	6	45	8	50	9	70	13	75	17
250	45	5	50	6	50	8	70	9	75	12	90	17
300	50	5	50	6	70	8	70	9	75	11	105	17
350	50	5	50	5	70	8	80	9	80	11	105	17
400	60	5	60	5	70	8	100	9	100	11	110	17
450	60	5	70	5	70	6	100	9	100	11	110	17
500	70	5	90	5	90	6	110	9	120	11	120	17

[1] *When special-application motors are involved or questions arise, these recommendations should be checked with the motor manufacturer.*

[2] *Open-type, NEMA design B, three-phase, 60-cycle, 230-, 460-, and 575-volt general-purpose induction motors.*

Table taken from IEEE publication No. 141, Electric Power Distribution for Industrial Plants, *Table 6.4 (1964).*

a condition that can be compared to connecting a synchronous generator to a system with which it is out of phase. The peak value of electrical torque is determined primarily by the magnitudes of the line and motor voltages, the angle between them, and the impedance of the motor. The maximum value that can be expected is a function of motor voltage of self-excitation (Fig. 3). This curve is drawn for one specific 200-horsepower motor after making simplifying assumptions, but it is accurate enough to make rough estimates on many motors.

Peak transient mechanical torque should not be permitted to exceed about six times full-load torque if damage to the shaft and coupling is to be prevented. The maximum mechanical torque transferred by the shaft is always less than the electrical torque estimated from Fig. 3. It is proportional to the load inertia as compared to the total inertia of the motor plus load:

$$T_m = \frac{J_L}{J_L + J_m} T$$

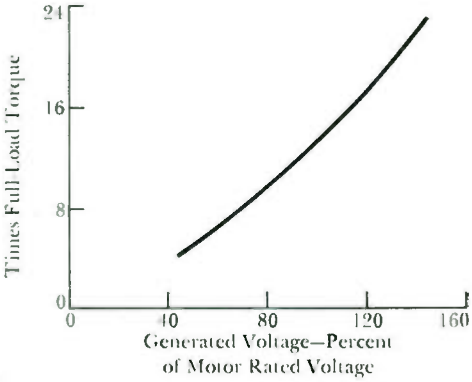
where T_m is mechanical torque (shaft torque), J_L is load inertia, J_m is motor inertia, and T is electrical torque from Fig. 3. If load inertia is small in comparison with motor inertia, very little torque is transmitted to the shaft; electrical torque is absorbed by the motor inertia and merely results in momentary deceleration or acceleration of the motor. If, on the other hand, the connected load has a high inertia, much of the electrical torque is transmitted by the shaft as mechanical torque and may cause dangerous stresses.

Recommended Capacitor Ratings

The accompanying table, which appears in various handbooks and publications, shows the maximum recommended capacitor ratings that will keep voltage of self-excitation within safe limits when motor and capacitor are switched as a unit. If capacitor ratings are chosen from this table, overvoltages of self-excitation will generally be held within the maximum permissible value (NEMA standard) of 110 percent. (When special-application motors are involved or questions arise, these recommendations should be checked with the motor manufacturer.) The transient torque that can occur will also be held within reasonable limits unless the application involves high load inertia or a manually operated transformer starter.

Under the latter conditions, a detailed application study of the transient torque should be made if the voltage of self-excitation is greater than 50 percent at the speed at which the transfer from one tap to the other (or re-energizing of the motor) is accomplished.

The capacitor ratings in the table are sufficient to correct the no-load power factors of their respective motors to approximately 100 percent, and full-load power factor to higher than 95 percent, which usually is sufficient. The reduction of line current (in percent of motor full-load current) gained when the specified capacitor is connected to the motor is shown in the table. Overcurrent protective devices used should be reviewed to take this current reduction into account. Ratings specified in the table do not necessarily correspond to standard capacitor ratings; when they do not, the next lower standard ratings should be used.



3—Excessive capacitance can also cause damaging shaft torques due to interaction of voltage of self-excitation and line voltage. Maximum electrical torque depends on the motor's voltage of self-excitation (from Fig. 2); the mechanical torque is somewhat less, depending on inertia factors.

When additional power-factor correction is desired, a capacitor larger than the size indicated in the table can be used under the following conditions:

1) If the motor is not likely to be reconnected to the circuit before it stops.

2) If open-transition starting is not used.

3) If the saturation curve for the motor is available and the self-excitation voltage is calculated and found to be within safe limits with the capacitor proposed.

4) If the self-excitation voltage is actually measured on the particular capacitor-motor combination and found to be within safe limits.

5) If the application does not conflict with Underwriter's requirements or applicable electric codes.

In all other applications where a capacitor larger than the recommended size is to be used, it should be connected to the line ahead of the motor switch or, if it is connected directly to the motor, it should be supplied with its own electrically operated switch (which in turn may be controlled by the motor switch).

Conclusion

Many industrial plant people fail to consider power factor until trouble develops in their distribution systems. Much trouble, time, and money can be saved by good initial motor application and by reviewing existing distribution systems to find ways of improving them by power-factor correction. The Westinghouse Electric Service Division can be of great assistance in these reviews by furnishing experienced engineering evaluation and the required instrumentation.

Residential Electric Heating... A Desirable Load for Utilities?

R. F. Cook

Recent simulation studies on residential electric heating demonstrate that both resistance heating and heat pumps can be desirable loads for northern electric utilities, but that heat pumps offer expanded marketing opportunities.

Residential resistance heating generally is accepted as desirable load for all electric utility companies. But, despite the many benefits to both consumers and utilities, the use of resistance heating in many areas has been retarded by the lower cost of heating with competitive fuels. Where home air conditioning also is desirable, the residential air-source heat pump considerably improves the ability of electricity to compete with fossil fuels for the home heating market. In an estimated two-thirds of the cities of the United States, the air-source heat pump can compete on an equal basis or better with natural gas-fired systems. Today, heat pumps are accepted widely in several southern states.

New and improved heat pump designs, now becoming available, are expected to accelerate use of heat pumps in northern states. But from the northern utility's standpoint, there is some concern as to whether the heat pump is really a desirable system load.

Although heat pumps require less total electrical energy than straight resistance heating, the maximum electrical demand of a heat pump and the maximum demand of electric heating are thought to be approximately the same. Since the costs associated with serving a customer are dependent largely upon maximum electrical demand, northern utilities must carefully evaluate load characteristics and the resultant cost of a high saturation of heat pumps on their systems.

This factor has been recognized widely and accounts for many industry efforts to improve the performance characteristics of heat pumps at low temperatures, or to develop a means of off-peak energy storage.

Load Characteristics and Cost Allocation

Residential heating load characteristics are significant to a utility because of their effect on the allocation of costs to various load classes. Three basic costs are associated with serving utility loads: a customer service cost, a cost associated with the production of energy, and a system capacity cost associated with total plant investment. The most difficult problem in setting rates is the allocation of the latter—system capacity cost—among the various load classes. For the purposes of this article, the average and excess demand (AED) method, used in conjunction with incremental costing, has been selected as representative of those methods that apportion cost in a fair manner and allow maximum flexibility for future system load changes.

Basically, the AED method allocates capacity costs to each load class according to the average load of the class plus an allocation proportional to the difference between the class average load and class peak load. The use of the AED method in conjunction with incremental costing is shown on facing page, *Rate Structures by AED Allocation and Incremental Costing.* Incremental costs include only those system capacity costs that would be incurred *if* the new load is added to the system.

For a complete cost allocation, the important characteristics of a new load class are its peak load, average load, and diversified peak loads coincident with the peak loads in various portions of the system (generally distribution and total system). These load characteristics, together with system load characteristics, can be used to determine the full AED apportioned costs and the incremental costs for the new load class. The specific calculations for determining required revenue for a new load class are summarized on page 172, *Determining AED Apportioned Rates and Incremental Rates.*

The business and rate philosophies applicable when using the AED method in conjunction with incremental costing can be summarized as follows:

1) System capacity cost allocation should recognize the possibility of changing system characteristics, should yield a fair apportionment of system capacity costs to all customer classes, and should permit maximum flexibility in the procurement of new business.

2) If the incremental cost of adding a new customer is *less* than the full apportioned cost, both the existing customers and the utility will benefit when the rate to the new customer class is based on allocated costs anywhere between the incremental cost and the full-apportioned cost. This rate latitude permits the utility to be more competitive with alternative sources of energy supply.

3) If the incremental cost of adding a new customer class is *greater* than the full apportioned cost, then the rate to the new customer class must be based on, at least, the full incremental cost and no rate latitude exists. (In other words, existing load classes should not be penalized to accommodate new customers.)

Load Characteristics Determination

The most reliable method of determining the load characteristics of various types of home electric heating would be to construct a number of total electric homes and measure their characteristics over several yearly periods. However, since it is desirable to understand the general characteristics of alternative electric heating devices before any major test program is undertaken, an hour-by-hour computer analysis[1] can be used to estimate these load characteristics. If the conclusions of studies based on this type of simulation indicate that a heating device should perform favorably, then measured load characteristics can be obtained to verify study conclusions.

Such a simulation was recently conducted on a typical medium-priced suburban home in a northern location to determine the characteristics of electric-resistance heating and heat-pump loads. The home has a gross floor area of 2,000 square feet, is tightly constructed, insulated to electric heating specifications, and has storm windows and doors. The maximum design heat loss of the house is 46,800 Btu/hour and the maximum heat gain for air conditioning is 3.2 tons.

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Rate Structures by AED Allocation and Incremental Costing

Of the many acceptable basic methods of allocating system capacity costs to various load classes, the *average and excess demand* (AED) method seems particularly useful because it apportions costs in a fair manner and allows for future system changes in an acceptable fashion. With this method, system capacity costs are allocated to the various load classes according to the average load of each class (average demand) and the difference between each class average and peak load (excess demand).

To demonstrate the AED method, consider a simplified utility system in which two load classes, A and B, use power during different time periods, as shown in Fig. *a*. The total system capacity requirement of five power units is allocated to loads A and B as shown in Fig. *b*:

Average system load ($22 \div 10 = 2.2$ units) is apportioned between A and B on the basis of the average of each of these two loads. Thus, the average demand of A is $10 \div 10 = 1$, and the average demand of B is $12 \div 10 = 1.2$. The remaining system capacity requirement ($5 - 2.2 = 2.8$) is assigned to A and B in direct proportion to the difference between the average and peak loads for each class. Thus, the system capacity allocation to A is 1 power unit (average demand for A) plus 1.65 units (excess demand for A). The excess demand for A is found by multiplying the remaining system capacity requirement (2.8 units) by the ratio of the peak load of A minus average load of A to the summation of class peak loads minus system average load. The complete arithmetical relationship is expressed:

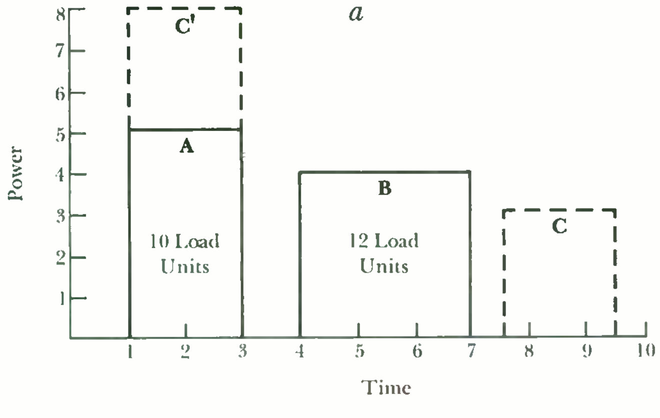
$$A = 1 + \left[2.8 \times \left(\frac{5-1}{5+4-2.2}\right)\right]$$
$$= 2.65 \text{ units, and}$$

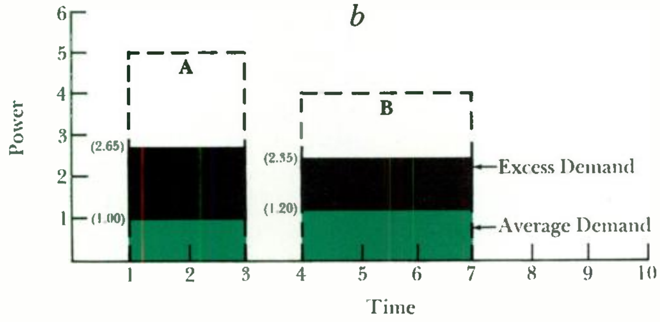
$$B = 1.2 + \left[2.8 \times \left(\frac{4-1.2}{5+4-2.2}\right)\right]$$
$$= 2.35 \text{ units.}$$

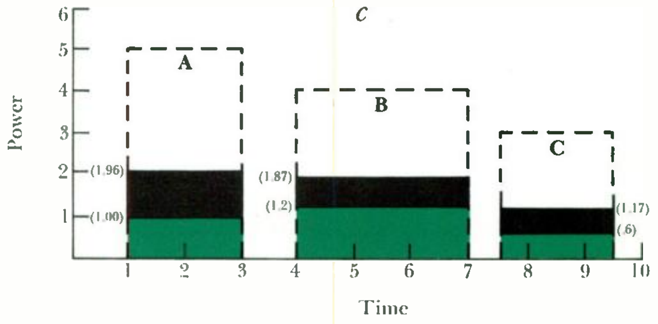
If this simplified utility system has the opportunity to add a new load class C (Fig. *a*), a rate schedule for C is needed that will be low enough to attract the new customer and at the same time provide an adequate return to the utility with due consideration to existing load classes. In this case, load C does not coincide with either A or B so that the addition of load C does not increase system capacity requirements. Thus, no incremental system capacity costs result from adding C, and the utility can add load C at a rate schedule based on a system capacity allocation to C anywhere between zero and the full "fair share" allocation determined by the AED method (Fig. *c*).

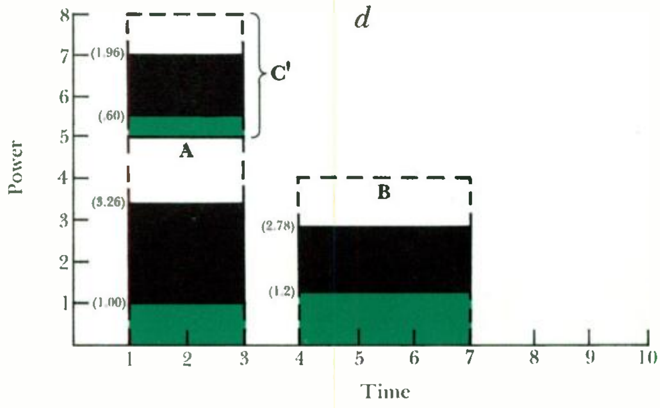
If C is added at a rate based on the full AED allocation, substantial reductions will result to customers A and B; even if capacity costs are not completely allocated, A and B stand to benefit to some extent.

But what if a potential new load class C' (Fig. *a*) is coincident with system peak load? This same load addition would then increase system capacity requirements from 5 to 8 power units. On the basis of full AED apportionment, system capacity would be allocated to the load classes as shown in Fig. *d*, and allocations to A and B would be substantially greater than before the addition of C'. However, if C' is assigned the full incremental amount of 3 power units, the apportionments to A and B will remain the same as before the addition of C'. Thus, when incremental system capacity costs are greater than the AED allocated costs for a new load class, the new class cannot be added to the system with a rate based on anything less than this incremental capacity cost if the load allocations to existing load classes are to be maintained.









The load characteristic curves that resulted from the study for actual hourly weather data of a typical northern climate are shown in Fig. 1. To account for diversity that would exist between houses, the load curves represent the hourly averages of the five most severe days. The important load characteristics applicable to a northern area are listed in Table I on a per house basis.

Analysis of Load Characteristics

Before utility revenue requirements for a residential electric heating load can be analyzed, it is necessary to make some basic assumptions concerning the system load characteristics and the projected magnitude of the new load class.

Determining AED Apportioned Rates and Incremental Rates

Using the average and excess demand (AED) method of allocating system capacity costs, the required revenue per kilowatt hour from a new customer class is:

$$RR_{\mathrm{FA}} = \frac{\$/kw\ (\Sigma NCP - SP)}{8760\ (\Sigma NCP - SAL)} + \frac{CP\ (SP - SAL)}{CAL\ (\Sigma NCP - SAL)} + PC + \frac{FCC}{(CAL)\ (8760)} \qquad \text{(Eq. 1)}$$

where RR_{FA} is required revenue on a full apportioned basis—\$/kwh, $\$/kw$ is total system capacity charge to be allocated on an annual basis, ΣNCP is summation of non-coincident peak loads for various load classes, SP is system peak load, SAL is system average load, CP is class peak load, CAL is class average load, PC is production cost per kilowatt hour apportioned on an energy usage basis, and FCC is annual charges associated with each customer.

The required revenue on an incremental basis for a new customer class is given by:

$$RR_{\mathrm{IB}} = (\$/kw_{\mathrm{S}})(\Delta SP)+(\$/kw_{\mathrm{D}})(\Delta DP) + (PC)\ (CAL)\ (8760) + FCC \qquad \text{(Eq. 2)}$$

where RR_{IB} is required revenue on an incremental basis—\$/year, $\$/kw_{\mathrm{S}}$ is incremental cost of system capacity, $\$/kw_{\mathrm{D}}$ is incremental cost of distribution capacity, ΔSP is class load coincident with system peak, and ΔDP is class load coincident with distribution peak.

AED Allocated Cost—For the sake of illustration, assume that system parameters are as listed in Table II, and that the additional home heating loads do not materially affect any of the system parameters used to determine AED apportioned rates (Eq. 1, below left). Further, assume that $SP=1$ per unit, $\Sigma NCP=2$ per unit and $SAL=0.65$ per unit. With these assumptions and with the class load characteristics given in Table I, the revenue required to cover full AED allocated costs is \$.0133/kwh for resistance-heated homes and \$.014/kwh for heat-pump-conditioned homes.

Incremental Cost—The determination of incremental costs for various portions of an electric utility system is complicated, and requires the simulation of system performance and capacity additions over a large number of years considering various load growths. Fortunately a number of references are available that present results of typical studies, and these results can be used in this analysis.

The incremental cost rates derived from various system studies are developed in Table III. The incremental cost rate of generation and main transmission lines and stations is based on Reference 2. The incremental cost rate for subtransmission lines and substations, distribution substations and primary feeders was derived from Reference 3. Similarly, the incremental cost rate for the distribution primary lateral, distribution transformer, and secondaries was determined from Reference 4.

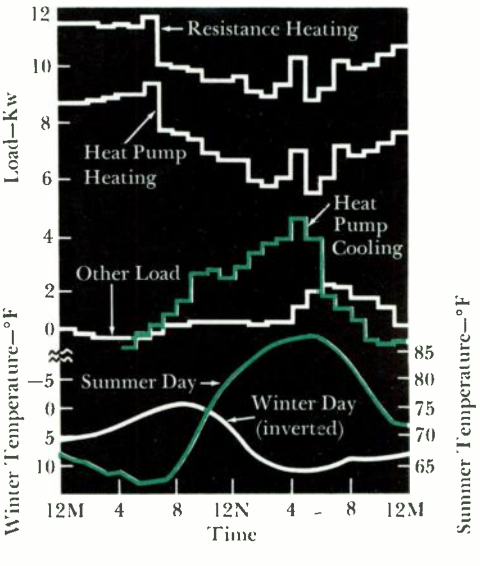
Assuming class loads at the time of distribution and system peaks are as listed in Table I, the revenues required on an incremental cost basis for utilities with summer peaks and utilities with winter peaks can be calculated (Eq. 2). For this study, it was assumed that no additional diversity exists in the load characteristics, and also that a utility with a present summer or winter peak will continue to maintain that seasonal peak after the addition of the new load class.

Study Results

The annual revenues derived from existing total electric rates for five representative northern utilities with *summer peak system loads* are shown in Fig. 2. The revenue requirements, as determined by the study, for total electric homes with resistance heating and with heat pumps are shown on the basis of full AED allocated costs and on the basis of incremental costs.

In the case of resistance heating, the study results indicate that the rates probably are based on a full allocation of costs. Since incremental costs are substantially lower than allocated costs, these utilities should be in an excellent position to serve resistance loads competitively with the full benefits of the resulting system growth available to existing customers. Even more important is the indication that the heat pump should yield these same benefits to both the utility and its existing customers in spite of the lower annual revenue from each individual customer. Furthermore, since the heat pump results in a sizable reduction in a consumer's energy cost, yet provides the additional function of air conditioning, the heat pump should offer to northern utilities with summer peaks greatly expanded marketing opportunities in competing with other energy sources.

The study results for utilities with *winter system peak loads* are shown in Fig. 3.



1—Load curves for typical northern utility company.

Table I—Load Characteristics for Northern Climate

	System Type	
	Resistance Heating	*Heat Pump*
Class Peak (CP)	12.34 Kw	10.03 Kw
Class Average (CAL)	3.98 Kw	2.94 Kw
Load Coincident with Winter Peak System Load (ΔSP_W)	11.46 Kw	8.33 Kw
Load Coincident with Summer Peak System Load (ΔSP_S)	2.30 Kw	4.24 Kw
Load Coincident with Winter Peak Distribution Load (ΔDP_W)	12.34 Kw	9.39 Kw
Annual Energy Consumption	34,848 Kwh	25,776 Kwh

Table II—Sample Utility Full Allocated Costs

Item	*Cost/Kw*	*Reference**
Generation ($110 plus 15% for losses and 15% adder)	$145.40	5
Main Transmission ($30 plus 15% for losses)	34.50	5
Subtransmission Lines and Stations ($21/kva plus 11% for losses, .85 power factor)	27.40	5
Distribution Substations and Main Feeders ($23/kva including losses, .85 power factor)	27.00	3
Primary Lateral, Distribution Transformer and Secondary ($80/kva plus 9% for losses, .9 power factor)	96.90	4
Subtotal	$331.20	
Allowance of 10% for overhead and contingencies	33.12	5
Subtotal	$364.32	
Annual Charge at 14%	51.00	5
Generation O and M	.95	5
Transmission O and M	1.40	5
Distribution O and M	1.10	5
Total Annual Charge Per Kw	$ 54.45	
Total Annual Charge per Kwh (estimated, mainly production cost)	$ .003	
Total Annual Fixed Customer Charge (estimated, mainly annual charge for services and meters, billing and collecting and some maintenance)	$ 25.00	5

**See "References" section, p 174.*

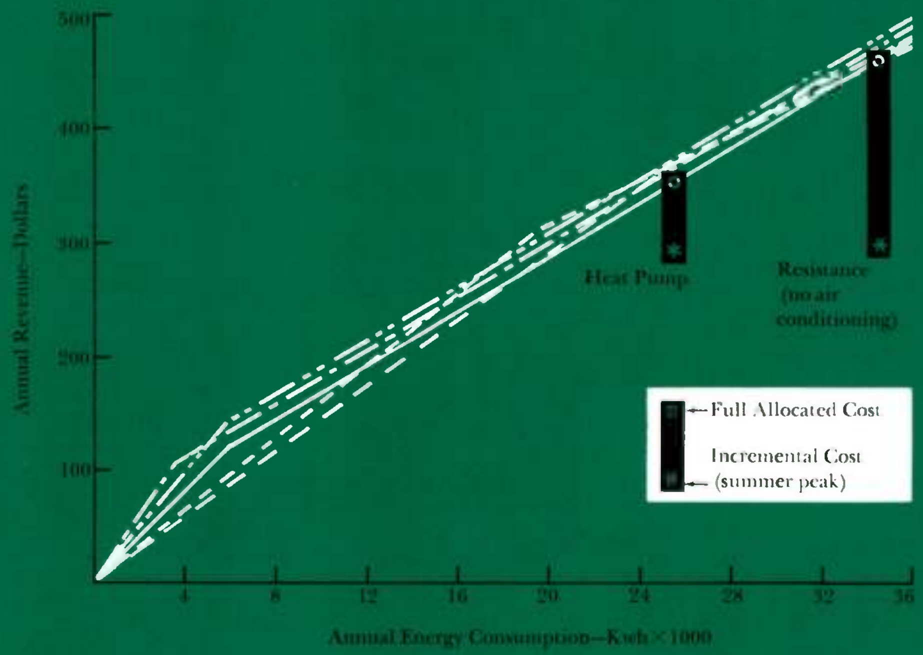
Table III—Sample Utility Incremental Cost Rate

Item	*Cost/Kw*	*Reference*
Generation (assume greater than a 2% incremental load factor and thus full allocated rate)	$145.40(1)	2
Main Transmission (same basis as generation)	34.50(1)	2
Subtotal	$179.90	
Annual Charge at 14%	26.19(2)	5
Subtransmission Lines, Stations, Distribution Substations, Main Feeders (46.4% of values listed in Table II).	25.20	3
Primary Lateral, Distribution Transformer and Secondary (38.6% of $96.90)	37.40	4
Annual Charge at 14%	$ 8.76(3)	5
Annual Cost per Kwh	$ .003	

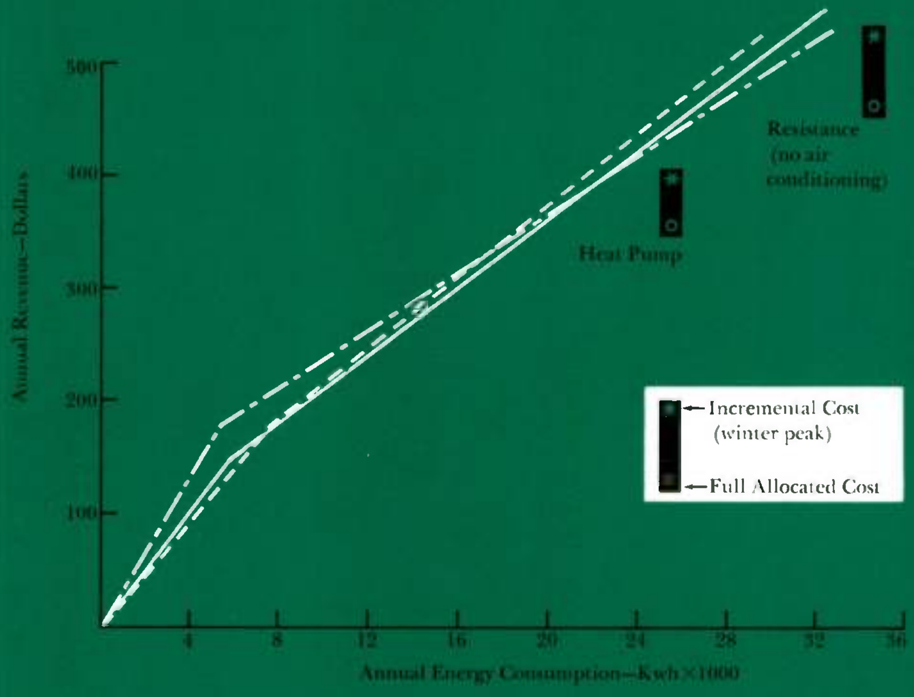
(1) *In reference 2 it is shown that when the diversified load of a new load class, at the time of system peak, is in excess of two percent of the total system load, system capacity charges for these components must be charged on a full pro-rata basis.*

(2) *Applied to incremental system load.*

(3) *Applied to incremental distribution load.*



2—*(Right)* **Comparison between rates, full allocated costs, and incremental costs for two types of total electric home classes for northern utilities with summer peaks.**



3—*(Below)* **Comparison between rates, full allocated costs, and incremental costs for two types of total electric home classes for northern utilities with winter peaks.**

The incremental cost of serving these loads is higher than the full allocated costs because the individual residential peak loads coincide with the system peak load. Therefore, no rate latitude exists and revenue requirements must cover full incremental costs. The annual revenues under the existing rates of these utilities for total electric homes with resistance heating already are marginally higher than the calculated incremental cost. Therefore, total electric homes with resistance heating are desirable loads for these utilities, at their present rate schedules. By comparison, the heat pump offers the northern utilities with winter peaks the opportunity, at their present schedules, of providing both heating and cooling to their total electric home customers at lower annual costs.

In summary, utilities are using methods of cost allocation that reflect the incremental as well as fully allocated costs of new load classes. Using these methods of rate determination, the residential heat pump seems to offer northern utilities the opportunity to add a profitable new load class to their systems, and at the same time offer year around total electric living at significantly lower costs to their customers.

Westinghouse ENGINEER November 1967

References:

[1] Cook, R. F., "Electric Heating Load Analysis," *IEEE Transactions on Industry and General Applications*, Vol. IGA-1, No. 2, March-April 1965, pp. 149-152.

[2] Baldwin, C. J., Hoffman, C. H., Jeynes, P. H., "A Further Look at the Cost of Losses," *AIEE Transactions, Pt. III (Power Apparatus and Systems)*, Vol. 80, (TP No. 61-1014).

[3] Lawrence, R. F., Reps, D. N., Patton, A. D., "Distribution Planning Through Optimized Design-II-Comparative Economics of System Voltages," *AIEE Transactions, Pt. III (Power Apparatus and Systems)*, Vol. 79, (TP No. (60-178).

[4] Cook, R. F., "New Analysis of Home Heating Loads Could Aid in System, Sales Planning," *Electrical World*, July 26, 1965.

[5] "What Price Electric Heat," *Electrical World*, (Management Newsletter), May 18, 1964.

Fractional-Horsepower Induction Motors... Versatile Power Sources

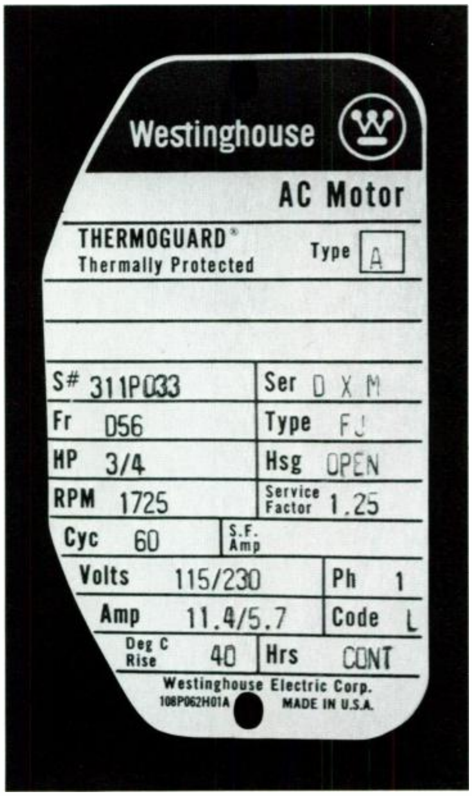
T. E. M. Carville

Just as increasing mechanization has multiplied the horsepower available to users of large machines, so has it increased the power available in the home, the office, and small industrial devices. Ability to apply the wide variety of small motors efficiently and effectively depends on understanding their characteristics.

Small motors are made in such a variety of types and ratings that, to the uninitiated, the choice may seem bewildering. Actually, however, the wide variety is the result of logical development to exploit characteristics of various motor types for service in various applications.

The information presented in this article is intended to show the characteristics of the main types of fractional-horsepower induction motors and indicate how they are best applied. Additional information is available in the NEMA Standards and other industry standards. For selecting and applying motors, though, the best source of information is the motor manufacturer. His people should always be consulted before selecting a motor, or when evaluating an existing application, because years of experience have given them a depth and breadth of motor knowledge that few if any motor users have.

A fractional-horsepower motor, according to the NEMA definition, is either (1) a motor built in a frame that has a two-digit frame number, or (2) a motor built in a frame smaller than the frame of an integral-horsepower motor that has a continuous rating of one horsepower, open construction, at 1700 to 1800 rpm. (Motors of less than 1/20 horsepower are rated in millihorsepower and are generally referred to as subfractional motors.) Of the millions of fractional-horsepower motors manufactured each year, only a small percentage are sold directly to the eventual user. Most are integrated into the original design of such devices as air conditioners, fans, oil burners, conveyors, food mixers, power tools, blowers for furnaces, vacuum cleaners, laundry machines, typewriters, water pumps, and garage-door openers.


Westinghouse
AC Motor
THERMOGUARD®
Thermally Protected
Type A

S# 311P033 | Ser D X M
Fr D56 | Type FJ
HP 3/4 | Hsg OPEN
RPM 1725 | Service Factor 1.25
Cyc 60 | S.F. Amp
Volts 115/230 | Ph 1
Amp 11.4/5.7 | Code L
Deg C Rise 40 | Hrs CONT
Westinghouse Electric Corp.
108P062H01A MADE IN U.S.A.

1—Typical small-motor nameplate defines the motor's type, characteristics, and features. All of the information is important in applying the motor.

Application Considerations

Features to consider in selecting a motor for a certain application include type of power supply, time and temperature ratings, speed, locked-rotor current, torque requirements, overload protection, and mechanical features such as mounting type. These features are shown on the motor nameplate (Fig. 1).

Style or model number (*S#*) and serial number (*Ser*) on the nameplate identify the motor and give the necessary information for proper service and parts. *Type* is the manufacturer's designation of electrical type, which will be discussed later. The frame (*Fr*) designation covers the motor size, such as NEMA 42, 48, or 56 frame, plus the manufacturer's letter prefixes for the various lengths of a particular frame. The number may also have a suffix to designate application or mounting, as 56L for laundry, 56C for face mounting, or 56N for oil-burner flange. Frame sizes have been standardized by NEMA so that motors made by various manufacturers are mechanically interchangeable. The frame size divided by 16 is the motor's height in inches from the centerline of the shaft to the bottom of the foot.

Power supply information includes voltage (*Volts*), frequency (*Cyc*), and number of phases (*Ph*). The most common supply is 115-volt (or 115/230), single-phase, 60-cycle, but polyphase ac sometimes is available. A motor should be connected only to a power source that matches its rating. Induction motors built to NEMA standards can be operated successfully at rated load with variation of ±10 percent in voltage, ±5 percent in rated frequency, or a combined variation of 10 percent. However, performance then is not necessarily in accordance with standards established for operation at rated voltage and frequency.

Horsepower rating (*HP*) of the motor chosen for a particular application depends on the torque required to drive the load both under normal operating con-

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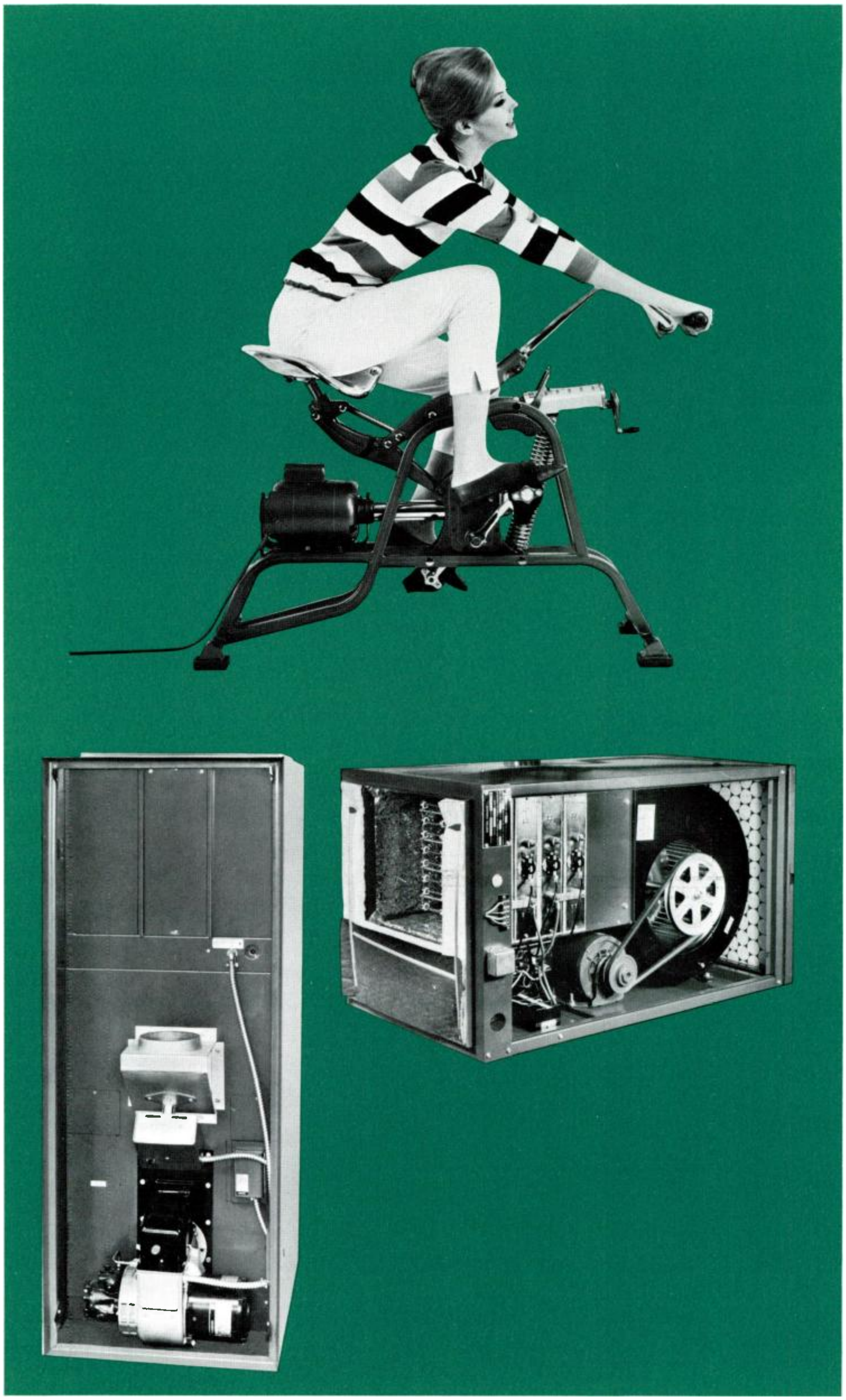
ditions and under momentary overloads. Duty cycle and frequency of starting (which may cause dangerous overheating) must be considered. NEMA has established a basis of rating single-phase induction motors on the basis of breakdown torque. For example, split-phase and capacitor-start motors with rated speed of 1725 rpm and breakdown torque in the range of 31.5 to 40.5 ounce-feet are rated ⅓ horsepower. This Basis of Horsepower Rating standard (MG 1-10.33) includes a table showing the range of breakdown torque to be expected by the user for any horsepower and speed.

The torque required by the driven machine at normal load is not the only torque to be considered: locked-rotor torque and breakdown torque also play important roles. Locked-rotor torque is the turning effort produced at the instant of starting; it is often the determining factor in selecting a motor. Direct-connected fans, for example, require very little torque to start as compared with torque at normal operating speed, but compressors may require locked-rotor torque above 200 percent of full-load torque. Breakdown torque is the maximum torque an induction motor can carry without an abrupt drop in speed that may make the motor inoperative.

Motor temperatures are measured in degrees C. Many "open" (open housing) induction motors are rated 40 degrees C rise (*Deg C Rise*) above an ambient temperature of 40 degrees C. Enclosed motors are rated 55 degrees C rise. Intermittent-duty motors are usually rated 50 degrees C rise open with a time specified. NEMA temperature rise standards cover Class A and B insulation systems (MG 1-12.39). On some motors, the temperature rise rating is based on air passing over the motor housing for the particular application.



Applications of fractional-horsepower motors range from the exotic to the merely useful. At top right, a capacitor-start motor on the home exerciser puts the lady through her paces. The split-phase motor in the domestic oil burner at lower left drives both an oil pump and a blower, while that in the electric furnace at right has a pure blower load.

Instruments should be employed to determine temperature rises. In many fractional-horsepower motors, frame temperature is more nearly that of the windings than it is on larger motors. With an ambient of 30 degrees C, for example, a motor running 40 degrees rise on the winding is rather cool (158 degrees F) but is still too hot to touch. In general, if one can hold one's hand on a motor for a reasonable period, the motor is operating rather cool.

The rating of 40 degrees C rise for open motors is conservative and allows for unusual service conditions, especially because many motors usually operate in an average ambient considerably below 40 degrees C and are not operated continuously. For these reasons, NEMA has adopted the service factor standard shown in Table I. The *Service Factor* shown on the motor nameplate allows the maximum safe output to be obtained where operating conditions are known to be usual. It means that, for example, a ½-hp motor can be loaded to 125 percent of its full rated load without exceeding safe operating temperatures. Peak loads above even the service-factor rating can be carried for short periods if they are offset by operating periods below rated load so that the average heating is under the limit for the insulation class. Service factor depends on motor rating—higher for motors of smaller ratings.

When operated at the service-factor load, a motor has a higher temperature rise and may have different speed, power factor, and efficiency than it has at rated load. Breakdown torque, locked-rotor torque, and locked-rotor current remain unchanged.

The motor nameplate shows the amperes drawn at rated load (*Amp*) and may show amperes at service-factor load (*S F Amp*). It also has a code letter (*Code*) that indicates locked-rotor kva per horsepower, measured at full voltage and rated frequency (Table II). This code letter gives information needed for proper determination of branch-circuit overcurrent protection as provided in the National Electrical Code. The letter varies for different motors of the same horsepower rating and type, since some are for use in

Table I—Service Factors for Fractional-Horsepower Induction Motors

Horsepower	*Service Factor*
1/20	1.4
1/12	1.4
1/8	1.4
1/6	1.35
1/4	1.35
1/3	1.35
1/2	1.25
3/4	1.25
1	1.25

(From MG 1-12.44)

Table II—Locked-Rotor Kva-per-Horsepower Designations

Code Letter	*Kva per Horsepower**
A	0 – 3.15
B	3.15 – 3.55
C	3.55 – 4.0
D	4.0 – 4.5
E	4.5 – 5.0
F	5.0 – 5.6
G	5.6 – 6.3
H	6.3 – 7.1
J	7.1 – 8.0
K	8.0 – 9.0
L	9.0 – 10.0
M	10.0 – 11.2
N	11.2 – 12.5
P	12.5 – 14.0
R	14.0 – 16.0
S	16.0 – 18.0
T	18.0 – 20.0
U	20.0 – 22.4
V	22.4 and up

**Includes the lower figure up to, but not including, the higher figure; e.g., 3.14 is letter A and 3.15 is letter B.*
(From MG 1-10.38)

Table III—Maximum Locked-Rotor Currents of Design O and N Single-Phase Motors; Two-, Four-, Six-, and Eight-Pole; 60-Cycle

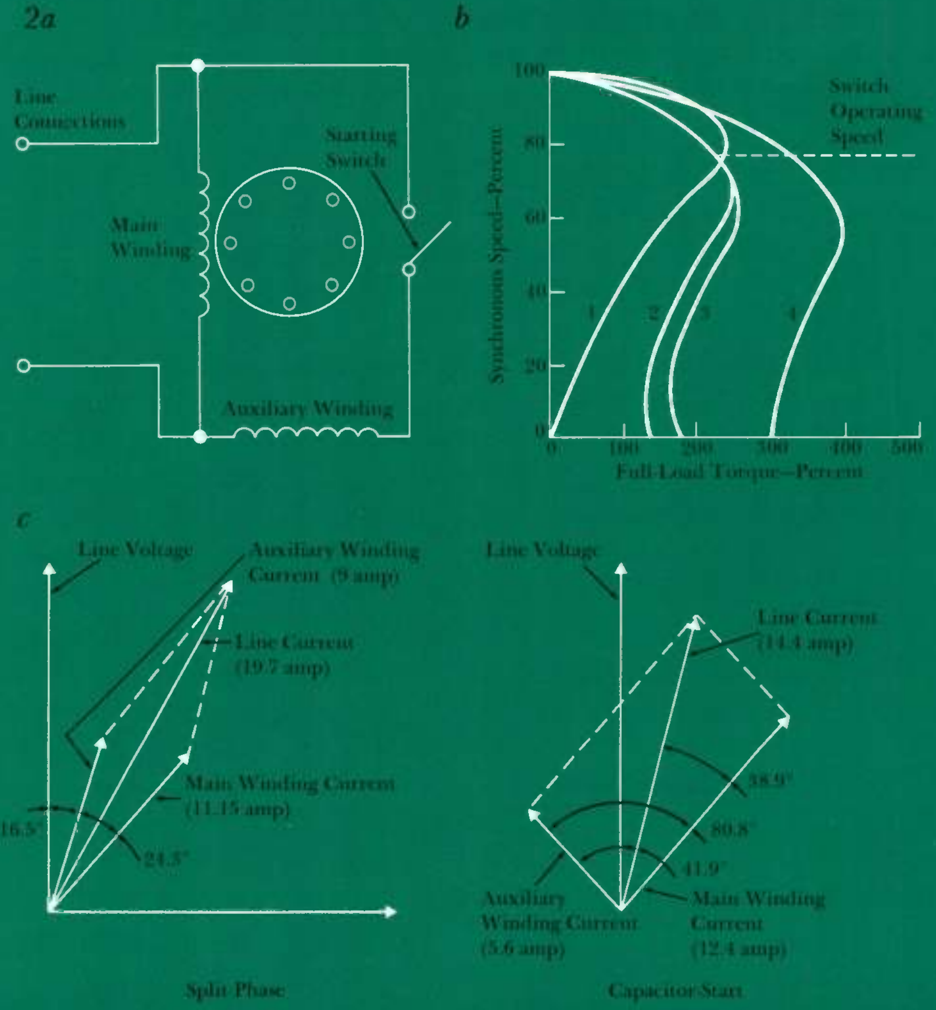
	115 Volts		*230 Volts*	
Horsepower	*O*	*N*	*O*	*N*
1/6 and smaller	50	20	25	12
1/4	50	26	25	15
1/3	50	31	25	18
1/2	50	45	25	25
3/4	..	61	..	35

(From MG 1-12.32)

frequently started applications (such as oil burners, furnace blowers, and household refrigerators) that operate intermittently for possibly 6 or 8 minutes out of 20 minutes, while others are for applications (such as automatic washers and clothes dryers) in which the motor operates up to an hour or more but only a few times a week. Other applications, such as a sump pump, may have extremely intermittent service—only a few operations a year.

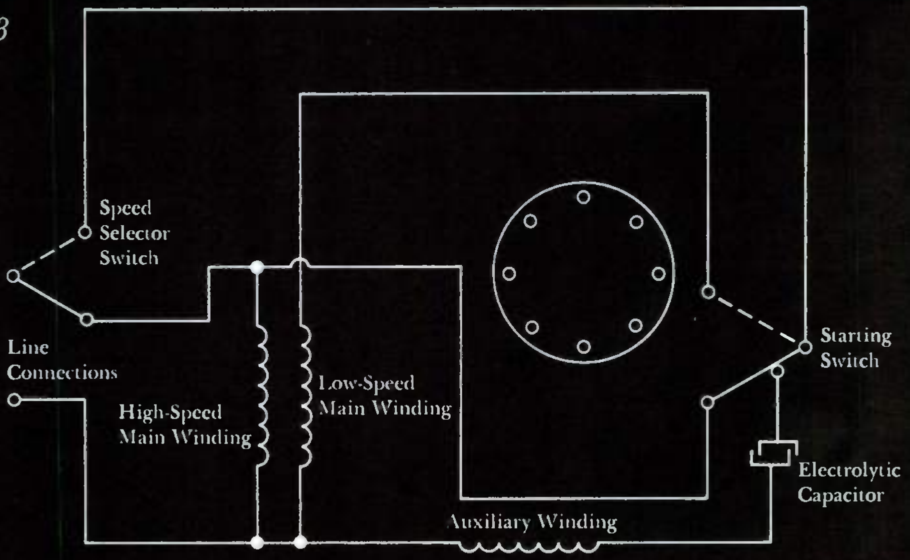
The possible production of light flicker by high locked-rotor current is less objectionable with infrequently started devices than with such devices as furnace blowers. For that reason, NEMA has adopted a standard for locked-rotor current defining two different designs of single-phase motors (Table III). Motors of the same type having higher locked-rotor currents also have higher locked-rotor torques.

Motors are often subjected to overload, abnormal heating from external sources, or severe starting conditions, which may cause excessive motor temperatures. Excessive temperature probably produces the greatest deteriorating effect on motors, especially of the insulation and lubrication. The National Electrical Code requires that fractional-horsepower motors started automatically be protected against



2—In a split-phase motor (*a*), a rotating electrical field is provided for starting by supplementing the main winding with an auxiliary winding having a higher ratio of resistance to reactance. A capacitor-start motor is similar except that a capacitor produces the phase displacement for starting. (*b*) Typical speed-torque curves reveal the higher locked-rotor torque of the capacitor-start type. Curve *1* is with main winding only. The others are with combined windings—*2* is split-phase design N, *3* split-phase design O, *4* capacitor-start design N. (*c*) Vector diagrams of typical split-phase and capacitor-start motors explain the difference in locked-rotor torque, which is mainly a function of the currents in main and auxiliary windings and the sine of the angle between them. A capacitor-start motor produces much more torque per ampere under locked-rotor conditions than a split-phase motor.

3



3—Two-speed operation can be provided in split-phase and capacitor-start motors by adding another main winding. Switch selects one winding for operation as four-pole motor or the other for six- or eight-pole motor.

overcurrent by use of a thermal protector integral with the motor, and that the motor be permanently marked "Thermally Protected" [Section 430-32 (c-2)]. The manufacturer usually indicates the kind of protection by a *Type* letter or letters. Some motors have inherent thermal protection, but the protector application has not been submitted to the Underwriters' Laboratories for approval; this is indicated by use of a type (or code) letter or letters different from those used on motors that are approved for automatic reset, manual reset, or locked-rotor protection.

Integral protective devices are generally of two types: a disc type mounted in the end bell of the motor or on a combined terminal board and stationary starting switch, or a sealed type assembled in or on the wound primary before dipping in the insulating varnish. Underwriters' Laboratories approval of thermal protector applications is based on tests to prove that the limits in its Safety Standard 547 are met, or on blanket approval of protectors applied in compliance with a method for the line of motors approved by Underwriters' Laboratories on the basis of its tests. Safety Standard 547 covers the construction of protectors and their installation and performance when used in given motors only. Obviously, inherent thermal protectors should be applied by the motor manufacturer at his plant and not by anyone else at a later time.

A protector may be of automatic-reset or manual-reset type. Automatic reset is a convenience, although of course it is not safe on some applications, such as a hand-fed power saw.

Safety Standard 547 requires that when the motor is running with the maximum load it can carry without causing the protector to open the circuit, its temperature shall not be more than 140 degrees C for a motor employing Class A insulation and not more than 160 degrees for a motor employing Class B insulation. Under locked-rotor conditions, an automatically reset protector must cycle to prevent the motor from attaining a temperature greater than 200 degrees C for Class A insulation (225 degrees for Class B) during the first hour of operation, and 175 degrees maximum and 150 degrees average for Class A insulation (200 degrees maximum and 175 degrees average for Class B) after the first hour of operation. Similar limits for ten cycles of operation are given for manual-reset protectors.

The temperature limits are for protection against abnormal conditions. Any attempt to load the motor above its service-factor load will result in unsatisfactory insulation life or unsatisfactory performance due to nuisance tripping of the protector. An old rule of thumb is that for each increase of 10 degrees C above rated temperature, insulation life is cut in half. For example, a motor operating at 50 degrees C rise used in a 40-degree ambient has a total temperature of 90 degrees; if it were to operate at 140 degrees, the maximum allowed in applying the protector, the life of the insulation would be cut to 3.12 percent of its life at 90 degrees.

Electrical Types

If one lead to a running polyphase induction motor is disconnected from the line, the motor continues to operate on the one remaining phase as a single-phase induction motor (provided the load is not too great), although at reduced speed. Rotation is supported by the pulsating field produced by the single phase connected to the line and by the rotor cross field. That is also the way a single-phase induction motor runs. However, the polyphase motor at rest will not start with only two leads connected to the supply line, because the single-phase pulsating field does not rotate and hence cannot start motor rotation.

Thus, a single-phase motor must be started by auxiliary means. One way is to provide a revolving magnetic field, a method used in *split-phase* and *capacitor motors.* The revolving field is provided by two windings—a main or running winding and an auxiliary or starting winding. The windings are usually separated by 90 electrical degrees, and the field is made to revolve by creating an electrical phase displacement between the currents in the two windings. Both fields are needed for starting, but only one is required for running; if the auxiliary winding remained in the circuit under load conditions, excessive losses would cause overheating. Hence, when the motor reaches approximately 75 percent of full speed, a centrifugal switch or relay disconnects the auxiliary winding.

In the *split-phase motor*, phase displacement is caused by an auxiliary winding that has a high ratio of resistance to reactance as compared with that of the main winding connected in parallel with it (Fig. 2). Locked-rotor torque is medium to low. (The locked-rotor torque classifications are shown in Table IV.)

A *capacitor-start motor* is similar to the split-phase motor except that phase displacement is produced by an electrolytic capacitor in series with the auxiliary winding and the starting switch. This motor has high locked-rotor torque.

The reason for the difference in locked-rotor torque between split-phase and capacitor-start motors is illustrated in Fig. 2c. The capacitor-start motor diagrammed draws much less locked-rotor current from the line than does the split-phase motor of the same horsepower, and it has nearly twice as much locked-rotor torque.

For ratings of ⅓ hp and above, many capacitor-start motors are manufactured for dual-voltage operation. In a 115/230-volt motor, for example, the main wind-

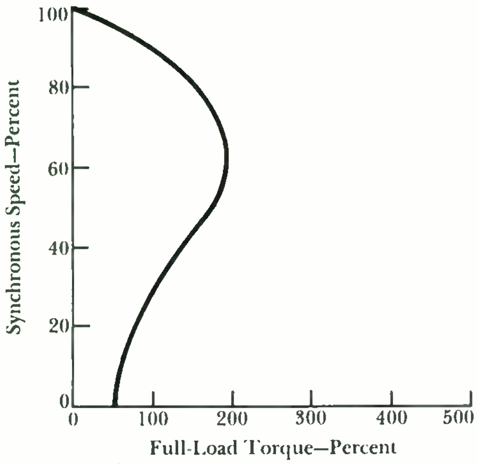
Table IV—Locked-Rotor Torque Classifications

Term	*Locked-Rotor Torque (% of full-load torque)*
Very Low	Below 85
Low	85 to 160
Medium	160 to 275
High	275 to 375
Extra High	Above 375

ing is in two sections, connected in parallel for 115-volt operation and in series for 230-volt operation. The auxiliary winding, capacitor, and starting switch are connected across one of the main winding sections.

Two-speed operation can be obtained with split-phase or capacitor-start motors for some applications by changing the number of poles. Two different main windings are used—one for the high speed and the other for the low speed (Fig. 3). The windings are so arranged that if one connection is used the motor operates at the speed of a four-pole motor, and if another connection is used it operates at the speed of a six- or eight-pole motor. Other speed combinations and connections are used in special motors for particular devices.

A *permanent-split capacitor motor* is similar in construction to a capacitor-start motor except that the starting switch is omitted and the capacitor in series with the auxiliary winding is a continuous-duty oil-filled capacitor. The auxiliary winding and capacitor are connected in parallel with the main winding at all times, resulting in high power factor. Locked-rotor torque is very low (Fig. 4). Speed control is possible, when load is accurately matched to motor characteristics, by impressing different voltages on the windings by means of an autotransformer or a tapped winding. Solid-state speed-control systems have been developed for use on fans, washing machines, pumps, machine tools, and other applications where motor and control are accurately matched to the driven device.



4—Permanent-split capacitor motor has high efficiency and power factor, but its locked-rotor torque is very low. Its auxiliary winding and capacitor remain connected in parallel with the main winding at all times.

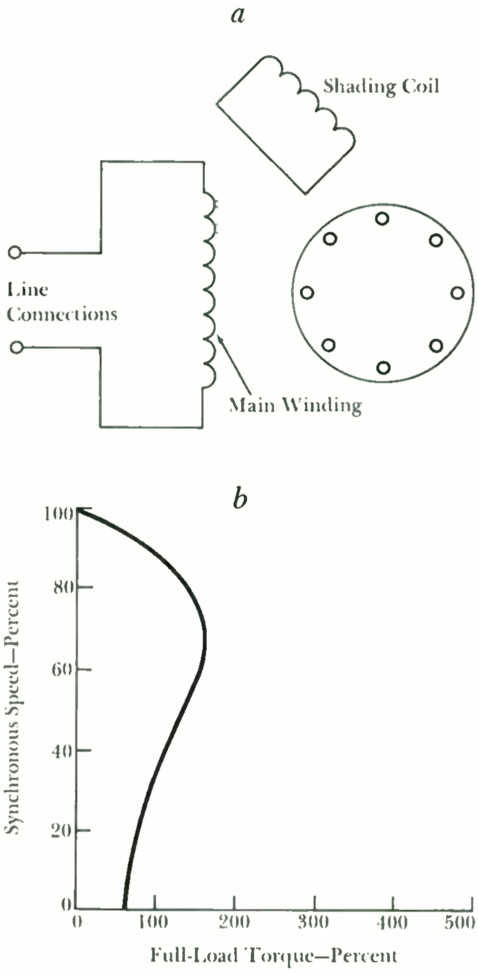
The two-value capacitor motor employs different values of effective capacitance for starting and running to obtain the high locked-rotor torque of the capacitor-start motor and the higher efficiency and power factor of the permanent-split capacitor motor. The motor has an electrolytic capacitor disconnected by the starting switch and an oil-filled capacitor in the circuit under running conditions.

In the *shaded-pole motor*, locked-rotor torque is provided by use of an auxiliary winding or windings (permanently short-circuited) placed around a portion of the main pole (Fig. 5a). The shading coil, which may be several turns of wire or one turn of a copper or aluminum strap, delays buildup of magnetic flux in that section of the main pole to produce a form of rotating field. This motor is rugged, reliable, and simple in construction, but its low efficiency due to losses produced in the shading coil has limited its application to the smaller ratings. Locked-rotor torque is very low (Fig. 5b), and power factor also is low. Speed control can be obtained, when the load is accurately matched to motor characteristics, by impressing different voltages on the main winding or by using a tapped main winding.

The *polyphase* fractional-horsepower motor is similar to its integral-horsepower counterpart, except that it is generally manufactured from components designed for split-phase or capacitor-start motors because of its relatively low activity. Locked-rotor torque is medium to high (Fig. 6). The motor is suitable for all constant-speed applications where polyphase power is available. It is simpler and requires less maintenance than single-phase motors, but its control isn't as simple because at least two leads have to be opened and closed.

Mechanical Considerations

Most fractional-horsepower motors have sleeve bearings, but some have two ball bearings and others have one sleeve bearing and one ball bearing. Ball bearings are used where the thrust load is high, as in a vertical motor with a heavy pulley or fan on the shaft, or in a pump motor whose shaft receives high thrust load. When sleeve-bearing motors are mounted vertically, it is important to determine the amount of thrust load to be handled by the end thrust washer assembly

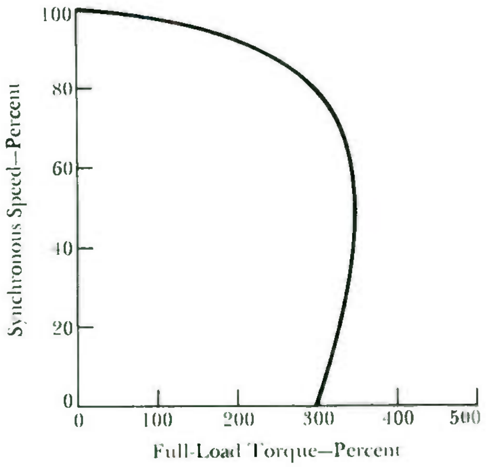


5—Shaded-pole motor (*a*) achieves starting torque with an auxiliary winding that is placed around part of the main pole and permanently short-circuited. (*b*) Locked-rotor torque is very low, as are efficiency and power factor; these characteristics limit it to the smaller ratings.

A motor may be attached to the driven machine in various manners, including a rigid foot, resilient base, face mounting, flange mounting, stud mounting, or machined hub mounting, depending on the application. If quietness is essential, a resilient mounting is necessary to isolate the vibration caused by the pulsating torque that alternates at twice line frequency in single-phase motors. Circular rubber rings affixed to the motor end shields provide flexibility for motion about the center of the shaft. Sometimes a belt or a flexible coupling is required to provide elasticity between the machine and motor shafts.

General-Purpose and Definite-Purpose

NEMA Standards define general-purpose and definite-purpose motors. A *general-purpose* fractional-horsepower motor is an induction motor that is of open construction, is continuously rated, has a service factor in accordance with Table I, and has a Class A insulation system with a temperature rise of 40 degrees C. Such a motor is designed in standard ratings with standard operating characteristics and mechanical construction for use under usual service conditions without restriction to a particular application or type of application.



6—Polyphase fractional-horsepower motor's locked-rotor torque is medium to high, so it is used in all constant-speed applications where polyphase power is available.

Breakdown torque of general-purpose single-phase induction motors is the higher figure in each torque range given in NEMA's Basis of Rating tables, subject to tolerances in manufacturing and other conditions in that standard, including:

1) The breakdown torque that determines horsepower rating is that obtained in a test, with the temperature of the winding and other parts of the machine at approximately 25 degrees C at the start of the test.

2) The minimum value of breakdown torque obtained in the manufacture of any design determines the rating of that design. Tolerances in manufacturing result in individual motors having breakdown torque from 100 percent to approximately 115 percent of the value on which the rating is based, but that excess torque shall not be relied on by the user in applying the motor to its load.

Locked-rotor torque of a single-phase motor at rated voltage and frequency must not be less than shown in Table V. Locked-rotor currents must not exceed the values for Design N motors shown in Table III.

Breakdown torque of a general-purpose polyphase squirrel-cage motor, at rated voltage and frequency, must not be less than 140 percent of the breakdown torque of a single-phase general-purpose motor of the same horsepower and speed rating. Motors rated 208 volts may have 10 percent lower torques than 220-volt motors having the same horsepower and speed ratings. Speed at breakdown torque is ordinarily much lower in polyphase motors than in single-phase motors. Higher breakdown torques are required for polyphase motors so that polyphase and single-phase motors will have interchangeable running characteristics, rating for rating, when applied to normally single-phase motor loads.

A *definite-purpose* motor is any motor designed, listed, and offered in standard ratings with standard operating characteristics or mechanical construction for use under service conditions other than usual or for use on a particular type of application. NEMA definite-purpose motor standards include those for hermetic refrigeration compressors, belt-drive refrigeration compressors, shaft-mounted fans and blowers, belted fans and blowers, air-conditioning condenser and evaporator fans, cellar drainers and sump pumps, gasoline dispensing pumps, oil burners, home laundry equipment, jet pumps, and coolant pumps.

Selecting a Motor

Each type of equipment usually is best driven by a particular type of motor; many of the traditional applications are indicated in Table VI. The selection for a new machine usually is made by a process of elimination until the choice of motor is narrowed down to one or two.

For example, the small domestic oil burner application is analyzed as follows: Single-phase 60-cycle power is usually available where oil burners are used; polyphase power is seldom available in

Table V—Minimum Locked-Rotor Torques of Single-Phase General-Purpose 60-Cycle Induction Motors

	Speed (rpm)		
	3450	*1725*	*1140*
Horsepower		*Torque (oz-ft)*	
1/8	—	24	32
1/6	15	33	43
1/4	21	46	59
1/3	26	57	73
1/2	37	85	100
3/4	50	119	—
1	61	—	—

(From MG 1-12.30)

Table VI—Application Guide for Fractional-Horsepower Induction Motors

Type of Motor			HP Range	Speed Data		Approximate Torque (four-pole motors)		Built-In Starting Mechanism	Reversibility	
				Characteristics	Control	Starting	Breakdown		At Rest	In Motion
Single-Phase	Split-Phase	Design N	1/20 to 3/4	Constant	None	Medium to low	Medium	Centrifugal switch	Yes. Change connections.	No, except with special design and relay.
		Design O	1/4 to 3/4	Constant	None	Medium	High	Centrifugal switch	Yes. Change connections.	No, except with special design and relay.
		Two-Speed (two windings)	1/8 to 3/4	Two-speed	Single-pole double-throw switch	Medium	Medium	Centrifugal switch	Yes. Change connections.	No
	Capacitor	General-Purpose Capacitor-Start	1/8 to 3/4	Constant	None	High	High	Centrifugal switch	Yes. Change connections.	No, except with special design and relay.
		Two-Speed Capacitor-Start (two windings)	1/4 to 3/4	Two-speed	Single-pole double-throw switch	Medium	Medium	Centrifugal switch	Yes. Change connections.	No
		Permanent-Split Capacitor	1/20 to 3/4	Constant, or adjustable varying (varies with load)	Two-speed switch or autotransformer	Very low	Low	None	Yes. Change connections.	Yes. Change connections.
			1/20 to 1/2	Varying, or adjustable varying	Tapped winding or choke coil	Low	Low	None	Yes. Change connections.	Yes. Change connections.
	Shaded-Pole		1/20 to 1/3	Constant, or adjustable varying	Tapped winding or choke coil	Very low	Low	None	No	No
Polyphase (two- or three-phase)			1/8 to 3/4	Constant	None	High to medium	Very high	None	Yes. Change connections.	Yes. Change connections.

Application Data
For oil burners, office appliances, fans, blowers. Low locked-rotor current minimizes light flicker, making motor suitable for frequent starting. For applications where medium to low starting torque and medium breakdown torque suffice.
For washing machines, ironers, sump pumps, home workshops. For continuous and intermittent duty where starting is infrequent and locked-rotor current in excess of NEMA values is not objectionable. May cause light flicker.
For belted furnace blowers, attic ventilating fans, similar belted medium-torque jobs. Starts well on either speed, so is used with thermostatic or other automatic control. Thermal protection recommended, as tight belt or incorrect pulley ratio may overload motor.
For all heavy-duty drives such as compressors, pumps, stokers, refrigerators, air conditioning. All-purpose motor for high starting torque, low starting current. Single voltage in 1/6, 1/4, and 1/3-hp ratings; dual voltage in some 1/3-hp ratings and all ratings above 1/3 hp.
Supplements line of two-speed split-phase motors. Used on identical applications, but provides higher starting torques.
For direct-connected fan drives, especially unit heaters. Adaptable for 115 or 230 volts for one-speed, two-speed, or multispeed service by use of single-pole single-throw switch, two-pole double-throw switch, or speed controller.
Companion to shaded-pole motor. Higher efficiency and power factor suit it for driving fans in room air conditioners and window fans.
Constant-speed switchless motor for low-power applications such as fans, small blowers, unit heaters, hair driers. With fan load matched to motor output, speed control can be obtained by series choke, series resistance, or tapped windings.
For all applications where polyphase circuits are available. Special designs with extra-high starting torque for hoists, door operators, tool traverse, and clamp devices. High-frequency motors are used for high-speed applications such as rayon spinning and portable tools.

small houses, and a polyphase motor would be undesirable anyway because of the greater cost of motor and control. The power requirement generally is ⅛, ⅙, or ¼ horsepower at 1725 rpm or possibly 3450 rpm. Locked-rotor torque requirement is low because the load is mostly blower load, plus a small pump load; however, it is high enough to eliminate the shaded-pole motor for most oil burners. Locked-rotor current should be low because the motor starts frequently; this calls for a NEMA Design N motor. The Underwriters Laboratories safety standard requires a manual-reset type of inherent overload protection. As for mechanical features, the industry standard is a totally enclosed flange-mounted motor. Capacitor-start motors have no advantage for these small ratings, as locked-rotor torque required is low. This leaves the split-phase definite-purpose motor, Design N, as the logical choice for the oil burner.

Larger oil burners for commercial purposes employ motors rated ¼ horsepower and larger, and the motors can be chosen by a similar analysis. Split-phase motors are generally used in ratings up to ⅓ horsepower, and capacitor-start motors are used in the larger ratings (principally because of their low locked-rotor current). Still larger industrial oil burners may require integral-horsepower motors, generally polyphase.

The type of motor best suited for other applications is selected in the same manner, taking into consideration the characteristics of the various motor types and of the driven device. Fractional-horsepower motors for an application that requires a large quantity often are not specified until after device manufacturer and motor manufacturer have cooperated closely to select the proper motor for the particular application.

After the type of motor and its rating have been tentatively selected, an application test of the motor should be made on the actual driven device or on prototype machines. This is especially important if large-scale production is anticipated. If possible, the test should be made with a motor for which data is available, so that wattmeter readings can be used to determine the actual horsepower required for different loads on the machine.

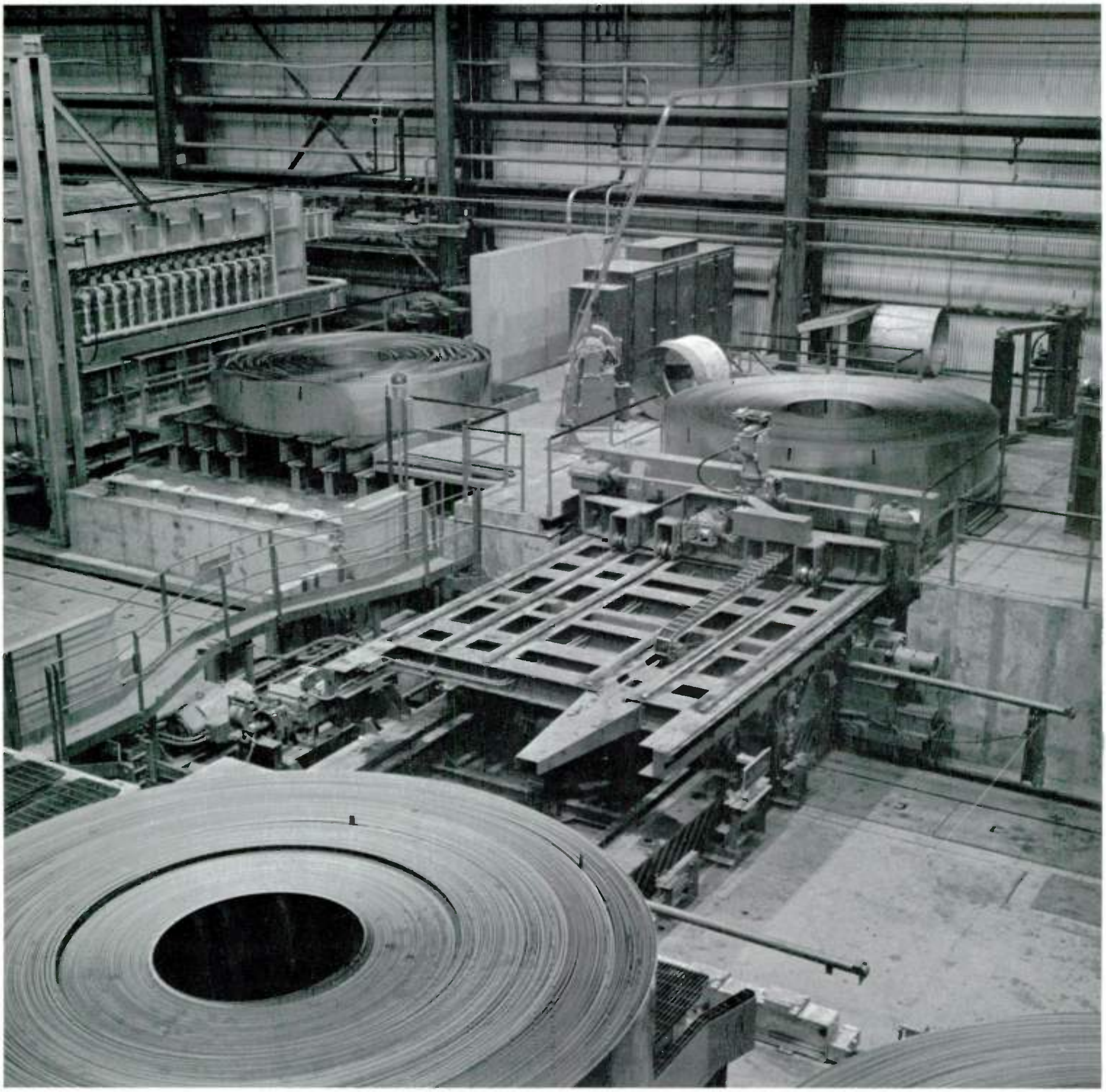
Motors are designed to give long and trouble-free service when operated under conditions indicated by the information on the nameplate, which means that the average load imposed by the device should be near the rated load of the motor. The most obvious means of checking the load on the motor is to compare the amperes taken by the motor with that shown on the motor nameplate. However, that is not the best method and cannot be relied on entirely, because the full-load amperes may be only 40 to 50 percent greater than no-load amperes and in some motors may actually be no greater. Also, a 15-percent change in current may mean a 25- to 35-percent change in load, so when a motor is loaded to 115 percent of its nameplate amperes it may be considerably overloaded. Moreover, variations in motor construction and applied voltage have considerable effect on current at a given load.

The accurate means of determining actual load is to read the watts supplied to the motor when driving the required load, together with the voltage at which the test is run and any duty-cycle variations. The watts input with the motor running without load (disconnected from the device) should be included in these readings where possible and submitted to the motor manufacturer with the other data. Variation in wattmeter reading between no load and full load normally is from 300 to 700 percent, depending on the motor rating. Tests should be taken at reduced line voltage to insure that the motor has sufficient locked-rotor torque and breakdown torque to operate during starting and at peak loads under the lowest voltage conditions likely to be encountered in service.

Such testing, performed in close cooperation with the motor manufacturer, can accurately determine the suitability of a motor for a given application. And a wise motor choice can do much to retain or improve the position of the device manufacturer in today's competitive market.

Open Coils and Fast Handling Speed Batch Annealing of Steel Strip

F. A. Woodbury



A special transfer car moves 15-foot coils of cold-rolled steel strip between storage locations and a double row of batch annealing furnaces at Sharon Steel Corporation. It and the use of loose-wound coils (which heat and cool much faster than tight-wound coils) greatly increase productivity over conventional batch annealing. Here, the car's lifting fingers are extended to the right, under a coil. They will be raised to pick up the coil and retracted to the left to bring the coil onto the car. *Photos courtesy Lee Wilson Engineering Company, Inc.*

Large loose-wound coils are handled quickly and efficiently by an automated transfer car that deposits and retrieves the coils on command. The car speeds handling and also permits use of unusually large coils.

Large coils of cold-rolled steel are batch-annealed in about 30 hours in a new facility at Sharon Steel Corporation, instead of the 72 hours formerly required with the company's conventional batch-annealing process. The much faster processing enables Sharon Steel to greatly reduce the inventory it has to keep on hand to fill orders. Another economic benefit is that the new facility can process larger coils—up to 60 tons in contrast to the former maximum of 30 tons.

The key to the process is the ability to handle giant coils, which measure up to 15 feet in diameter. A special transfer car moves the coils into and out of storage locations and furnaces automatically, under the control of a Westinghouse programming system. The overall facility was designed and built by Lee Wilson Engineering Company, Incorporated, Cleveland, Ohio.

The Process

Conversion of a hot-rolled strip into the annealed product, suitable for deep drawing, begins with pickling, cold rolling, and storage. When it is needed, the coil is taken out of storage and rewound as a loose coil—a coil with space between its laps. Several strip coils can be joined by welding to make one large coil for economical handling; in fact, different customer orders of different widths and various thicknesses can be combined into one coil.

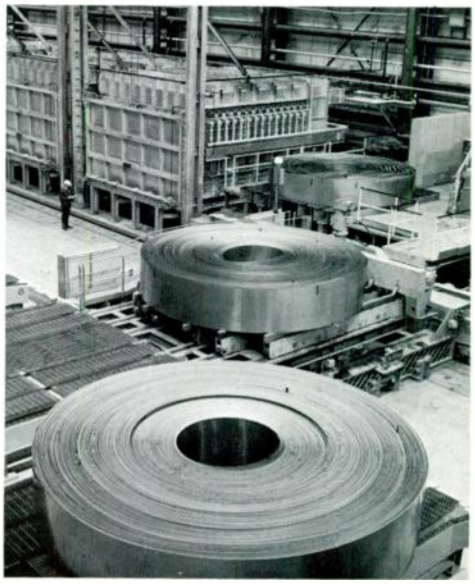
A typical sequence in transferring a coil from one location to another is as follows: At the press of a button, the special transfer car comes to the loose-coil table, picks up the coil, recenters itself on the track, and rotates its lifting fingers 180 degrees so it can deposit the coil on the opposite side of the track. (See photographs.) At a second pushbutton selection, the car travels to one of the 16 annealing furnaces alongside its track, deposits the coil in the furnace, and recenters itself on the track. The furnaces are arranged on both sides of the track beyond the storage areas.

In the furnace, heat-radiating tubes over the coil heat the coil directly and also heat convection gases that pass through the loose-wound coil continuously. This convection heating and convection cooling afterward are the biggest factors in the speed of the process, because heat absorption and dissipation are much faster than with the tight-rolled coils used in the former batch annealing process. When the coil has been cooled to a temperature at which it will not oxidize, the transfer car is called again, the furnace is opened, and the car removes the coil.

The transfer car has separate reversing dc gearmotors, with tachometer feedback and a common generator, for driving its track wheels, rotating its pickup fingers to face right or left, and moving the fingers right and left into and out of storage locations and furnaces. A squirrel-cage gearmotor raises and lowers the fingers to pick up and deposit coils. Control and sequencing for the various motions are accomplished by limit switches and relays, some mounted on the car and some in the furnace and storage areas.

An initiating signal from an operator station goes to the car by carrier frequency superimposed on the car's 440-volt ac lines, and it also lights a slowdown light at the destination. The car moves toward the destination until a photocell on its front end intercepts the beam of light. The resulting signal slows it, and a mechanical limit switch then initiates accurate stopping at the required position. The fingers rotate if necessary and go through the other motions to perform the act called for.

The system has been carefully interlocked to prevent any sequence of motions that would damage equipment. Its program logic is designed to accomplish each task in the most direct manner, creating an efficient and successful coil-handling system.



Top—The fingers have been rotated 180 degrees here so that the coil can be placed in one of the furnaces to the left of the track. Remote pushbutton controls and program logic put the unmanned car through the required motions to retrieve the desired coil from storage and put it into the proper furnace.

Lower—The car moves down the track, stops accurately at the designated furnace, and deposits the coil in that furnace. It also retrieves coils from the furnaces, after annealing, and takes them to temporary storage locations or to the next operation.

F. A. Woodbury is District Engineer, Westinghouse Electric Corporation, Cleveland, Ohio.

Flash Evaporation Studied for Purifying Mine Drainage

Pennsylvania's "clean streams" program includes plans to build a demineralization plant for turning acid coal-mine wastes into pure water. Preliminary engineering and field survey work are now in progress, before actual construction of a demonstration plant at Altoona that will process 5,000,000 gallons of mine drainage a day. The plant will employ the flash distillation process now successfully used to convert seawater into fresh water; the process has been tested on acid mine water in the laboratory.

The planned flash-distillation plant will remove the mine acids so thoroughly that the resulting pure water can be used by a municipality as drinking water or to attract specialized industries that require ultrapure water. The study is being conducted by the Westinghouse Water Province Department.

Plutonium Reactor Fuel Will Be Developed

Plutonium, the artificial fissionable element created as a byproduct in nuclear reactor operation, has not been commercially available in quantity because relatively few reactors have been in operation so far. As a result, no commercial plutonium reactor fuel has been produced. That picture is changing rapidly, though, simply because many more commercial reactors have recently gone into operation, are under construction, or are on order.

Consequently, a significant amount of plutonium will be available in a few years for fabrication into replacement fuel for reactors. To prepare for that day, the Westinghouse Nuclear Fuel Division is building a laboratory to be used in developing the know-how to manufacture plutonium fuel elements for commercial nuclear reactors. Plutonium fuel is seen as an alternate to enriched uranium for fueling the pressurized-water reactors of the commercial nuclear power plants being built today, and it is also expected to fuel the probable next generation of reactors—the fast breeder reactors.

Although plutonium is a toxic material, the laboratory's facilities will meet and in most cases exceed Atomic Energy Commission safety requirements. All fabrication will take place inside glove boxes, and special ventilating equipment will be installed.

The laboratory will first fabricate test assemblies of plutonium fuel elements to experimentally verify the manufacturing processes; then the assemblies will be installed in a commercial nuclear reactor during a normal refueling. The operating data they provide will permit more efficient design of plutonium reactor cores.

Zap! Flash! Tilt! Electric Eels Perform at Zoo

Electric eels show off their power by activating loudspeakers, lights, and meters installed above their tank in the new Aqua-Zoo at Pittsburgh, Pennsylvania. That power is impressive—its voltage ranges up to 600 volts.

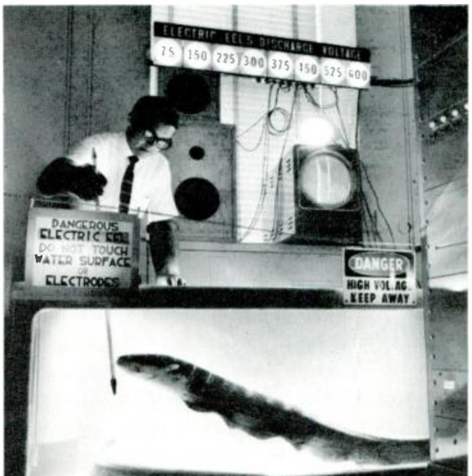
When swimming, an electric eel gives off radar-like pulses of low-voltage electricity that serve as a kind of radar. But when it detects food or an approaching enemy, it switches to full power and unleashes its death-dealing burst of high voltage.

In the zoo display, electrodes at the ends of the eel tank pick up the electrical discharges. At feeding time, spectators can hear over a loudspeaker the pips caused by the radar signals and can see them on an oscilloscope. When an eel attacks, the spectators hear a startling "zap" and see the oscilloscope trace jump. The number of volts registers on a row of colored circles that light up and blink like the panel of a pinball machine. If the voltage is high enough—over 375 volts—it also causes a strobe lamp to give off a brilliant flash. The display was contributed by Westinghouse and was developed by the company's Research Laboratories.

Engineers first studied the currents produced in water by electric eels so they could devise circuitry that would run off the fish's complex electric currents. They found that a single discharge from an eel actually consists of a series of quick surges of current, the surges differing in voltage but each lasting 0.002 second. They follow quickly on one another, but a long discharge includes several pauses of a few thousandths of a second. One recorded discharge lasted five seconds. The eel can strike several times before it has to rest a few minutes to recharge.

The electric eel's tail consists of thousands of power-generating muscle cells. Unlike other animals, the eel can combine the currents of its cells into a single circuit by switching them into a series connection. When an eel strikes, current flows out from its head into the surrounding water, where it traces zig-zag loops back to the tail along conducting paths formed by dissolved materials. Electric eels are insulated against their own shocks and those from other eels, but other fish and animals are good conductors. If one is in the water nearby, the current tends to follow a path that includes it, often killing or stunning it.

Zap! An electric eel attacks the rod waved in front of him, producing a 600-volt discharge that is collected by electrodes at the ends of the tank. The discharge turns on all the lights of the voltage indicator at the top of the picture, flashes the strobe light just below, is registered on the oscilloscope, and sets off flash lamps to take the picture.



TV Tuning System Employs Picture Tube as Indicator

Fine tuning of the local oscillator in a color television receiver is even more important than it is in a black-and-white receiver, because all color information can be lost if the fine tuning is misadjusted. Accordingly, a precise visual method for fine tuning has been developed for Westinghouse color sets.

The method, called on-screen tuning, utilizes the screen of the cathode-ray picture tube as the indicating device to show the degree of mistuning, the necessary adjustment direction, and when correct tuning has been achieved. When the viewer wants to check or adjust fine tuning, he presses a switch on the set. Two heavy vertical lines appear, superimposed on the picture; one is stationary for a reference, while the other moves from side to side as the fine-tuning knob is turned. When the two lines coincide, the set is properly tuned and the color controls can be adjusted to achieve the desired color balance. The viewer then deactivates the tuning control switch to remove the lines from the picture.

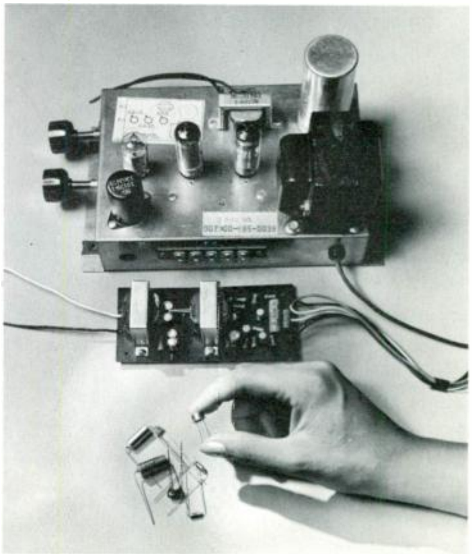
The tuning lines are generated by auxilliary circuits arranged in an alternating time-sharing system, in which the reference line is produced while one picture is being scanned and the control line is generated during the next picture. To the viewer, the lines appear on the screen simultaneously. The signals that produce the lines are series of narrow video gating pulses, synchronized to the horizontal scan rate, that cut off the video amplifier for one or two microseconds. The position of the stationary line is controlled by a reference voltage, while the movable line is positioned by an adjustable voltage that is a function of the fine-tuning control setting.

Color television tuning system provides accurate fine tuning through the use of two vertical lines displayed temporarily on the picture tube. One line moves as the fine-tuning knob is turned; when it coincides with the stationary line, the set is tuned.

Integrated-Circuit Devices Invading Consumer Field

Ninety percent of the electrical circuitry of a new audio amplifier is no larger than the proverbial mustard seed, because it is a self-contained integrated-circuit device. The circuit does the job of amplifying the weak signals from a phonograph pickup thousands of times and feeding them directly to a loudspeaker. This WC334 amplifier, produced at the Westinghouse Molecular Electronics Division, is intended for such applications as low-cost portable phonographs, tape recorders, radios, intercoms, walkie-talkies, dictating machines, and do-it-yourself electronic circuits.

The revolutionary new integrated-circuit technology was first developed primarily for military applications, where high reliability, low power requirement, and savings in size and weight are of utmost importance. More recently, the great advantages of some or all of those characteristics in industrial applications have been recognized; there, as in most military systems, integrated circuits have been mainly used as *switching* devices, especially in electronic computers and related control circuitry. Now, with continued development of the technology, widespread introduction of *linear* integrated circuits is beginning. That type, which faithfully reproduces electrical signals fed into it, is the kind broadly needed in consumer applications. The



Three generations of audio amplifiers illustrate a trend in electronic circuitry for consumer applications. The device held in the hand at bottom is an integrated circuit that performs essentially all of the functions of its predecessors, the transitorized phonograph amplifier *(center)* and the vacuum-tube amplifier *(top)*. The capacitors shown with the integrated-circuit device are used to shape its output.

WC334 is a linear integrated circuit developed to the point where it can be used in consumer-oriented devices competitive in price with those based on conventional circuitry. Such devices are expected to be a significant part of the total integrated-circuit market in the years immediately ahead.

The WC334 amplifier's electrical drain is so low that battery life is comparable to that in transistor radios. If desired, an appliance using the amplifier can also be arranged for operation from an ac power line. The amplifier has a power output of one watt at an acceptable distortion level, and frequency range is well beyond that required for typical low-cost consumer applications. It is usable with supply voltages from less than six volts to more than 20.

Research Facility Will Speed Deep-Diving Developments

One of the key laboratories in the Ocean Engineering and Research Center now being completed on Chesapeake Bay near Annapolis, Md., is the man-rated pressure facility. Its three-chamber complex will be used by life-support engineers and scientists to study diving physiology and equipment and to train divers. Its maximum depth capability is a pressure equal to that produced by 1500 feet of water, about 700 pounds per square inch. The facility includes the pressure chambers and supporting equipment such as tanks and handling systems for the breathing gases, compression equipment, instruments, and laboratory and office space.

The three chambers can be pressurized independently. The entry chamber is a sphere about six feet in diameter, connected by a pressure-tight hatch to a second chamber about nine feet in diameter and eleven feet long. Divers and researchers will live for days or weeks at a time in the second chamber. A third chamber, a sphere about nine feet in diameter, is positioned below and toward the end of the second chamber and is linked to it by a pressure-tight hatch. It is partly filled with water.

Research in the new facility will be an extension of the Westinghouse Underseas Division's diving research and experience such as that performed with the existing Cachalot diving system. Since the research can now be done under better conditions, advances in techniques and equipment should be made more quickly. The two major areas of research will be diving physiology and improvement of deep-diving equipment and techniques.

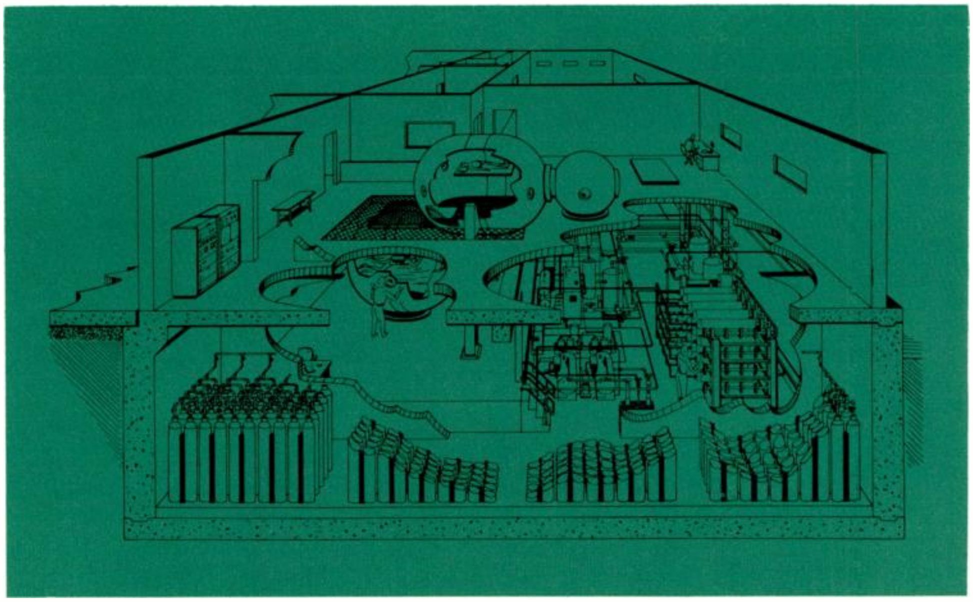
In diving physiology, the most significant present problem is defining proper breathing-gas mixtures for various depths. Air cannot be used for diving beyond a depth of about 150 feet because, under pressure, its nitrogen produces a narcotic effect and the amount of oxygen in it is toxic. The narcotic effect, known as nitrogen narcosis or rapture of the deep, increases with depth. The amount of oxygen in air becomes toxic at depths of about 300 feet; compression of the air causes a diver to take in 10 times as many oxygen molecules with each breath as he does at normal pressure.

To eliminate the narcotic effect, helium is substituted for part or all of the nitrogen in a breathing mixture. The relative quantity of oxygen in the mixture is reduced to prevent oxygen toxicity; its proportion, in terms of partial pressure, must be varied in relation to depth. Diving tables are determined by calculation and verified by diving research to provide the proper breathing-mixture proportions.

Research on equipment and techniques will be aimed at increasing the diver's working time and efficiency and improving his safety. Some of the present equipment problems are communications difficulties caused by voice distortion in helium (the Donald Duck effect), breathing difficulty because of resistance to gas flow in breathing apparatus and because of gas density at high pressure, thermal protection for divers, and illumination under water.

One of the first research programs scheduled will consist of experiments in saturation diving, or prolonged-submergence diving, to a simulated depth of 1000 feet. The experiments will provide the basis for diving tables and techniques for working dives that will be made with the Westinghouse Cachalot-850 saturation diving system now being completed. With that system, divers will live under pressure for a week or two weeks and commute to working depth in shifts from a surface chamber by means of a submersible chamber. Experience gained in more than two years of diving with an existing

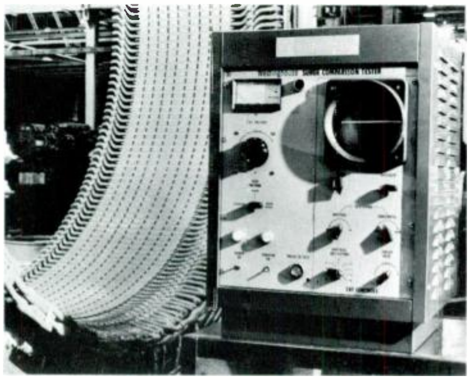
Heart of the undersea research pressure facility is a system of three connected pressure vessels. Surrounding it are the necessary support systems, materials, and instrumentation.



Cachalot system designed for depths of 400 to 600 feet has led the engineers to expect to achieve working-dive depths of 850 feet by the end of 1967, and 1000 feet within a year if there is work to be done at that depth.

Extended Service Lamp is a new fluorescent lamp with a life rating of 18,000 hours (on the basis of three hours burning per start). On rapid-start circuits, this is a life increase of 50 percent over the ordinary 40-watt lamp. The life increase has been accomplished with no sacrifice in light output. It is the result of a smaller-diameter glass tube, improved control of phosphors, change in combination of internal lamp pressure and gases, and advanced electrode design. The lamp operates on all standard 40-watt ballasts and in all 40-watt fixtures. *Westinghouse Lamp Division, 1 Westinghouse Plaza, Bloomfield, New Jersey 07003.*

High-power transistor, type 1401, is rated 625 watts continuous, 250 amperes. It is designed for voltage regulation, amplification, and switching of large blocks of power, as in inverters, electrical distribution systems of aircraft and missiles, and sonar systems. The 1401 is a diffused-junction transistor (*npn*) with the junction made in a unique "sunburst" design to give maximum area for current flow. Spring pressure eliminates the usual soldered joint that attaches the silicon wafer to its container, eliminating also such solder-joint deficiencies as resistance and cracking. *Westinghouse Semiconductor Division, Youngwood, Pennsylvania 15697.*


Surge Comparison Tester


Induction Heating Generator

Surge comparison tester performs fast and accurate testing for faults in windings of motors, generators, and many types of transformers and electromagnetic coils. Used in manufacturing, maintenance, and repair, it indicates presence of faults (shorts, grounds, or dissimilarity in number of turns) by comparing impedances in two identical windings or sections of a winding. The unit is so sensitive that it indicates a difference of just one turn, or a short between one turn and another, even in a winding with hundreds of turns. The tester delivers a low-energy high-voltage 60-cycle transient to the winding under test and presents each cycle on a cathode-ray tube. If no fault is present, only one trace appears on the tube, but if a fault causes different impedance between the two windings or sections, then two different wave forms appear. *Westinghouse Aerospace Electrical Division, P.O. Box 989, Lima, Ohio 45802.*

Induction heating generators, new type 20K65, provide simpler control, faster response, improved regulation, lower noise level, and smaller size than former line of r-f generators. Applications include brazing and soldering, annealing, zone refining, plasma torch, and epitaxial processing. Power output ratings range from 5 to 20 kilowatts, and frequency from 250 to 490 khz. A new thyristor power control provides fast overload protection and eliminates transformer inrush problems and moving contactors. *Westinghouse Industrial Equipment Division, Box 868, Pittsburgh, Pennsylvania 15230.*

Consulting services to help small businesses become established in the aerospace and defense industry include assistance with proposal preparation, contract negotiation and administration, manufacturing engineering, purchasing and subcontracting, planning and scheduling, quality control, and reliability. Initial exploratory discussions are free of charge; if services are required thereafter, a fee is negotiated on the basis of the amount of consultation needed. *Consulting Services Marketing, Westinghouse Astronuclear Laboratory, P.O. Box 10864, Pittsburgh, Pennsylvania 15239.*

Laser laboratory leasing gives a company the use of an advanced laser facility, including the engineers who man it, for complete manufacturing cost and feasibility studies without having to invest in equipment. The leasing concept is designed to make the laser's transition from research laboratory to production line as realistic and efficient as possible. A user delivers materials or devices from his production line to the laser laboratory, where they are cut, drilled, welded, or finished to his specifications. The laboratory's equipment provides a wide variety of laser energies, spot sizes, pulse widths, and laser head configurations. Processing is performed by experienced laser engineers and metallurgists, and it is accompanied by an engineering analysis of results, a process suitability study, and an economic comparison with conventional machining methods. *Westinghouse New Products Division, 7800 Susquehanna Street, Pittsburgh, Pennsylvania 15221.*

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Author Index

(Author biographies appear on the inside back cover of each issue.)

About the Authors

After graduation from Lafayette College in 1930, **M. J. Boho** was employed by Bailey Meter Company as a field sales-service engineer. He next spent three years with Potomac Electric Power Company as a power station instrument and test engineer. In 1936, he joined Hagan Corporation as a field service engineer supervising the installation and adjustment of combustion control equipment in the electric utility and steel mill fields. Boho became a field salesman in 1938, and sales manager in 1944. In 1948, he became vice president, general manager, and a director of Hagan.

In 1963, Boho joined Westinghouse as a marketing consultant, Generation Marketing, Electric Utility Headquarters Department. In his present position he is responsible in a staff capacity for evaluating and coordinating varied company activities relating to electric power generation.

Boho was active in early pioneering efforts in establishing automatic control as an essential tool in the steel and electric utility field. He has written articles for industry and the technical press during his career and is a registered Professional Engineer.

Roger Alke graduated from the University of Washington in 1948 with a BSEE. He joined Westinghouse on the graduate student course and went to the Transportation and Generator Division to work on development and field problems. He moved to the Kansas City district office as Consulting and Application engineer in 1952, and in 1955 he started a district electric service operation in that area. Alke rode herd on equipment installation and field problems there for the next 10 years, while the area was expanded to include the Rocky Mountain district. Since 1966, he has been District Electric Service Manager in the Pittsburgh office.

Richard F. Cook came to Westinghouse in 1956 after graduating from the University of Cincinnati with a BSEE. From the graduate student course, he was selected to attend the company's Advanced Design School.

Cook spent eight years as a distribution system engineer, one year as an advanced development engineer, and two years as a marketing consultant before assuming his present position of manager of the distribution systems and application section of Electric Utility Headquarters Department.

Although this is Cook's first appearance on these pages, he has written many technical articles and papers that have described his wide-ranging activities, from electric space heating and air conditioning, to isolated generation evaluation, to electric utility distribution system design and planning. He conceived and developed the first hour-by-hour computer analysis of building energy systems. Cook also designed the first total underground distribution system that uses submersible distribution transformers.

Cook obtained an MSEE degree from the University of Pittsburgh in 1960 by attending evening classes, and in 1961 he became a Registered Professional Engineer in Ohio.

T. E. M. Carville has been designing and applying fractional-horsepower motors since 1925, when he joined the Small Motor Division right off the graduate student course. He served first as a design engineer and then as an assistant section manager and section manager before being appointed Engineering Manager in 1944. Since 1954 he has been Advisory Engineer and Engineering Supervisor, in charge of development expenditures, engineering budgets, licensee information, engineering systems, and service information.

Carville has contributed to or been responsible for the design of many ac, dc, and universal motors, as well as special generators. He has served "about 15 years" on the Underwriters Laboratories industry advisory conference on motor-operated appliances and thermal protectors for motors, and "about 20 years" on NEMA technical committees developing motor standards. Carville has been awarded three patents and has written a textbook on fractional-horsepower motor maintenance. He is a registered professional engineer and an IEEE Fellow.

Carville graduated from the University of Maine in 1924 with a BS in Electrical Engineering, and he received an EE degree there in 1923. He is a long-time Boy Scout leader and member of the youth committee of the Lima, Ohio, YMCA. His public service also includes a term on the Lima city council and two years on the county planning commission.

Frank A. Woodbury graduated from the University of Utah in 1952 with a BS in Electrical Engineering and entered the Westinghouse graduate student course. He completed a consulting and application training program and thereafter served as a Consulting and Application Engineer in the Cleveland District Sales Office. Woodbury became Industrial District Engineer there in 1961, and in that role he developed and installed the electrical system for the coil transfer car described in his article. He has produced 29 patent disclosures and presented several technical papers.

New Laser Pump

A ball of light, which "bathes" a laser rod from all directions, may turn out to be the most efficient way to energize a laser. The new reflector design developed by scientists at the Westinghouse Research Laboratories puts the laser rod and lamp along the center of a hollow spherical reflector, the entire inside surface of which is reflecting. The spherical reflector focuses the pumping light in three dimensions, flooding the laser rod with light from all directions. With standard cylindrical reflectors, the idealized coupling between the light source and laser rod is considerably reduced by the need for cooling tubes and for envelopes around the lamps, which obstruct the path of the radiation and lower the efficiency of the cylindrical reflector. The spherical reflector, on the other hand, does not have the reflector closely wrapped around the pumping lamp and laser rod. This permits a more convenient arrangement of the lamp and rod, thereby reducing interference with the pumping light.

The work on the new spherical laser pump was supported in part by the U. S. Army Electronics Command, Ft. Monmouth, N. J.