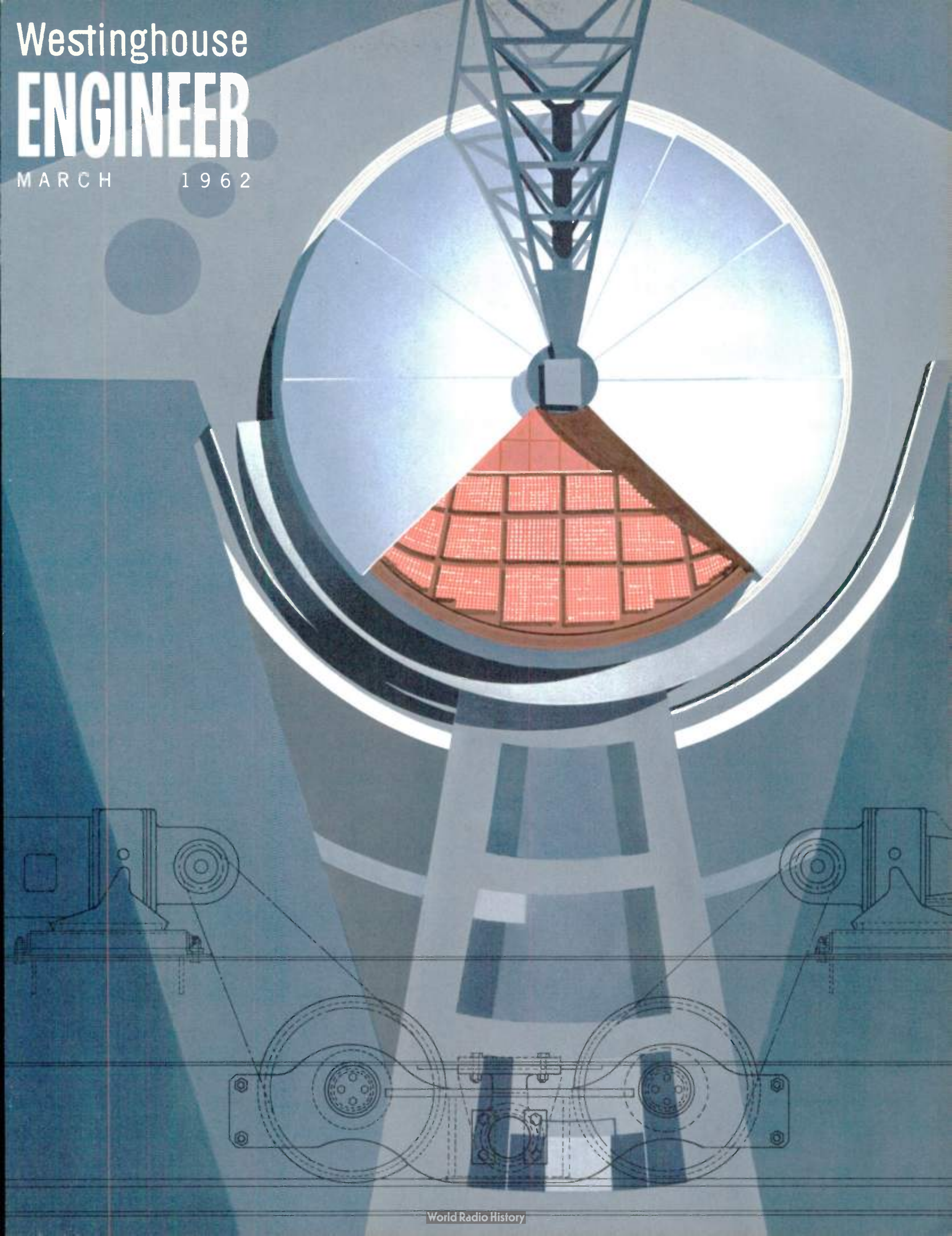
Westinghouse ENGINEER

MARCH 1962



Poised above its bath of liquid helium is a Westinghouse superconducting electromagnet. The magnet coil itself is enclosed in the small perforated case just above the metal cylinder. It contains a half mile of fine wire and has twice the strength that the massive iron-core conventional magnet behind it has when run to saturation of the iron.

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editor
RICHARD W. DODGE

managing editor
MATT MATTHEWS

assistant editor
OLIVER A. NELSON

design and production
N. ROBERT SCOTT

editorial advisors
J. A. HUTCHESON
J. H. JEWELL
DALE McFEATTERS

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Cover Design: The new Pittsburgh Auditorium with its retractable domed roof is the subject of this month's cover by artist Dick Marsh. The artist has caught the great dome partly open, revealing the interior of the unique structure that changes from an auditorium to an open-air amphitheater and back again at the touch of a pushbutton. The main components of one of the motorized trucks that actuate the movable roof sections are sketched at the bottom.

EXPERIENCE WITH WATER REACTORS Developments in many technical areas are contributing to the progress in atomic power.

ROBERT J. CREAGAN
Engineering Manager
Atomic Power Department
Westinghouse Electric Corporation
Pittsburgh, Pennsylvania

The feasibility, safety, and reliability of atomic power plants are now well established. Atomic generating stations can now be considered on the basis of economics, along with long established energy sources, in many areas.

This technological landmark has been reached in a field that abounds with severe technical problems, some of which have been solved, while others still lie ahead. In the case of water reactors, where the most experience is concentrated, a large number of individual technical developments have contributed to this progress.

overall progress

In any kind of a heat engine, higher operating temperatures lead to higher efficiencies. Therefore, progress in power reactor design is probably best illustrated in Fig. 1, which compares certain key temperatures and pressures of the Yankee plant and the plant design offered to Southern California Edison.

On the basis of experience with the Yankee plant and other designs, four significant improvements have been made in the pressure-temperature area:

1. Minimum operating pressures have been increased from 1800 psia to 2182 psia, which allows,
2. An increase in permissible coolant temperature rise through the core—from 30 degrees F to 43.5 degrees F—without boiling;
3. Temperature drop from the primary to the secondary system has been increased, allowing improved heat transfer through the steam generator; and thus,
4. Higher steam pressures are obtainable for the turbine generator (680 psia instead of 500 psia).

These improvements were made possible by an intensive effort in every phase of reactor design, with experience in Yankee and other plants serving as a source for most new developments. A simultaneous effort has been made to improve even further the reliability of nuclear plants, and to simplify the designs.

No single component improvement provides such significant gains; instead, the overall performance of a plant has been raised by progress in several areas of reactor design. The nature of these improvements can best be indicated by examples of specific design trends, some of which contribute directly to the temperature-pressure gains, and others to overall plant economy, simplification, and reliability.

Editor's Note: The United States Atomic Energy Commission has supported, and continues to support, most of the research and development effort in the areas described in this article. Without such support, and without the combined efforts of the Atomic Energy Commission, the electric utility industry, and the reactor manufacturers, the development of the peaceful uses of atomic energy could not have progressed as rapidly as it has.

thermal and hydraulic

The Yankee reactor differed from earlier Westinghouse reactors in that surface—but not bulk—boiling was allowed. Although accepted today, such boiling was questioned when it was first suggested because of its possible adverse effects on corrosion and erosion in the reactor. The net gain from surface boiling is a reduction in required coolant flow through the core, which in turn means that less pumping power is required.

Present closed-cycle water reactors are designed with thermal limits to prevent melting at the center of the UO_2 fuel pellet, and a design margin to prevent departure from nucleate boiling (DNB) at the fuel-element surface. By definition, DNB occurs when steam vapor starts to blanket the fuel cladding surface, thus reducing heat transfer and rapidly raising the temperature of the cladding. To prevent this, experimental data must be correlated with reactor design so that a minimum DNB heat flux is not exceeded. The conservative DNB correlation developed for Westinghouse water reactors is a curve below 99.2 percent of all presently available data points at 2000 psia.

Information necessary to evaluate power density distributions experienced during operation is obtained from the Yankee core. The in-core instrumentation system consists of 27 thermocouples for monitoring the core outlet temperatures, and flux wires that can be inserted in 22 different locations in the core as indicated in Fig. 2.

The location of the in-core instrumentation is such that a complete quadrant of the core can be selectively monitored. With quadrilateral symmetry, this is sufficient to allow evaluation of the behavior of the entire core. If an asymmetrical power distribution exists, the in-core data can be used to infer total core behavior and the effect of corrective action.

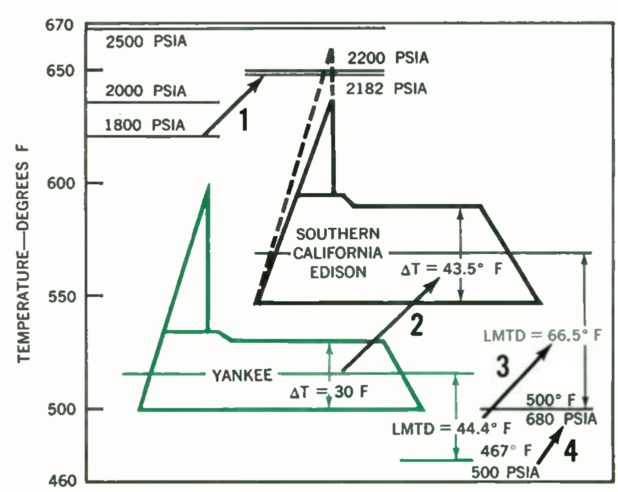


Fig. 1 Key temperatures and pressures of the Yankee plant and the proposed Southern California Edison plant.

Use of the thermocouples yields a measurement of the power distribution across the core. Flux wires are currently the only means of measuring axial variations in power density. The experimental flux wire data is combined with the results of calculations to obtain the values of hot channel factors during Yankee operation.

"Hot channel factors" are design allowances so selected because the heat output of a reactor is governed by the hottest conditions, as indicated by the temperature spikes shown in Fig. 1, rather than by average conditions. By definition, hot channel factor F_q is the ratio of the maximum to the average heat flux in the reactor. Hot channel factor $F_{\Delta H}$ is defined as the ratio of the maximum to the average increase in enthalpy (temperature) of water passing through the reactor. Because the hot channel factors govern design heat power output and calculational errors might result in fuel burnout, the correct prediction of operational results is important. Predicted and operational data for Yankee hot channel factors, as they vary with reactor operation, is shown in Fig. 3.

These results indicate that the theoretical predictions were both realistic and conservative in that hot spots did not exceed predicted values. Based on such results, the heat power output license for the Yankee first core has been increased from 392 to 485 mw—at which power it now operates.

nuclear

The nuclear developments for Yankee and other water reactors have been both analytical and experimental. Small critical experiments were performed at the Westinghouse Reactor Evaluation Center (WREC) and the results were used to check analytical procedures to be used later for design purposes. A full-sized critical experiment was not required for Yankee because the boric acid dissolved in the coolant could provide practically any specified shutdown; and one function of a full-sized critical test would be to prove experimentally that the reactor could be held sufficiently subcritical. With the results of the development program, the Advisory Committee for Reactor Safeguards accepted, and the USAEC licensing authorities approved, use of the chemical method of shutdown control.

In the field of physics, nuclear predictions and final results agreed closely, as shown in Table I.

In predicting core lifetime, power distribution (and hence burnup) as a function of fuel position in the reactor is an important factor. As an indication of ability to calculate results in this area, Fig. 4 shows a comparison of the predicted and measured spatial (RZ vertical section) burnup distribution in Yankee. The numbers are in units of accumulated equivalent full-power hours (EFPH) averaged over the given fuel regions.

The measured burnup distribution was obtained from in-core flux wire instrumentation data after reduction by a computer code. The predicted results were calculated by two-dimensional, two-group diffusion theory.

In addition to the comparison of theoretical with measured values for Yankee, similar comparisons have been made in multi-region critical experiments. Evaluation of analytical methods for nuclear design was increased greatly in scope by comparison with approximately 400 experiments performed at WREC.

The excellent agreement between the theoretical results and results of experiments conducted at WREC is shown in Fig. 5. The core configuration (quadrant plan view) is illustrated in the upper left hand corner. Fuel rods of 1.6 percent, 2.7 percent and 3.7 percent uranium-235 are arranged as indicated. The total loading is 10 541 fuel rods, with approximately equal numbers of each enrichment. The points indicated represent the experimentally measured fuel-rod radioactivity as a measure of power output. The curves illustrate results obtained by three different analytical techniques. Best results were obtained by the use of the mixed number density model, which involves the computation of neutron density, rather than neutron flux, as a function of core position.

In addition to power distribution, important nuclear reaction rates were also calculated and measured. Two of the most significant parameters are ρ^{28} (ratio of nonthermal to thermal neutron captures in U-238) and δ^{25} (ratio of

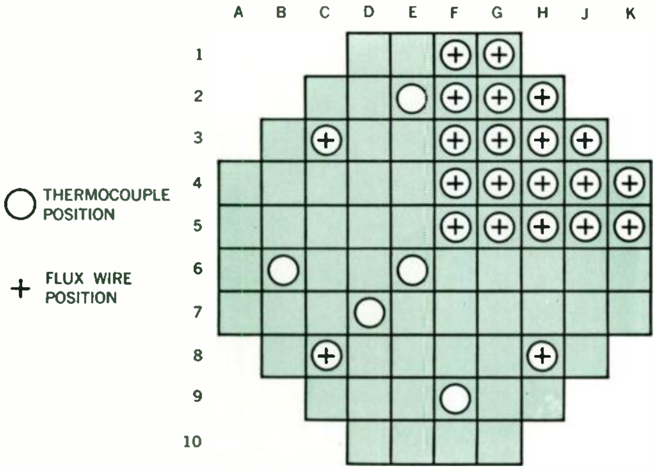


Fig. 2 The location and types of instrumentation incorporated in the core of the Yankee reactor.

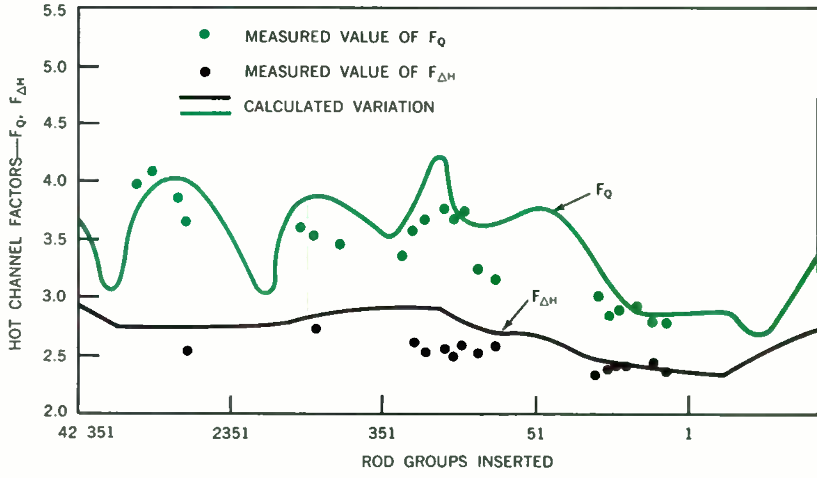


Fig. 3 The relation between predicted and operational values for hot channel factors for the Yankee plant.

Table I YANKEE STARTUP EXPERIMENTS—COMPARISON OF CALCULATION WITH EXPERIMENT

Parameter		Calculated	Experimental
Boron Concentration in Core (No rods) for criticality at 100°F		2050 ppm	1895±20 ppm
at 514°F		1750 ppm	1707±17 ppm
Boron Worth at 514°F (C_B=0)		6.8×10^{-5}/ppm	$7.5\pm0.3\times10^{-5}$/ppm
at 100°F (C_B=1400)		7.4×10^{-5}/ppm	$7.9\pm0.5\times10^{-5}$/ppm
Excess Reactivity at 514°F, C_B=0,		10.2×10^{-2}	$11.4\pm0.4\times10^{-2}$
Control Rod Worth at 514°F—24 Rods		16.5×10^{-2}	$16.2\pm1.2\times10^{-2}$ [a]
—10 Rods		6.9×10^{-2}	$7.4\pm0.4\times10^{-2}$ [b]
Cold to Hot Reactivity at 1700 ppm		2.0×10^{-2}	$1.6\pm0.2\times10^{-2}$
at 1100 ppm		4.4×10^{-2}	$3.7\pm0.4\times10^{-2}$
Zero Station Load			
Moderator Coefficient— (10^4/°F)	100°F, 1200 ppm	−0.3	−0.5±0.09
	250°F, 1200 ppm	−0.9	−0.6± .09
	514°F, 1200 ppm	−2.0	−1.3±0.2
	514°F, 600 ppm	−2.6	−2.2±0.3
	514°F, 0 ppm	−3.2	−3.1±0.7
Pressure Coefficient (1000–2000 psig) (10^6/psi)	514°F, 1200 ppm	+1.3	+1.0±0.5
	514°F, 0 ppm	+2.5	+2.7±0.7
Full Station Load (120 MWe)			
Power Coefficient (10^4 MWt)		−0.40	−0.33±0.10
Xenon Worth (Saturation)		2.7%	2.5%
(Peak)		3.4%	3.2%
Samarium Worth (Peak)		0.8%	~0.9% [b]

[a] Corrected to zero boron concentration.
[b] Estimated, based on operating data up to 50% equilibrium.

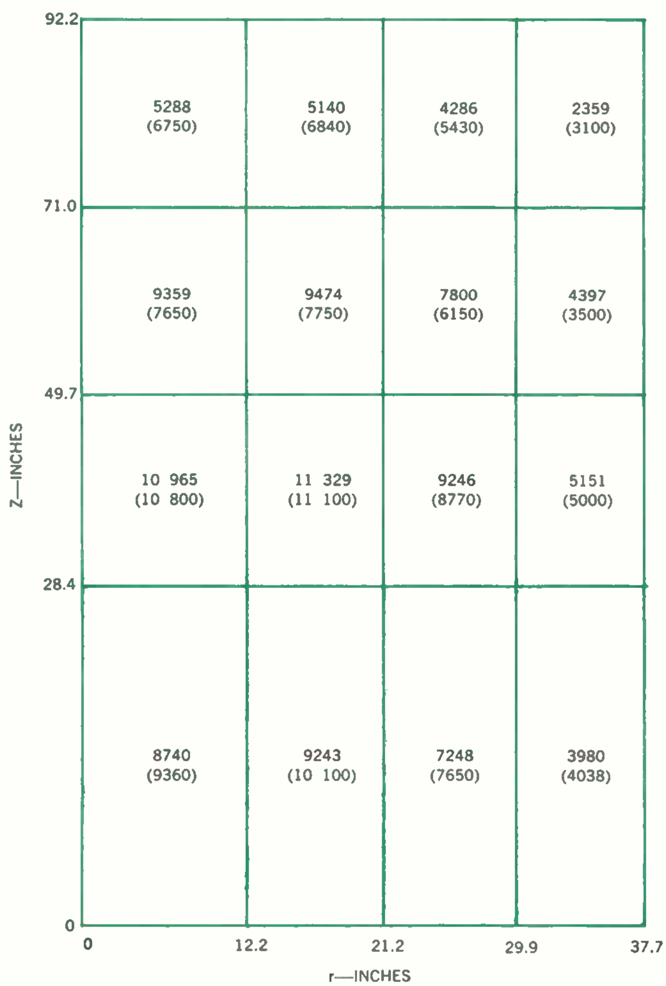


Fig. 4 A comparison of measured and calculated values for burnup distributions; measured values correspond to 6310 EFPH, and calculated values (in parentheses) to 6400 EFPH.

nonthermal to thermal neutron fission in U-235). Intensive investigation of these parameters has been made in reactors of 1.6 percent, 2.7 percent and 3.7 percent enrichment with water-to-uranium ratios of 2.5 to 1 and 4.5 to 1. Early theoretical results at Westinghouse and other laboratories disagreed with experimental data by as much as 25 percent; however, agreement to better than 10 percent is now obtained as a result of development effort.

This excellent agreement between theoretical predictions and experimental results, as in the case of Yankee and the multi-region work, means that future reactor plants can be designed closer to their ultimate nuclear capability with assurance of reliable performance.

chemical

The formation and mobility of the magnetite corrosion products of stainless steel (usually referred to as "crud") has not proven a deterrent in the neutral pH water maintained in Yankee. Neutral pH causes more crud formation than higher pH, but it also provides higher mobility and hence helps crud removal by ion exchange or filtration.

Some concern has been expressed about the use of stainless steel cladding, particularly with respect to its cobalt impurity content, since this impurity becomes radioactive and might plate out on the primary loop to cause a high radiation level that would inhibit maintenance. Good agreement has been obtained thus far between calculated and observed dose rates (25 mr/hr at the steam generator surface opposite the middle of the tubes). This indicates that commercially available stainless steels are suitable for fuel cladding and do not cause excessive radiation levels.

Yankee employs boric acid for hot-to-cold reactivity control, based on a successful development program. Plant operation has demonstrated no problems or difficulties. There are many significant advantages to using a neutron absorber in the primary coolant water. These advantages include a substantial reduction in the number of control

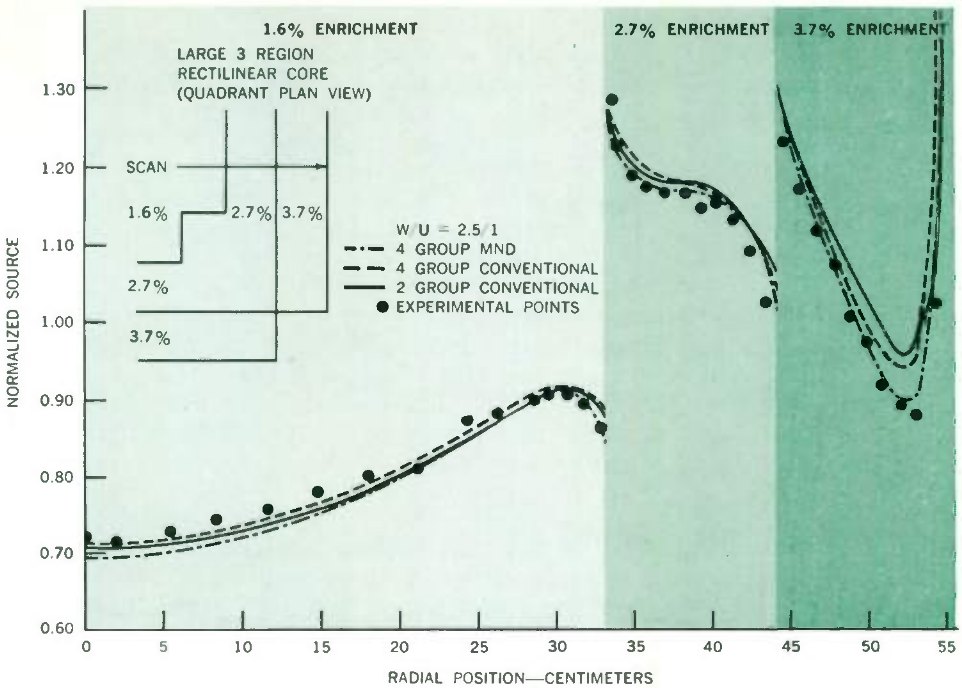


Fig. 5 Calculated and measured values for power distribution in a multi-region core. Measured results were obtained at the Westinghouse Reactor Evaluation Center, and calculated values were obtained by three different techniques.

rods, mechanisms, and associated equipment required and provision of almost unlimited shut-down ability because of the high cross section of boron and its high solubility as boric acid. These advantages have been somewhat offset by the necessity for providing some auxiliary equipment and by the inconvenience of purifying water to remove boron.

At the cost of essentially no additional plant complications, but with the necessity for proving its feasibility, boric acid can be used as a chemical shim in the coolant of a reactor during power operation. A program is now underway to demonstrate the feasibility of this concept.

Chemical shim provides better power distribution in the reactor and allows longer reactivity lifetime for the core. These two advantages result in lower capital requirements and lower fuel cost respectively.

materials

An example of materials development is the effect of various parameters on UO_2 pellet temperature distributions; namely, the effect of gas composition, and variation in the gap in the pellet-to-cladding annulus as a function of power per unit length of fuel rod. Experiments show that the pellet center temperature rises: (a) if argon is used instead of helium for the gap; (b) if the gap is increased; and (c) if the power produced per foot of rod is increased. Motives for the study include, respectively: (a) fission fragment gases in actual operation vary the conductivity of the gap; (b) manufacturing tolerances vary pellet-cladding gap; and (c) power output capability of a given fuel rod with no center melting depends on power per foot of rod.

The necessary experiments were performed in the Westinghouse Testing Reactor. The cladding was Zircaloy-2 and the pellets were 0.430-inch diameter and 93 percent of theoretical density.

After irradiation, the fuel rods were sectioned and the UO_2 fuel examined microscopically. The temperature distribution within the UO_2 fuel was estimated by measuring the radius at which various characteristic microstructural changes occurred.

Examination indicated that center holes in the pellets were usually formed by pore migration to the center at temperatures below the melting point of UO_2. Definite melting of the UO_2 was observed in only one fuel rod.

These experiments point to the possibility of increasing tolerances for fuel tubes or pellets, thereby reducing the cost of fuel elements; or, as an alternative, maintaining present tolerances and increasing power output per unit length of rod.

mechanical

Due to the greater weight of the Yankee control rod and its follower, it was necessary to develop a new control rod drive mechanism. The magnetic-jack latch type of control rod drive mechanism, developed for Yankee, is an excellent example of an ingenious mechanical design that solved a tough problem in an economic manner. All the mechanical moving parts are inside the primary coolant environment, separated by a sealed pressure housing from the external electrical coils which supply the motive power. While the initial design required five coils, the present design requires only three coils to accomplish the same purpose.

In the fuel assembly shown in Fig. 6, fuel rods are inserted in special fuel assembly cans. These cans contain grids equipped with spring fingers that grip the fuel rods with controlled pressure. This spring pressure is sufficient to prevent fretting but allows relatively free differential thermal expansion in an axial direction. This is much simpler than the previous design, which required brazing of tubes between the fuel tubes to maintain proper spacing.

With the new grid structure, no brazing of the fuel rods is necessary. This, in turn, allows thinner cladding steel to be used for the fuel tubes, since the heat cycle previously required for brazing reduced the mechanical strength of the cladding.

The net effect is a reduction of the amount of structural material by over 20 percent. In addition to the material saving, the reduction in the amount of material also means that fewer neutrons are absorbed and lost to the nuclear reaction.

In reactor design, the heavy reactor core traditionally has been supported on a plate-type structure of high strength. Studies of larger reactors have indicated high thermal stress problems in large thick plates due to gamma heating from the core. A new concept, illustrated in Fig. 7, has been developed to alleviate this condition. In this new design, a single thin plate is supported through control-rod guide tubes fastened to a heavy plate located at a considerable distance from the core. The thin plate is not as susceptible to gamma heating damage, and the thick plate is far enough away from the core to be relatively unaffected. As a result, there has been a significant reduction in stress without compromise of strength and rigidity, which adds to the reliability of the plant.

The plant for Carolinas-Virginia Nuclear Power Associates differs from other closed cycle reactors in that the fuel is contained in many individual pressure tubes through which the coolant flows. Thus no thick-walled reactor vessel is required. Heavy water is used as the coolant, and a separate body of heavy water surrounds the outside of the tubes and serves as a moderator.

To avoid heavy heat losses from the coolant through the tube walls to the moderator, some thermal insulating barrier is required. Studies and experiments show that a layer of noncirculating heavy water inside the pressure tubes can be used as thermal insulation, and the reduced temperature of the wall permits a thinner Zircaloy tube to be used.

Another development reduces the amount of Zircaloy required, thereby reducing cost. This involves the use of stainless steel, instead of Zircaloy, for the pressure tube, except in the area immediately adjacent to the core. Engineers have developed a joint between these two materials that performs satisfactorily in spite of the large difference in thermal expansion between Zircaloy and stainless steel. This joint consists of an Inconel sleeve, which engages a shoulder of the Zircaloy pressure tube and is welded to the stainless steel pressure-tube extension. As the weld cools, a high axial tensile force develops in the sleeve which maintains the joint solidly in compression at all times, thus preventing leakage. The joint has been tested for all the various postulated reactor accident conditions and has performed satisfactorily in all respects.

systems

A prerequisite to the development of individual components and technologies is the development of systems and subsystems required for a nuclear power plant. The objective of such system analysis is to establish reliable optimum nuclear power plants that will provide a proper economic compromise between the considerations involved in the various components. The Yankee Atomic Electric Company plant illustrates the result of system planning.

To study systems problems in a situation more amenable to development programs, the Saxton Experimental Reactor is being constructed for the Saxton Nuclear Experimental Corporation. Westinghouse has the responsibility for planning and directing the development program which will be implemented in this reactor. The following factors will be evaluated:

1. System transients, under operational and simulated accident conditions.
2. Chemical shim operation.
3. Boiling in the core, even to the extent that net steam is carried to the steam generator.
4. Higher kilowatts per foot of fuel rods.
5. Thinner stainless steel cladding, ultimately leading to the use of collapsed cladding.
6. Various cladding materials, such as zirconium.
7. Nuclear superheat in a special loop in the reactor.

conclusions

The reliable performance of the Yankee plant, which verified and even exceeded the design and development goals of the plant, represents a significant step in the technical and economic development of water reactors for the commercial generation of electricity. Agreement between theoretical predictions and operational data is excellent, thus providing confidence in future design predictions.

Development and performance experience to date indicates that water reactors have great potential for competitive power costs and that they can be built in the much larger sizes required by many electric utility companies throughout the world.

Westinghouse ENGINEER Mar. 1962

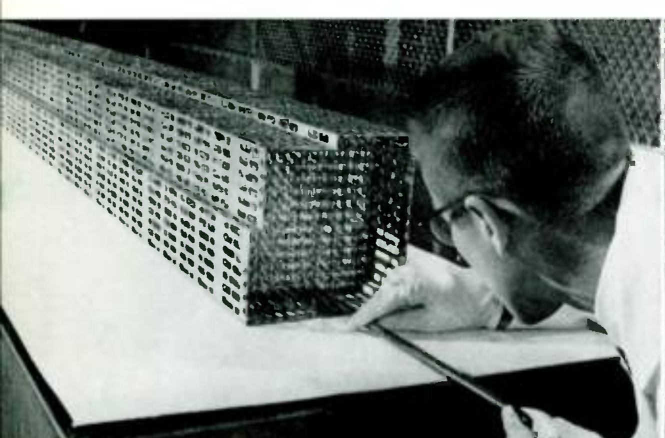


Fig. 6 (Far left) A spring-clip fuel assembly. The grids have spring fingers, which grip the fuel rods.

Fig. 7 (Left) In a recent reactor design, a thinner core support plate is supported by control-rod guide tubes (as shown) fastened to a heavy plate at some distance from the core.

PROGRAMMED INSTRUCTION AND TEACHING MACHINES

In the automated future, these tools may ease the increasingly difficult tasks of industrial and military education and training.

REUBEN LEE
HENRY F. DEFRANCESCO
Electronics Division
Westinghouse Electric Corporation
Baltimore, Maryland

The growing complexity of industrial control and military electronic systems requires vastly increased corps of trained technicians for operation and maintenance of the equipment. In some areas the problem has become especially acute because of inadequate means for training such personnel. The situation here parallels that of education, where school enrollments are swollen and teachers and facilities are in short supply. A potential solution to both the education and training problems has been found in programmed instruction and teaching machines, which hold promise of improving educational methods, raising the standards of education, alleviating the teaching load of overburdened instructors, and increasing the effectiveness of the truly skilled instructors.

Programmed instruction and teaching machines will not replace the educator and training director; rather, they constitute a new tool to aid the educator in the difficult tasks of education and training, an aid that can take a significant amount of drudgery out of the teaching process.

principles of programmed instruction

Behavioral psychologists, in their experiments with animals (pigeons, rats, monkeys) have noted that these animals learn when a sequence of *stimulus-response-reinforcement* is employed for controlling the behavior of the animal. They also note that the stimulus must be simple and direct; response must be active; and reinforcement (reward) should be immediate.

These findings have been translated to the human learning situation. The correspondence between the animal and human learning situation runs roughly as follows:

Sequence	Animal	Human
Stimulus	Some physical or audible command	Subject matter presentation
Response	Animal makes desired response	Active answer or completion
Reinforcement	Reward, usually food	Praise, correct answer, or advancement

Psychologists also note that programmed learning consists of five basic principles. These are: (1) *Small Steps*—only one unit of information is supplied at a time; (2) *Active Response*—the student must make an active (overt or covert) personal response to each item of information, i.e., the student learns by doing; (3) *Immediate Confirmation*—learning is improved when the student can confirm immediately whether his answer to each information item is correct; (4) *Self-pacing*—each student has his or her own reflex latency, i.e., the time between beginning of stimulus and beginning of response. Learning proceeds more efficiently when a student can pace himself at his natural speed or latency; and (5) *Student Testing*—one sequence of information items (programmed instruction) will be more efficient than another for covering the same material. Checks to insure that the program material organization is suited to the student are provided by recording his responses.

The sequence of actions in the learning process become: Stimulus—read small step; active response—write or note answer; reinforcement—check, advance.

Experienced instructors recognize that this stimulus-response-feedback sequence is of far-reaching potential for imparting motivation. In addition to the five main principles, the programs generally warn against wrong concepts; the student is cautioned against them, and then encouraged to choose correct concepts. Rules are given to guide the student in making his answers. Examples are

RANGE OF TRAINING AIDS

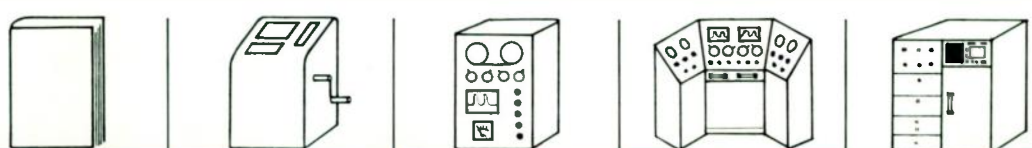


Fig. 1 Programmed instruction can be used in many forms of teaching machines; several kinds, illustrating the range of devices possible, are shown here.

Auto-instructional program of incremental learning steps; multiple choice questions and answers (scrambled book). Branching method.

Similar to book but printed on rolls. Presents one question at a time to trainee, who writes answer and turns crank for next question. Indicates correct answer. Linear method.

Special model with cards or tapes of instructions and recorded responses. Has means of indicating tones, measurements, wave shapes, or other signals. Valuable for training technicians.

Simulator for specific electronic system. Embodies exerciser, training aid, automated testing and maintenance procedure, and optimized control.

Complete equipment monitor with built-in auto-instructional equipment to accelerate training of maintenance personnel. May be equipped for automatic detection of malfunctioning parts.

Fig. 2 A typical teaching machine for presenting a linear-programmed course of instruction.

provided frequently, sometimes in incomplete form and the student is asked for an answer to complete the example. Practice consists of repetition of such examples, with supporting cues gradually withdrawn. At various points the student is reminded of his previous knowledge before proceeding to a new concept.

teaching machines

Many discussions concerning programmed learning and teaching machines are appearing in teaching journals and the daily press. Although the two items are often considered synonymous, this is not the case. Programmed learning is the application of the principles of learning (as determined by learning theorists) to the preparation and presentation of course materials. Teachers and subject matter specialists are required in the construction of programmed instructions. Psychologists are necessary to insure that basic learning principles are practiced effectively in the preparation of programs. The teaching machine, on the other hand, is a method of control and presentation. These machines assume many forms, ranging from specially prepared books and pamphlets for instruction in verbal skills, to elaborate consoles for instruction in complex motor and verbal skills. The design of the teaching machine depends upon its purpose and function in the teaching system. Several typical teaching machines are shown in Fig. 1.

Many advantages have been accorded to programmed instructional devices. Time is saved because the learning rate can be maximized for each trainee. The instruction is improved in a number of ways: Programmed instruction can be optimized more readily than a human teaching procedure; trainee response can be recorded so that the instructor knows how well the student is learning; the trainee must understand each point before he goes to the next; programming encourages correct answers, so that there is less to unlearn because of faulty notions; if a substantial

EXAMPLE I

The following presentation is part of a programmed introduction to instruction for the operation and maintenance of Navy Shipboard Transmitter AN/WRT-2. This introduction demonstrates linear programming for instruction on transmitter frequency range. The trainee writes his answers in the column at right. The answer is checked by advancing a frame (which covers trainee's answer with transparent mask). A teaching machine suitable for this sort of linear program is shown in Fig. 2.

FRAME 1 Radio Transmitting Set AN/WRT-2 provides complete coverage over the 2 to 30 megacycle (mc) radio-frequency range. Thirty mc means 30 million alternations between positive and negative electric current or voltage per second. Write the carrier frequency range in megacycles in the space at the right: ___ to ___.

2 to 30

FRAME 2 Frequency stability is achieved by choosing the carrier frequency within the 2 to 30 megacycle radio-frequency range in 1 kilocycle (kc) steps (30 megacycles = 30 000 kilocycles). There are 30 000 minus 2000 or 28 000 of these 1 kc steps in the whole WRT-2 frequency range of 2 to 30 mc. How many 1 kc steps are there between 2 mc and 15 mc? How many between 15 mc and 30 mc?

13 000
15 000

FRAME 3 The radiated carrier frequency may be selected at 1 kc intervals by the operator anywhere in the range of 2 to 30 mc, regardless of the kind of emission (CW, AM phone, etc.). Now write down, at the right, the missing item in this statement: the highest r-f carrier frequency of the AN/WRT-2 transmitter is ___ mc.

30

FRAME 4 An operator can select any carrier frequency of the transmitter from 2 to 30 mc by tuning controls located on the Radio Frequency Oscillator. The lowest carrier frequency that the operator can select is ___ mc.

2

FRAME 5 The frequency range available to an operator of the WRT-2 transmitter is ___ to ___ mc.

2 to 30

FRAME 6 (Continuation of instructions.)

Fig. 3 Navy shipboard radio transmitter WRT-2.

EXAMPLE II

This instruction covers the material in Example I, but uses branched programming.

FRAME 1 Radio transmitting set AN/WRT-2 provides complete coverage over the 2 to 30 megacycle (mc) radio-frequency range in 1 kilocycle (kc) steps. (2 megacycles = 2000 kilocycles) There are 30 000 − 2000 or 28 000 of these 1 kc steps in the whole WRT-2 frequency range of 2 to 30 mc. Remember that 30 mc means 30 million alternations between positive and negative electric current or voltage per second. The radiated carrier frequency may be selected at 1 kc intervals by the operator anywhere in the range of 2 to 30 mc, regardless of the kind of emission (CW, AM phone, etc.).

Now push the button corresponding to the answer which you think is correct. The highest r-f carrier frequency of the AN/WRT-2 transmitter is:

	PUSH BUTTON
2000 KC	A
28 000 KC	B
30 MC	C

FRAME 2 (BUTTON A) Your answer: 2000 kc

You are forgetting the difference between kilocycles (kc) and megacycles (mc). One mc is the same frequency as 1000 kc. So 2000 kc is the same as 2 mc, which is the *lowest* r-f carrier frequency of the AN/WRT-2 transmitter. Now go back to the first frame and choose the right answer.

FRAME 3 (BUTTON B) Your answer was 28 000 kc

You evidently confused the highest carrier frequency with the difference between highest and lowest carrier frequencies. Since

30 megacycles = 30 000 KC
2 megacycles = 2 000 KC
(Subtract) 28 000 KC

is the difference between these frequency limits, not the higher limit. Now return to the first frame and choose the right answer.

FRAME 4 (BUTTON C) Your answer: 30 mc.

You are correct. The transmitter frequency range is 2 to 30 mc, so the highest carrier frequency in this range is 30 mc.

In order to communicate with distant vessels, the AN/WRT-2 transmitter delivers 500 watts of average power, and 1000 watts of peak envelope power (PEP), into a 50-ohm nonreactive load with a standing wave ratio (SWR) lower than 4:1. The power amplifier drawer contains a linear power amplifier of 500 watts average power output, driver circuit for this amplifier, input mixers, and r-f monitor circuits. Tuning and coupling controls and indicators are mounted on the power amplifier front panel. All these controls must be adjusted properly in order for the transmitter to deliver the rated CW average power into a 50-ohm load.

Now choose the right answer to this question:

The average rated CW power of the AN/WRT-2 transmitter is:

	PUSH BUTTON
500 watts	B
50 watts	C
1000 watts	A

FRAME 5 (Continuation of instructions.)

EXAMPLE III

This example demonstrates the use of branched programming techniques for training personnel to locate a fault in the frequency divider section of the WRT-2 transmitter (Fig. 4).

FRAME 1 Before attempting any adjustments verify that a one (1) mc signal of two (2) volts amplitude is present at the input (terminal J-1301) of the 10:1 frequency divider.

Connect the output (terminal J-1304) to the oscilloscope. The correct signal level is signified by an *output* reading of 7.7 volts rms or 22 volts peak-to-peak minimum. The correct output frequency is signified by oscilloscope reading of 100 kc.

The output of the 10:1 frequency divider can assume one of the following four states:

State 1—Correct frequency and correct signal level
State 2—Correct frequency and incorrect signal level
State 3—Incorrect frequency and correct signal level
State 4—Incorrect frequency and incorrect signal level

Based on the state which you detect in observing oscilloscope, follow the instructions tabulated below; 1 signifies reading is correct, 0 signifies reading is incorrect.

STATE		INSTRUCTION
FREQUENCY	SIGNAL LEVEL	
1	1	Push button A
1	0	Push button B
0	1	Push button C
0	0	Push button D

INSTRUCTIONS ON PUSHING BUTTON A Both frequency and signal level are correct. Hence the difficulty is not in the frequency divider proper. The fault may be in the input and output circuits of the frequency divider.

To check the input circuits, push button A for further instructions. To check the output circuits, push button E.

INSTRUCTIONS ON PUSHING BUTTON B Frequency is correct but signal level is incorrect. Set oscilloscope to 100 kc signal and check 100 kc signal at J-1304. Tune the transformer T-1304 shown in diagram. If this corrects the signal level the maintenance process is complete. If this does not correct the signal level a fault in the output amplifier stage is indicated. Advance to button E to obtain additional instructions.

INSTRUCTIONS ON PUSHING BUTTON C (Continuation of instructions.)

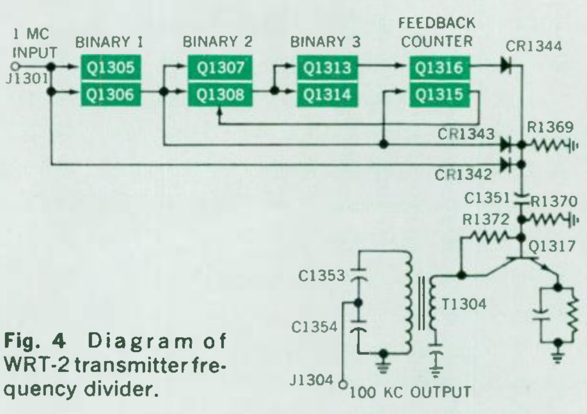


Fig. 4 Diagram of WRT-2 transmitter frequency divider.

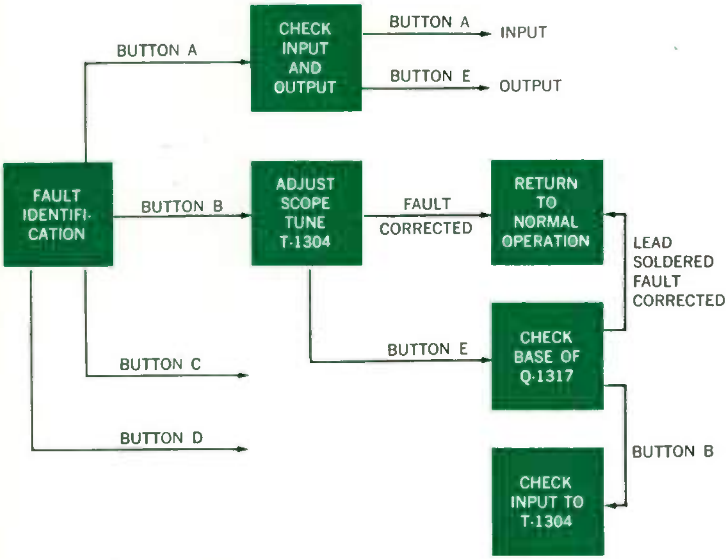


Fig. 5 Flow chart for fault location and correction of WRT-2 radio transmitter frequency divider.

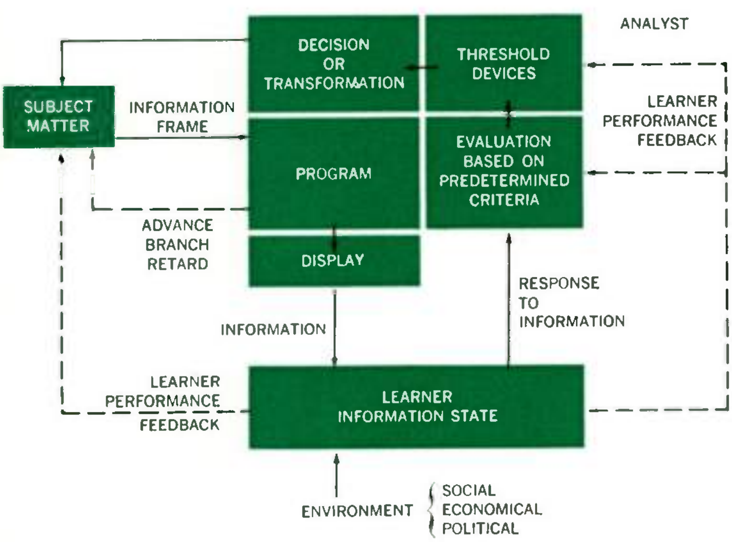


Fig. 6 Functional diagram of adaptive control system for presenting programmed instruction.

Fig. 7 Audio-visual aid used with programmed instruction forms an effective means for training manufacturing personnel.

number of wrong answers are generated, the program can be modified to clarify difficult points.

Once a program has been prepared, it can be reproduced and used simultaneously at many locations. Programmed instructional devices may be provided with rapid access to any frame of information, and used to assist operators or servicemen in emergency situations.

In teaching abstract or verbal skills (most subject matter falls in the latter category), teaching machines are supplements to subject presentation. Although some educators believe that teaching machines are effective in the presentation of programmed instruction for verbal skills, no extensive psychometric evaluations are yet available that state what teaching machines add to learning rate, how much they can decrease the error rate, or to what degree they can improve retention of subject matter.

Some psychologists feel that teaching machines will make their major contribution to the learning process where the instruction of motor skills is involved. The fields of equipment operation, assembly line staffing, testing, and maintenance all require the teaching of motor skills as well as verbal skills. In these areas, the more elaborate teaching machine and simulator is being applied with success.

A number of improvements in teaching can be partially attributed to teaching machines:

Teaching machines used in the training of complex motor skills are more economical than full-scale simulators.

When used as an aid in assembly, operation, and maintenance procedures, teaching machines reduce human errors and improve quality control.

Programmed instruction increases the amount of paper required to hold the same subject matter many fold. For example, a simple course in basic electronics might require 30 pages of written text and illustrations; the same subject matter, programmed and ordered, might require more than 200 pages. A teaching machine that uses film can store this course material on a small spool.

The nature of programmed instruction calls for small steps in presenting information. After the initial instruction, the trainee may need the help of ordering and access to previous or future frames or items. A teaching machine, if properly designed, possesses the ability to order and to provide access to material with considerable flexibility.

The machine offers many ways of displaying information items that cannot be done on a printed page. Human factors engineers agree that display techniques affect the learning process in that this is a more flexible way of applying the stimulus. Presentation modes other than visual (auditory, tactile) can be utilized when appropriate.

And finally, machines can be designed to prevent cheating, to keep a count of incorrect responses, and to record the time taken to complete the course. The human teacher is thereby relieved of these administrative chores.

kinds of programmed instruction

Programmed instruction generally takes one of two forms; *linear* (or extrinsic) programming, as distinct from *branched* (or intrinsic) programming. In the linear method, new information is gradually imparted to the student, so that he is almost certain to answer or respond correctly.

Linear programming is demonstrated in Example I, where operating information for a radio transmitter is presented. The response shown in Example I is called a constructed response. It is usually written, and involves more steps than the branching method.

In branched programming, the student is presented with multiple choice questions after a block of information. If the student replies correctly, he is told so and new information is presented, after which further questions are asked. If student responds incorrectly, he is given an explanation of why he was wrong, and then directed to try the first question again. The same subject matter covered in Example I is presented by the branched programming method in Example II.

As a more advanced example of branched programming, consider the training of personnel to locate a fault in the frequency divider section of the WRT-2 transmitter. Intrinsic programming is selected for this purpose due to its natural adaptability to logical branching techniques, which characterize interpreting and sequencing through a set of maintenance alternatives. The illustration outlined in Example III includes only the initial instructions that guide the maintenance man through establishing the existence of a fault and locating and correcting it.

The instructions lead the maintenance man through all possible alternatives, clearly stating the operations to be performed and giving reasons for performing each operation. Where adjustments on equipment or component replacements are required, photos of the units will be included with cues such as arrows leading to component to be adjusted or replaced. Where possible, maintenance flow charts will be included so that ready reference to a summarized procedure is possible. A flow chart is illustrated in Fig. 5.

Almost all the techniques of conventional instruction can be employed in programmed instruction. Their best use will require a certain ingenuity in programming and presenting the subject matter to be taught. Audio-visual aids, film strips, animated presentation and charts can be adapted to programmed instruction. The effective employment of some of these techniques may require the use of a teaching machine or a supplementary presentation by the instructor.

present applications

Industrial and military training supplements education received in public and private schools. Formal education, of necessity, concentrates on fundamentals of the arts and sciences and attempts to build a firm foundation on which future education and training can be based. However, the needs of industry and the military require that training be concentrated in management, clerical, administrative, technical and trade specialties. These needs also dictate that training become student-oriented rather than instructor-oriented.

A bevy of student-oriented devices has appeared in recent years. The management simulator via computer, the auto-instructional devices for training production workers, and training simulators for aircraft and radar as used by the military indicate the scope of this trend. Now the era of the teaching machine is upon us. Its appearance on the training scene broadens the front over which student-centered devices are finding applications in education and training. There are a multitude of areas where programmed instruction might improve on previous training methods. A partial list includes: instruction books prepared in programmed instruction form; training of production line and assembly personnel (see Fig. 7); management training; training of personnel to maintain or operate complex equipment; and new employe indoctrination in company benefits, rules, regulations, etc.

future applications

An ultimate goal in training is the maximization of learning rate. Here the field is largely uncharted. Learning rate varies from person to person. It depends on memory, imagination, visual perception, environment, subject matter and a host of other factors. Even if these factors are measured, the learning rate is not thereby determined. One discovery of recent years is that learning is statistical in nature, so that it appears feasible to apply adaptive control techniques to instruction programs, in a manner similar to applications of these techniques to industrial processes.

It is possible to visualize a model of a teaching system which contains all the elements of an adaptive control system. For example, the teaching system in Fig. 6 contains subject matter to be taught. The instructor or programmer selects an information frame or basic fact to present to the student. The selection of the information frame is determined by lesson plan or programmed instruction item. The information frame is displayed to the student, who responds overtly to the frame. His response is evaluated, based on some predetermined criteria, which may include time to answer, correctness of answer, etc. The evaluation measures the learning state of the student and if this exceeds some preset threshold, a new information frame is selected from the subject matter. The size of the information frame and the time duration of presentation may be determined in the evaluation period.

If the student does respond properly to the information item, the evaluation criteria measure how well the student performed. Based on the threshold levels obtained, a decision is made to repeat the item, supply the student a prompt, cue, or additional information, lower the threshold (which may set both time and performance levels), or modify the subject matter.

In any case changes can be made in size of information frame, evaluation criteria, threshold levels and decisions. More sophisticated systems might reorder the information item sequence. Thus if a student continues to answer rapidly and correctly, the evaluation criteria can raise the threshold or modify the program to present larger increments of information, present information more rapidly, or even delete certain frames in the sequence. If a student progresses slowly, the system will sense and measure this and adapt itself to the student accordingly.

In an increasingly automated industrial future, the need for rapid training of employes for complex tasks increases. So does the need for retraining people for new types of work that result from technological advances. Part of this future picture will be the widespread use of training aids to provide realistic simulation of on-the-job operating contingencies. Servicing can be facilitated by use of training aids. Maintenance and operating manuals may even be replaced by some form of visual presentation, with rapid access for use in emergencies.

DISTRIBUTION TRANSFORMERS WITH 65-DEGREE RISE

This leads to improved balance of operating characteristics.

A. M. LOCKIE
Advisory Engineer
Distribution Transformer Department
Westinghouse Electric Corporation
Sharon, Pennsylvania

For many years, most oil-immersed distribution transformers manufactured in the United States were designed to have an average copper temperature rise, at rated load, of less than 55 degrees C. Recently, however, distribution transformers have been developed with a nominal rated load rise of 65 degrees. Such a departure from previous practice can have many effects on transformer operation and economics; therefore, the decision to adopt the 65 degree C rise was carefully considered from every standpoint to assure that the net effect was beneficial. Consider, then, some of the theoretical and practical considerations behind this decision.

limitation on loading

An operator can increase the revenue from his transformer investment by loading the transformer more heavily, and some degree of deliberate overloading is almost universal. Almost equally evident, however, are three practical limitations on overloading. There is a *thermal* limit, because heavier loading means higher temperatures, which tend to shorten life expectancy. Since heavier loading also produces greater internal voltage drop, which reduces revenue and may cause customer complaints, there is also a *voltage* limit on loading. Finally, there is an *economic* limit, since I^2R losses increase at a faster rate than load, ultimately reducing net revenue per unit of output.

Since these limits restricted the economic utilization of transformers, a long-range program was instituted several years ago, aimed at relieving them.

Thermal Limit—When the program was begun, little was known about the life expectancy of distribution transformers or the factors that determined it. A guide for loading transformers existed, but it was based on the effect of temperature on the mechanical properties of insulation, and the correlation of these properties with service life was not established. To obtain a better insight on insulation aging and the factors that determine life expectancy, a novel method of measuring transformer life was developed. This technique, which involved accelerated aging, to destruction, of full-sized transformers, is now known as "functional testing," and is generally recognized as the best method of evaluating the effect of loading on life expectancy.

Information obtained by functional testing led to substantial improvement in the utilization of conventional insulation, and ultimately, to development of the Insuldur insulation system. Overall, a sizeable increase in life expectancy has been made. Thus, loading of transformers using Insuldur insulation seldom is restricted by thermal effects.

Voltage Limit—While this was going on, the voltage limit on loading also was being attacked. The factors affecting voltage drop were relatively well known, but means of reducing voltage drop without substantially increasing cost were difficult to find. With the aid of improved magnetic materials and new winding techniques, however, the average transformer impedance was reduced from 2.5 percent in 1950 to 1.8 percent in 1960. Some 40 percent more load could then be carried with the same voltage drop. While this was a significant achievement, further reduction in impedance was desirable, to be consistent with the increased thermal capability. At the time, however, no economic method was apparent.

Economic Limit—A review of the literature when the study was begun revealed that surprisingly little information on the economics of distribution transformer loading had been published, so a campaign was initiated to stimulate interest and publication of articles dealing with this subject. While a number of excellent articles have since appeared, certain areas need further exploration:

1. The actual nature of the distribution load, particularly the shape of daily, seasonal, and annual load cycles. More extensive information on typical load and loss factors of these cycles, and on rates of load growth, would assist greatly in designing more economical transformers and systems. The advent of magnetic tape load-survey recorders and computers of adequate capability have made the collection of such data practical. Westinghouse and several major utilities have collaborated in a large-scale survey, and are now analyzing the results.

2. Some difference of opinion exists among utility men regarding the most realistic method of establishing demand changes for load losses, and on how to evaluate the effect on operating costs of changes in transformer impedance. These differences can, and should, be reconciled through concerted action by the utilities.

3. Some economic studies of distribution transformer design have treated the transformers as discrete circuit elements. Others have considered them as part of an optimized system. The system approach seems likely to be most desirable as a guide for new construction, but it seems appropriate to consider the transformers separately in formulating operating policies for existing systems. A problem is presented to the transformer designer because the two techniques do not necessarily yield the same conclusions.

While some uncertainties in these areas remain, the economic picture was clarified sufficiently to permit the development of a method of calculating comparative operating costs of different designs, which has received wide acceptance in principle. This method was used in the following analysis.

origin of the 65-degree rise idea

The losses in a distribution transformer are usually considered in two categories—no load losses, and load losses. The no load, or iron losses, are essentially constant in a given transformer; i.e., they do not vary with loading.

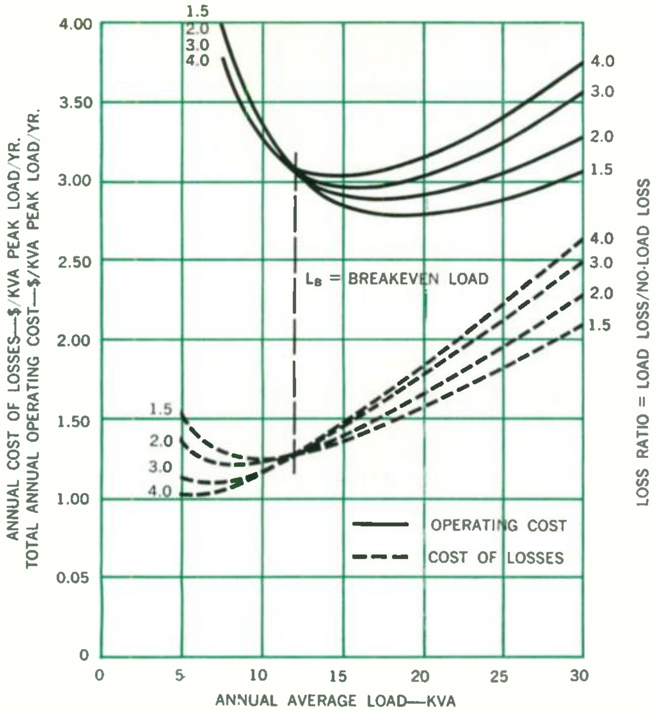


Fig. 1 The effect of change in loss ratio on the cost of losses and the total annual operating cost.

Photo Various sizes of the new LL-65 transformer are shown here as they are being readied for shipment.

Load or copper losses, however, are I^2R losses, and therefore increase with the load on the transformer.

In transformer design, each of these losses can be altered. For example, by increasing the amount of iron, the no-load losses can be reduced, and by increasing the amount of copper, the load losses can be reduced; however, these steps both increase the cost of the transformer. Thus, obviously, any changes in transformer design must be weighed carefully from the standpoint of first cost, and operating costs.

While distribution transformer losses have been substantially reduced over the years, the ratio of load loss to no-load loss has remained at a value of about 3 to 1. However, if *total* loss and selling price are held constant:

1. A reduced loss ratio reduces operating cost at any load above a "breakeven load"; the magnitude of this breakeven load is determined solely by how the operator evaluates losses. (See Figs. 1 and 2.)

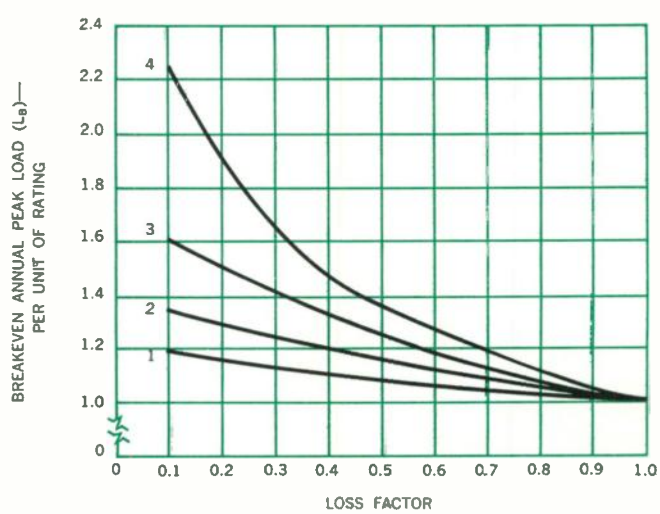
2. In load ranges somewhat above those commonly in use, but practical for modern transformers, and with commonly used values for cost of losses, a loss ratio of 2 to 1 would result in substantially lower operating costs than the prevailing ratios of 3 to 1 or higher.

3. In effecting a reduction in loss ratio, a reduction in impedance would also be practical, thus further relieving the voltage limitation on loading.

The study leading to these conclusions also showed that development and early production of transformers with a substantially reduced loss ratio, without a price increase, could be justified only if some means were found to reduce manufacturing costs. To summarize:

1. Full advantage of the improvements made in thermal capability could not be taken, in most cases, because of the voltage and economic limits on loading.

Fig. 2 These curves show the effect of loss cost components and loss factor on breakeven load.



Curve No.	Demand Component $/kw	Energy Component $/kwh	Diversity and Peak Responsibility Factors
1	400	0.003	1.0,1.0
2	300	0.005	1.0,1.0
3	200	0.007	1.0,1.0
4	200	0.007	0.5,0.5

Table I COMPARISON OF CONVENTIONAL, HL-65 AND LL-65 TRANSFORMERS (15 kva 7200 v 120/240)

Rise, Degrees C	Conventional 55 Degrees C	HL-65 65 Degrees C	LL-65 65 Degrees C
Ratio Losses—Copper/Iron	3/1	2/1	2.5/1
Nameplate Kva	15	15	15
Losses Guaranteed at	75 degrees C	85 degrees C	85 degrees C
APPLICATION LIMITATIONS			
1. THERMAL			
Breaker Trip Normal	30 kva	30 kva	30 kva
Breaker Trip Emergency	33 kva	33 kva	33 kva
Signal Light	21 kva	25 kva	25 kva
2. VOLTAGE			
Impedance	2 percent at 75 degrees C	1.6 percent at 85 degrees C	1.7 percent at 85 degrees C
3. ECONOMIC			
Signal Light	21 kva	25 kva	25 kva
Watts Iron Loss	90 at 25 degrees C	115 at 25 degrees C	83 at 25 degrees C
Watts Copper Loss	255 at 75 degrees C	230 at 85 degrees C	206 at 85 degrees C
Watts Total	345 at 75 degrees C	345 at 85 degrees C	289 at 85 degrees C
FIRST COST	100 percent	93 percent	100 percent
EVALUATED COST	100 percent	Lower at annual loads above break-even value*	Lower at *any* load*

*Amount of cost reduction depends on utilities' loading practice and evaluation of losses and impedance.

2. A reduced loss ratio would relieve both voltage and economic limits.

3. Some means of reducing manufacturing cost was necessary to justify the introduction of a new line of transformers with reduced loss ratio.

A way out of this impasse seemed to be the development of a new transformer with 65-degree C rated-load rise and a 2 to 1 loss ratio. By reducing the need for fins and tubes for supplementary cooling, the higher temperature rise would reduce the manufacturing cost of most ratings. By relieving the economic and voltage limitations on loading, at little or no reduction in thermal capability, the transformer would achieve well-balanced load limits. The price of this transformer could be held at the level of previous transformers and might be reduced when in volume production.

Such a transformer, called the HL (for high-load) 65 was developed, and a limited number of ratings offered on a trial basis. This transformer was more economical than the previous 55-degree unit when operated at above 42 percent annual average load. Reactions of the utility companies were varied. Some, after careful study, found the new design highly desirable. Others, however, were in areas where the low loss factor of the annual load cycle reduced the value of load loss, relative to that of no-load loss, or for other reasons assigned unusually high value to no-load loss, or low value to load loss. Naturally, the latter companies did not approve of the reduced loss ratio, since the critical load at which it would result in lower operating costs seemed impractically high (Fig. 2).

Since it was not practical to manufacture two different complete lines of transformers, after further analysis a different approach was selected. In the new design, savings effected by the change to 65-degree rise were used to reduce load loss and impedance, without the increased no-load loss of the HL65 (see Table I). This has been designated the LL (for low loss) 65. Here, then, was a design that would effect important reductions in operating cost, regardless of how heavily it was loaded or how loss costs were evaluated. A typical case is shown in Fig. 3. Cost studies, using information furnished by utilities, show that the new transformer will reduce operating costs, over the years, by an amount equivalent to 10 to 15 percent reduction in first cost.

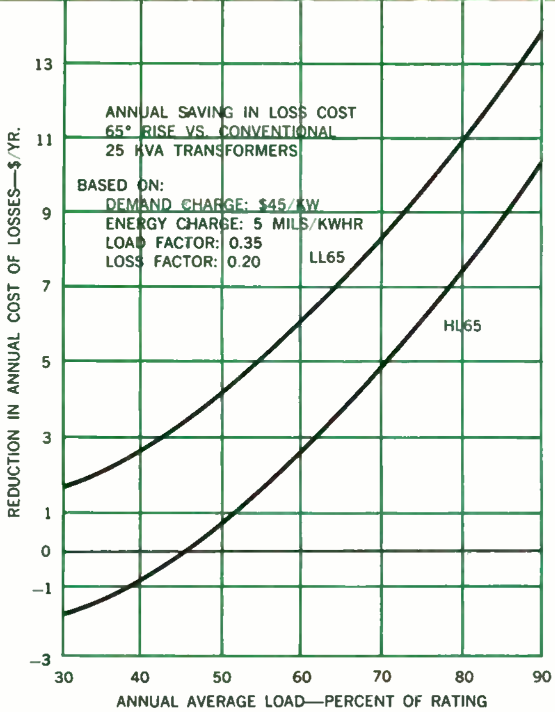
design problems

Since the adoption of a 65-degree rated-load temperature rise was the key to significant improvement in operating economy, it was necessary to make sure that the proposed LL65 design would be satisfactory in all other respects. This involved a review of the effect of the design changes on life expectancy, fire hazard, and resistance to external short circuits, and the establishment of new criteria for guaranteeing losses and calibrating CSP signal lights.

Life Expectancy—For a transformer on a given load cycle this is dependent, primarily, on the thermal endurance of its insulation system and on the temperatures developed by the load. The Insuldur insulation system has equal or greater life expectancy than conventional insulation, at temperatures ranging from 10 to 30 degrees C higher. But if a conventional transformer were given a 10 degree increase in temperature rise at rated load by removing cooling surface, with no other change in design, the increase in temperature on overloads would be substantially more than 10 degrees. Consequently, such a transformer, even if provided with Insuldur insulation, might have less than normal life expectancy when overloaded.

At overload, the temperature developed is primarily dependent on the loss ratio and on the ratio of hot-spot copper temperature rise to oil temperature rise at rated load, which might be called the "rise ratio." By reducing both the loss ratio and the rise ratio, the effect of load on temperature rise can be reduced substantially, as indicated in Fig. 4. In the LL65, these ratios have been reduced so that, at any load, its life expectancy is equal to, or greater than, that of a conventional 55-degree-rise transformer.

Fire Hazard—The resistance of Wemco CI oil to degradation by temperature is so great that it imposes no practical limit on loading. However, to minimize fire hazard, oil temperatures have been limited to less than the flash point of



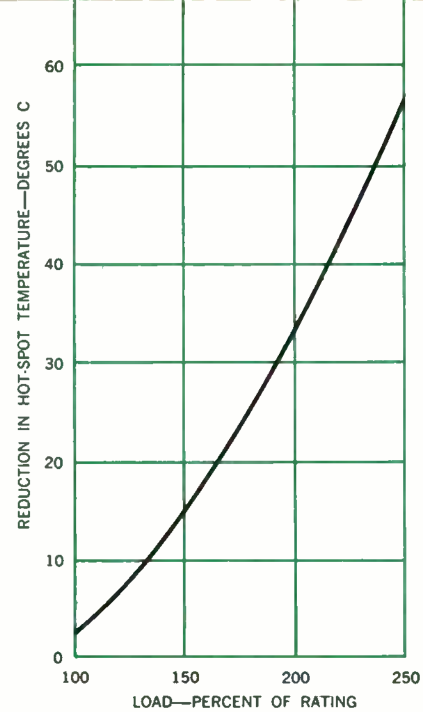


Fig. 3 (Far left) A comparison of the LL-65 and the HL-65 transformer for a typical case.

Fig. 4 (Left) The reduction in hot-spot temperature produced when the loss ratio is changed from 3.5 to 2.5, and the rise ratio is changed from 1.4 to 1.1.

Fig. 5 (Below) Load-time curves for a 10-kva CSP unit.

the oil. To permit loading the LL65 transformers to equal or higher levels than conventional transformers, a new oil with a higher flash point was developed. In all other respects, this oil can be used interchangeably with conventional oil.

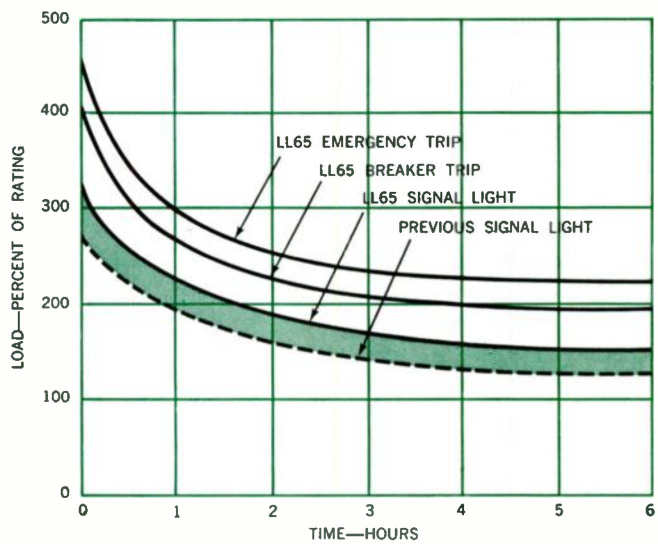
Short-circuit Strength—The relatively low impedance of the LL65 transformers means that they may be called upon to withstand higher short-circuit currents than conventional units. More compact windings that are better balanced electromagnetically, extended use of wide-strip conductors, and improved adhesive materials, provide adequate strength to resist faults likely to be encountered in service.

Loss Guarantees—Since the load loss and impedance of a transformer vary with the temperature of its windings, they must be guaranteed at a specific winding temperature. For transformers with 55-degree C rise, the guarantee temperature has been standardized at 75 degrees C. This seems logical, since it means that, at rated load and 20 degrees C ambient temperature, the actual load loss and impedance will not exceed the guaranteed values.

Applying the same logic to transformers with 65-degree C rise, these temperature-sensitive characteristics should be guaranteed at 65 plus 20, or 85 degrees C. The importance of this change in the guarantee temperature can be seen from an example.

Suppose an LL65 design has a load loss of 180 watts, guaranteed at 85 degrees C, and the conventional design it replaces had a load loss of 200 watts, guaranteed at 75 degrees C. Then, under the conditions of rated load and 20 degrees C ambient temperature, the LL65 unit will have 20 watts, or 10 percent, less load loss—a typical situation.

However, if the LL65 unit had the same 180 watt loss guaranteed at 75 degrees C, instead of 85 degrees C, then its load loss, under the same load and ambient conditions, would have been 186 watts, or 6 watts higher. Thus the actual loss reduction, compared to the conventional unit, would have been only 14 watts, or about 7 percent. In other words, had the loss guarantee temperature of the LL65 not been increased to 85 degrees C, about one third of the loss savings indicated by the lower guarantee would not have been realized in service.



Signal Lights—The signal light provided in CSP transformers is widely used as a means of indicating when the load on the transformer has reached its economic limit. But the reduced operating costs of the LL65 mean that its economic load range has been moved upward. Consequently, signal light calibration has been changed to reflect the greater economic loadability of the LL65, as shown in Fig. 5.

summary

Maximum return on electric utilities' investment in distribution transformers is realized when units are loaded as heavily as thermal, voltage, and economic limits permit.

In the LL65 transformers, a 65-degree C rated-load temperature rise has made practical a significant reduction in load loss and impedance, with equal or lower no-load loss. This improved balance of operating characteristics insures substantial economies on any electric utility system, whether it is used to reduce costs with conventional loading or to improve return on investment with heavier loading.

PITTSBURGH AUDITORIUM ROOF DRIVE SYSTEM A reactor-controlled drive moves the retractable roof segments.

A. J. BAESLACK
J. G. PETERSEN, JR.
Systems Control Department
Westinghouse Electric Corporation
Buffalo, New York

The new Pittsburgh Auditorium is the key structure in the redevelopment of the city's Lower Hill District. It occupies a 20-acre site that includes a parking area and mall, and it is built to serve the year around as an auditorium, exhibition center, convention hall, sports arena, ice rink, and open-air amphitheatre. It seats 7000 to 13 500 people, depending on the event being staged.

What makes the building different from any other large auditorium is its retractable domed roof, which permits conversion of a weatherproof auditorium into an open-air stadium in 2½ minutes. The hemispheric dome is approximately 417 feet in diameter and rises 109 feet at the center with no interior supports. It is divided radially into eight 45-degree sections, or leaves—six movable and two fixed. Each 300-ton movable leaf is supported at its base on motorized trucks, the wheels of which rest on steel rails. At the crown, the leaves pivot on spherical bearings supported by a cantilever space frame outside the dome.

Slight differences in radii permit the six movable leaves to move on concentric rails, three clockwise and three counter clockwise. In the open position, they nest over the two fixed sections, or bottom leaves. The two outermost leaves are called the top leaves, the next two the upper intermediate leaves, and the next the lower intermediate leaves. They will be referred to by these names.

Each movable leaf has a WK^2, about the vertical axis through the pivot, of 13.5×10^9 pound-feet squared. At the rail, vertical and horizontal dead-load reactions are 596 000 pounds and 350 000 pounds respectively.

drive requirements

The auditorium's designers specified a roof drive that, when actuated by a pushbutton, would start the movable leaf pairs in sequence and move them to the open position so that they arrived in 2½ minutes and stopped precisely when nested over the bottom leaves. The roof was to close in the same elapsed time when another button was pressed.

Roof operation was expected to be infrequent—practically no operations for 8 or 9 months and once a day or less during the rest of the year—yet reliable operation was highly important. The system also had to be completely fail-safe, have provisions for rapid trouble-shooting, and require little maintenance.

Side thrusts on the cantilever space frame had to be balanced during opening and closing, so precise position regulation was required of the two leaves in each movable pair. Speed regulation was needed to insure that all six sections would start at essentially the same time and reach their destinations in the specified time and also to prevent separation of the trailing edge of any leaf from the leading edge of the succeeding leaf.

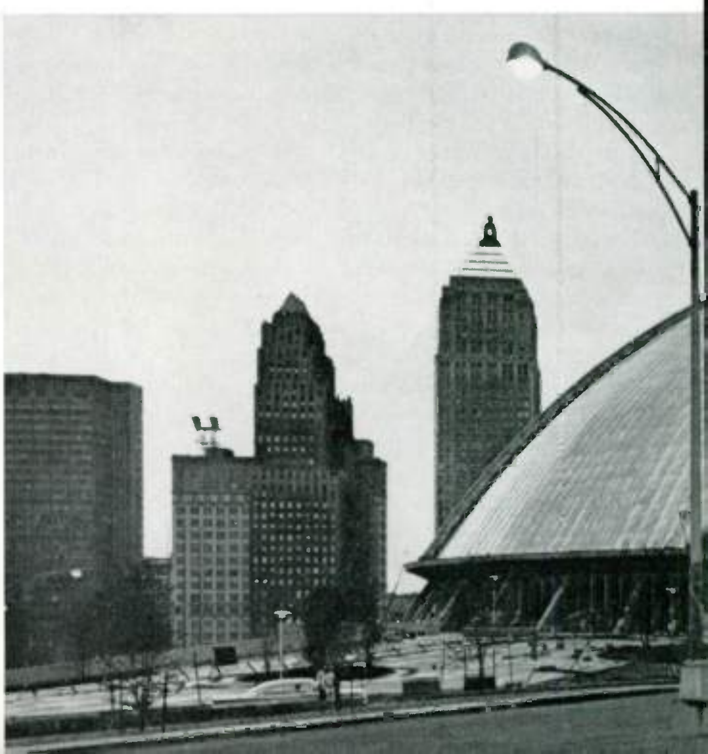
The possibility of sudden storms required that the installed drive capacity be capable of closing the roof in 2½ minutes against a 45 mile per hour wind exerting an opposing force of 4000 pounds on a leaf edge. Further, the drive had to be operable in a 60 mile per hour wind exerting an opposing force of 8000 pounds; however, there was no specified operating time under this extreme wind condition.

drive selection and description

Because of the highly intermittent nature of this application, an ac reactor-controlled drive employing squirrel-cage induction motors was chosen. Most industrial material-handling applications using reactor control for ac motors require wound-rotor induction motors so that the repetitive power losses at low speeds can be dissipated in external rotor resistors rather than in the motor itself. For the roof drive, however, intermittently rated squirrel-cage motors with sufficient thermal capacity to absorb the losses are practical because there is opportunity for the motors to cool between operations. Elimination of slip rings, brushes, and commutators and use of static reactors reduces maintenance and improves reliability.

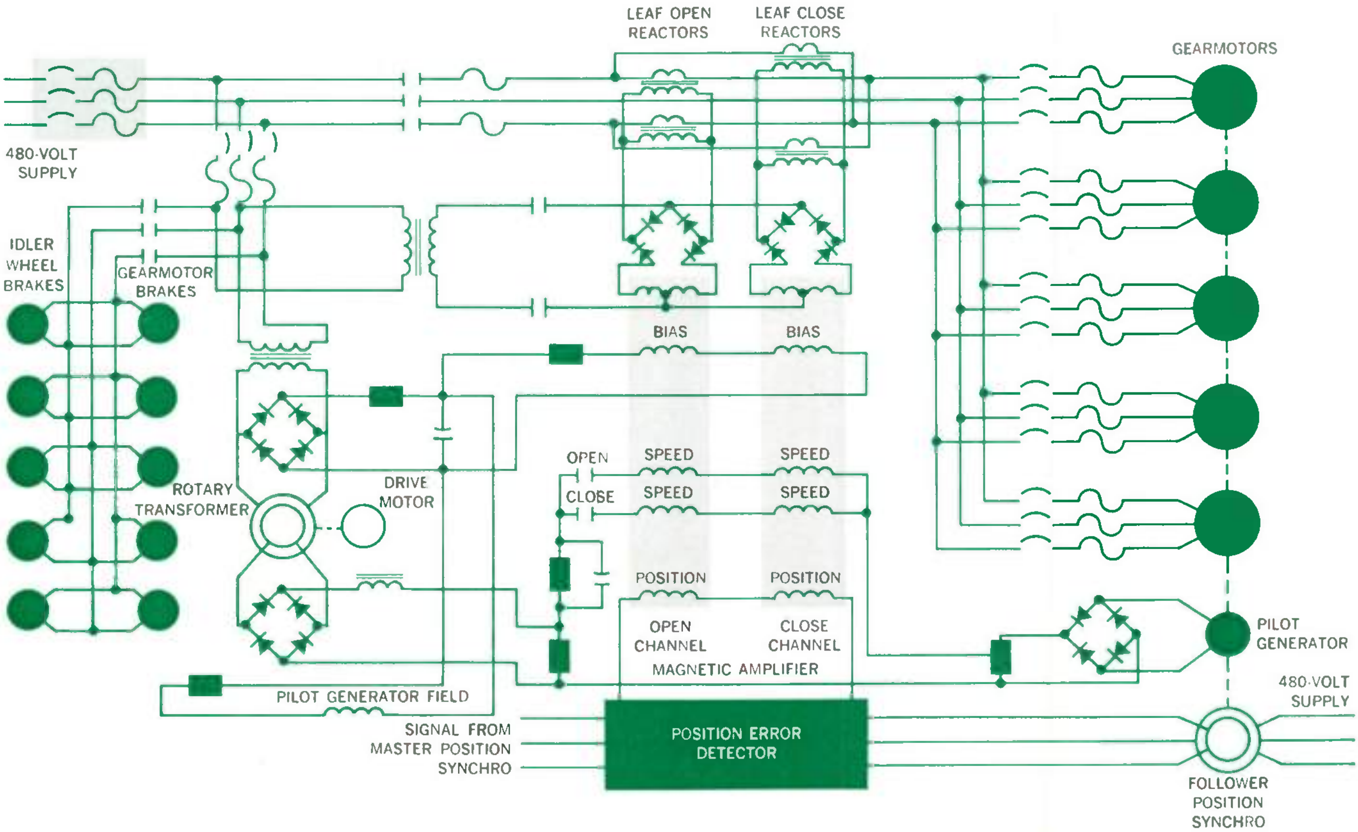
A simplified diagram of the drive system for one leaf is shown in Fig. 1. Five gearmotors, each having a circuit breaker for short-circuit protection, are connected in parallel. One line contactor and a single set of forward and reverse reactors control all five motors. A magnetic amplifier controls the reactors and thereby the motors.

Motor speed is set by a reference voltage signal from the rectified output of a rotary transformer acting through the magnetic-amplifier regulator. A pilot generator measures the actual leaf speed and feeds a voltage signal back to the regulator. If the pilot generator voltage differs from



Photos The new Pittsburgh Auditorium (bottom) is roofed by a sectional dome that can be opened (right) to convert the auditorium into an open-air amphitheater. The six movable roof sections are driven and controlled by an ac system that can open or close the dome in 2½ minutes. The sections are supported by motorized trucks.

Fig. 1 (Below) The basic elements of the ac reactor drive and control system for one follower leaf of the dome are shown here. The position error detector matches the leaf's position to that of the master leaf in the pair. The control system for the master leaf is identical except for having no position error detector.



the reference voltage, the regulator adjusts the reactors and brings motor speed back to the value set by the reference.

The rotary transformer's voltage depends on the angular position of its rotor, which is driven by a small dc motor at a controlled rate from one position to another. When the rotor is in the starting position, output voltage is low. As the rotor turns from starting position to running position, the reference voltage increases gradually to the full-speed running value. The leaf accelerates smoothly and moves down the track at regulated speed until it reaches a slow-down zone. The rotary transformer then is turned back to low voltage to decelerate the leaf, which runs at slow speed until a limit switch cuts off power and applies the brakes.

Each leaf has its own drive, but opposite leaves operate in pairs. One leaf in each pair is a master leaf and has the speed regulator just described. The other is a follower and has a combination speed and position regulator to match its position to that of the master leaf.

Each leaf has a position synchro unit geared to it to give a voltage signal proportional to the position of the leaf. A position error detector compares the signal from the follower position synchro with the signal from the master position synchro. If there is a difference, the error detector feeds a signal into the follower leaf regulator to accelerate or decelerate the leaf. This regulates the leaves with respect to each other well within the 10-foot error allowed.

equipment

Five integral right-angle gearmotors drive each leaf (Figs. 2 and 3). Motor ratings are 25 horsepower each for the top leaves, 20 horsepower each for the upper intermediate, and 15 horsepower each for the lower intermediate leaves. The squirrel-cage NEMA D high-slip motors have the current and torque vs. speed characteristics shown by curves *A* and *B* of Fig. 4. These characteristics provide maximum starting torque per kva of inrush current and are well suited to the requirements of a reactor-controlled system. Passing cooling air through the motors would be of little benefit during the short operating time, so totally enclosed nonventilated motors are used to minimize maintenance. The gearmotors drive the wheels through chain and sprocket drives.

Magnetic disk brakes are mounted on each motor. Acting through the gear and chain speed reductions, they exert a total force of 20 500 pounds at the rail for each leaf.

An additional braking force of 20 500 pounds is provided by brake units geared to five undriven wheels of each leaf. These consist of magnetic disk brakes and right-angle gear units identical to those of the gearmotors. One brake unit on each leaf has a shaft extension and drives the speed-regulating system pilot generator, an ac inductor unit that does not have brushes nor slip rings (Fig. 2).

All brakes are electrically released and spring set so that they are applied if power fails.

The saturable reactors that provide torque and speed control have series-connected ac windings for minimum time delay. This insures fast response and good stability.

Two-channel single-stage magnetic amplifiers excite the saturable-reactor windings. Voltage matching of the rectified pilot generator output to the reference voltage is employed, rather than magnetic field matching, to permit use of the least possible number of control windings on the magnetic amplifier and minimize its time delay.

This regulating system provides approximately 9 percent of synchronous-speed drive regulation from no load to full load at maximum speed and 7 percent at minimum speed. Curves *D* and *E* of Fig. 4 show these characteristics. Curve *C* shows the unregulated inherent characteristic of the motor with the reactor saturated. Curve *D* is selected as the maximum designed speed characteristic so that regula-

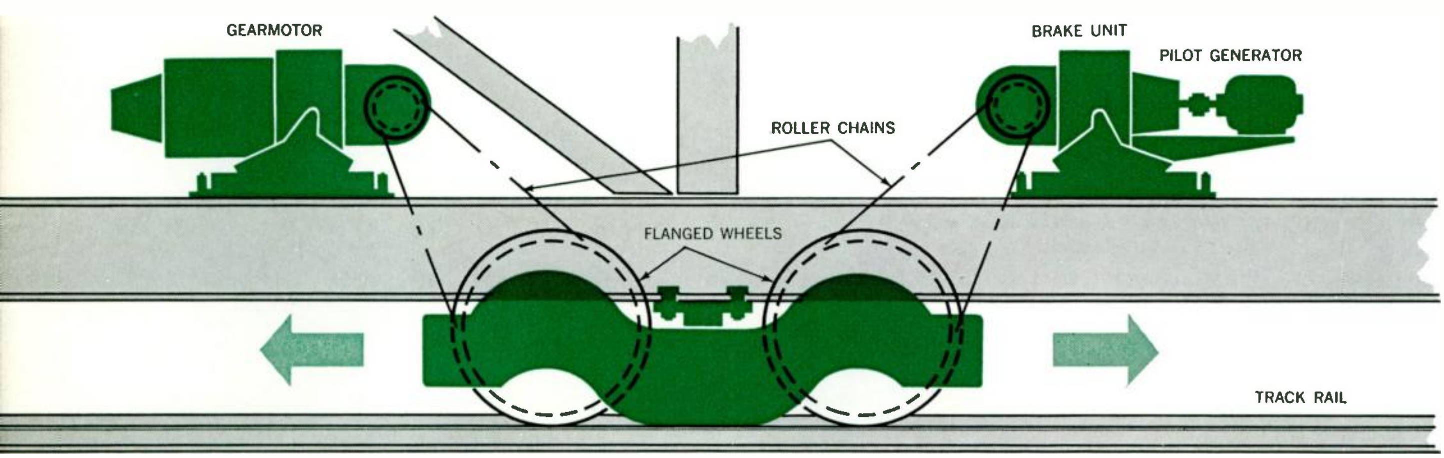
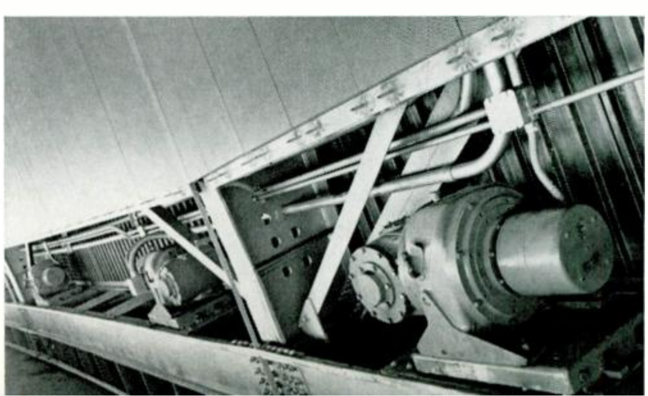


Fig. 2 (Above) Five drive trucks support each leaf. Each truck has a gearmotor and a brake unit connected to the wheels by roller chains. One brake unit on each leaf, shown here, drives a pilot generator that feeds a voltage signal to the leaf's speed-regulating system. The regulator compares the signal with a reference voltage and corrects motor speed, if necessary, to maintain desired leaf speed.

Fig. 3 (Right) The integral right-angle gearmotors and brake units are shown with cover panels removed.



tion range is available for position regulation of the follower leaf in the pair.

The breakaway torque for the 8000-pound wind load condition exceeds the maximum torque capability of the top-leaf drive with the reactors saturated (curve *C*), but it is less than the motor capability at rated voltage (curve *B*). To start under this condition, the close reactors are shorted by contactors controlled by a *Maximum-Torque* pushbutton to provide full-voltage starting. The other leaf drives have proportionately higher torque capacities and do not require this feature.

The position synchro units are two-pole wound-rotor induction motors with three-phase stators and two-phase rotors. A synchro unit is driven from one idler wheel on each leaf through gearing that establishes 90 mechanical degrees of rotor rotation for each 13.5 feet of leaf travel at the track. The position error detector circuit employs four phasing transformers, resistors, and rectifiers to add the synchro voltages vectorially to produce an error signal.

The main control console is located in the auditorium master control room at the top seat level, under the stationary leaves (Fig. 5). Another control station is provided in the basement with the control cubicles.

The main console has pushbuttons for *Reset*, *All Open*, *All Close*, *Minimum Speed*, *Open Leaf Pairs*, *Close Leaf Pairs*, and *Emergency Stop*. It also has all the other control and indicating devices needed for normal operation, including leaf position indicating lights, meters to indicate the position differential error for each pair of leaves, a local-remote transfer switch with a neutral lockout position to prevent operation from either location, manual and automatic fault-finder equipment to monitor 49 circuits for malfunction, and a motor overload indicating light.

The basement station includes all of the above controls with the exception of the position lights, fault finders, and transfer switch. It permits maintenance men to check leaf operation while observing the functioning of the components in the control cubicles.

operation

Depressing the *Reset* pushbutton prepares the control circuits for operation through *All-Open*, *All-Close*, *Minimum-Speed*, *Open-Leaf-Pairs*, and *Close-Leaf-Pairs* pushbuttons. When the *All-Open* button is held down, control for full-speed operation is initiated. The top leaves main contactors close to energize all top-leaf motors, and brake contactors close to release all top-leaf brakes. The starting of the other two pairs of leaves is delayed to keep the motor inrush kva within the capacity of the power system.

When the top leaves reach 70 percent of full speed, the upper intermediate leaves start and accelerate to full speed. (If the top leaves fail to reach 70 percent of full speed, a timing relay overrides the speed-sequence start function and starts the upper intermediate leaves.)

When the upper intermediate leaves reach 70 percent of full speed, the lower intermediate leaves start and accelerate to full speed. (Again, if the upper intermediate leaves fail to reach 70 percent of full speed, a timing relay starts the lower intermediate leaves.) The leaves operate until the slow-down limit switch is tripped near the full open position. Decelerating torque is applied to bring leaves to minimum speed (1/8 of full speed). At the full open position, the motors are de-energized and all brakes are set by a limit switch. Pilot lights on the operator's control console indicate the fully open position of all leaves.

Minimum-speed pushbuttons permit operation of the leaves to any desired point on the track for maintenance. Other maintenance pushbuttons operate the leaf pairs independently, and jog buttons permit operation of each leaf at minimum speed.

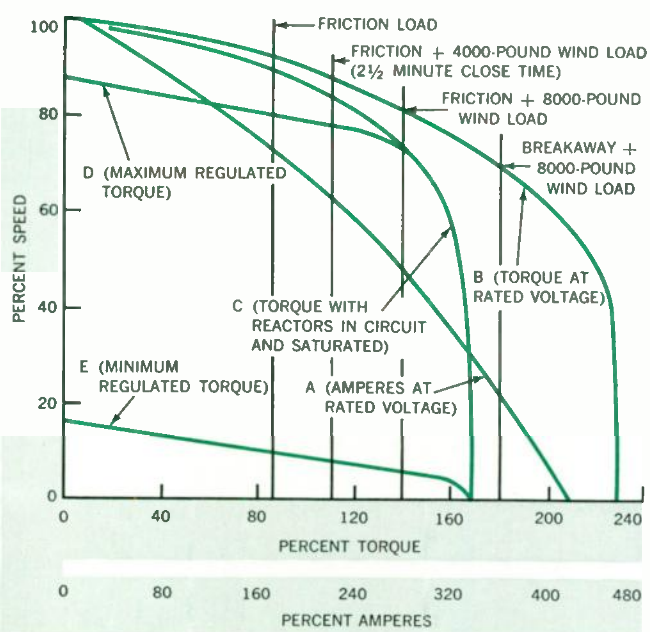


Fig. 4 Motor and load characteristics for a 25-horsepower top-leaf drive motor rated at 34 amperes full load are shown.

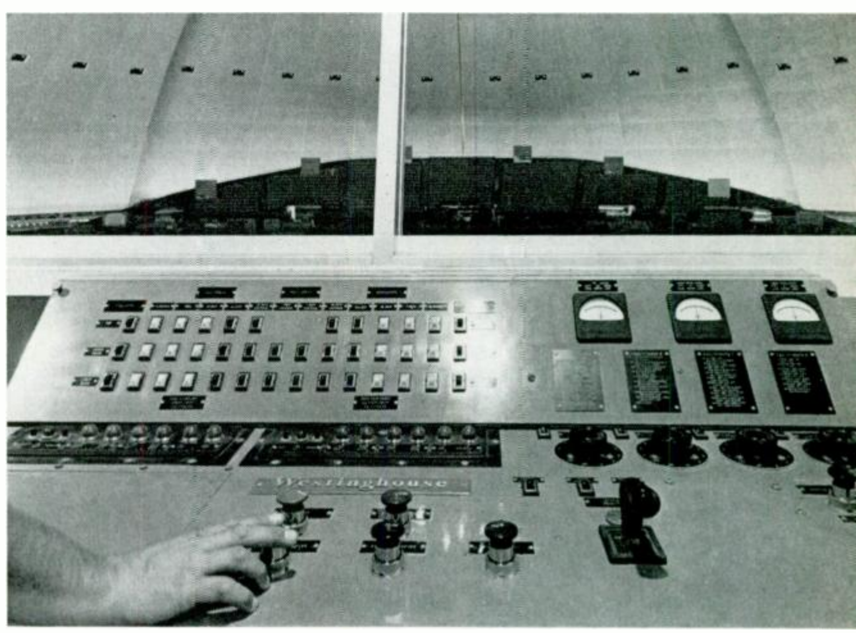


Fig. 5 The roof drive's main control console provides complete control and monitoring equipment for the system operator.

VOLTAGE SURGE SUPPRESSORS FOR SILICON RECTIFIER PROTECTION A static semiconductor device provides a shunt path for safely dissipating destructive transient overvoltages.

I. R. SMITH
General Purpose Control Department
Westinghouse Electric Corporation
Buffalo, New York

E. T. SPIRES
Management Development and
Compensation Services
Westinghouse Electric Corporation
Pittsburgh, Pennsylvania

The advent of silicon rectifiers a few years ago opened a new era in power rectification because of their small size, high efficiency, absence of aging, excellent regulation, and other desirable characteristics. Unfortunately, however, the monocrystalline silicon cells are easily damaged by transient voltages that exceed their peak reverse voltage (prv) ratings. This characteristic can be troublesome, although it by no means negates the advantages of silicon cells.

It was first thought that transient problems could be prevented by using silicon cells with prv ratings about four times the applied rms voltage. This has worked reasonably well in some applications but obviously is of no help if a transient of 10 times normal voltage occurs, as can easily happen. The prv ratings could be increased to a level that would withstand all possible surges, but cost would make this solution uneconomic.

The next approach was to use cells of fairly high prv rating—about four times the input rms voltage—in conjunction with some means of protection that bypasses the surge current and thereby places a ceiling on (or "clamps") the surge voltage at some point below the rectifier cells' prv ratings.

Resistor-capacitor networks have been used in this way with good results. Failures still occur, though, usually because the surge energies have been underestimated. The network itself may cause trouble, if the capacitors are large, because of the high inrush current that appears when the circuit is energized.

Nonlinear resistance shunts of silicon carbide also have been used, but the resistance change as a function of applied voltage is not always sufficient to give the needed protection.

Far more reliable shunt protection, with a minimum amount of equipment, is provided by the new Voltrap semiconductor surge suppressor. This device is often used solely to eliminate silicon-device field failures caused by transient overvoltages. In addition, it can sometimes reduce system cost by permitting use of lower prv-rated silicon devices. For example, one 230-volt dc power supply having an ac input to the rectifier of about 200 volts contained silicon diodes rated at 800 volts prv. Adding a 210-volt suppressor with a clamping voltage rating of 525 volts made it possible to replace the original diodes with diodes rated at 600 volts. (Clamping voltage is defined as the maximum instantaneous voltage that appears across the surge suppressor at its rated discharge current.)

causes of voltage surges

Any energy-storing circuit that can be switched is a potential source of voltage surges. Probably the most troublesome cause is interruption of the primary supply to a rectifier transformer at no load. If the transformer magnetizing current is interrupted at its peak, the silicon rectifier may be subjected to a transient voltage up to ten times the secondary voltage of the transformer. Again, on closing the primary circuit at the peak of the voltage wave, a double voltage transient can appear on the secondary winding connected to the rectifier.

Another common source is the energy stored in reactance on the ac side of a rectifier if the dc load is suddenly interrupted. Rectifier welders are a good example of devices that are subjected to this type of operation. If the reactance is on the load side, a voltage surge may occur when the input circuit is energized.

Magnetic loads, such as chucks or magnets, are frequently demagnetized by reversing the dc supply. The magnet cannot discharge in the high-resistance direction of the power rectifier, so a current path must be provided to prevent an overvoltage across the rectifier with possibly damaging consequences.

If unprotected Trinistor controlled rectifiers are suddenly shut off while feeding an inductive load, they receive an overvoltage in the forward direction. Other sources of overvoltage surges include disturbances on the power system supplying a rectifier, induced lightning discharges, rectifier commutation, and rectifier recovery current phenomena. Different types of overvoltage, far more prolonged, are the transients resulting from the sudden change in field strength of an adjustable-speed motor, from an overhauling load, and from synchronous motor starting.

Sometimes the source of the transient is not at all obvious, especially in complex control circuits. The transient may be so fast that it cannot readily be detected, even with an oscilloscope. The only evidence of its presence is the failure of the silicon cells.

the Voltrap surge suppressor

The Voltrap surge suppressor is a static, variable-resistance, semiconductor device that provides a relatively low-resistance shunt path for dissipating the energy of overvoltage surges. It is essentially one or more selenium cells specially processed for sharp reverse breakdown characteristics similar to the avalanche (or Zener) breakdown characteristic of silicon rectifiers.

This is a new concept in selenium cell technology in that it puts to use what, in rectifier service, is only a detriment—the reverse resistance characteristic of the cell. Controlling and utilizing this property required engineering and manufacturing development along distinctly atypical lines. The development of the Voltrap surge suppressor is thus a substantial extension of selenium cell technology.

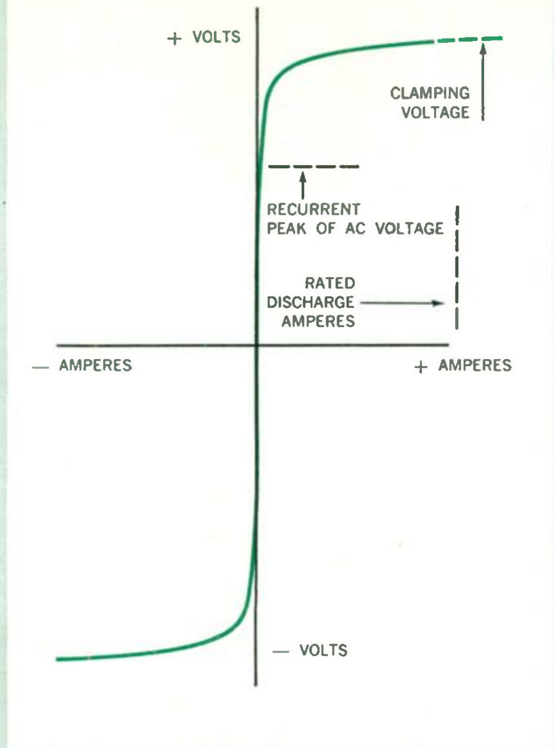
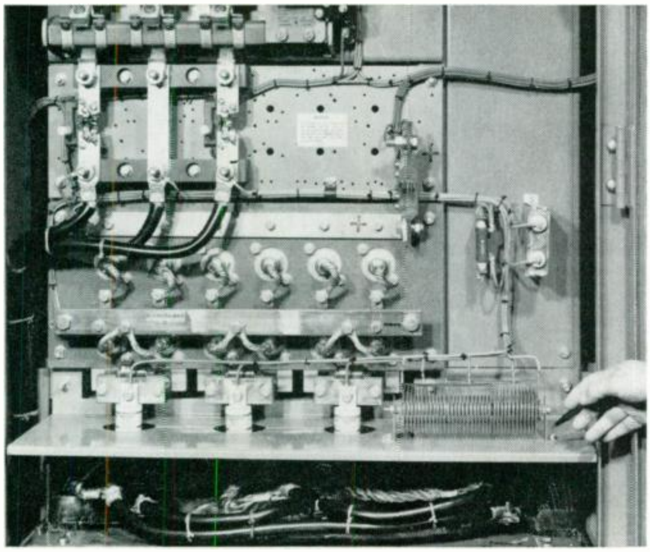


Fig. 1 Hardly any current flows through a Voltrap surge suppressor at rated steady-state voltage. Above this point, a large current flows with little increase in voltage. This bypassing of the surge current imposes a ceiling on the surge voltage safely below the ratings of the silicon cells being protected. (The curve is plotted in instantaneous values.)

Fig. 2 (Bottom) One Voltrap surge suppressor protects the six silicon diodes in the three-phase main rectifier bridge of this 50-kw rectifier power supply. The suppressor is a polarized unit rated at 10 amperes discharge current. For the application illustrated here, the surge suppressor is connected as a three-phase bridge.

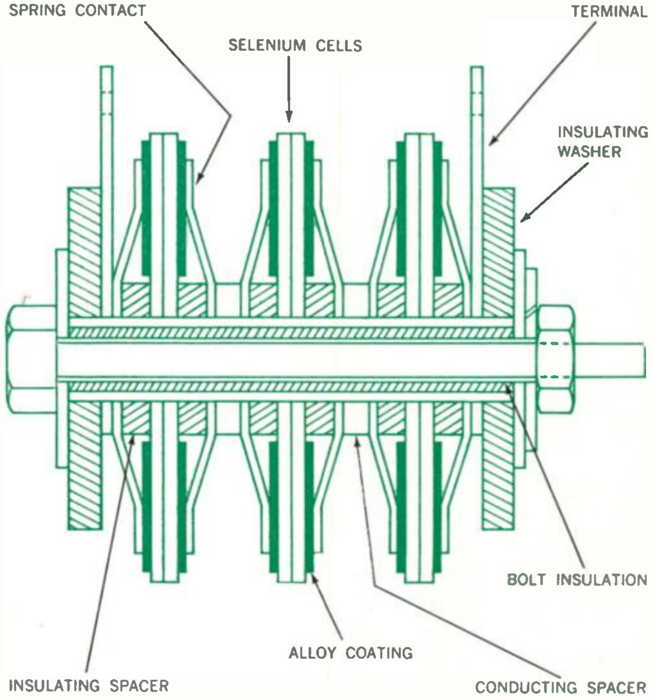
Fig. 3 (Right) Special selenium cells are stacked to make a Voltrap suppressor. The open construction permits sparks to clear if the unit is subjected to overvoltages far beyond its rating. This construction also helps dissipate heat, reducing steady-state temperature rise and increasing the unit's energy-absorbing capability for repetitive surges.

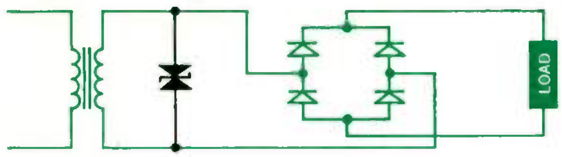


The suppressor has two modes of operation. Normally, connected across a steady-state ac or dc voltage, its resistance to current flow is quite high and losses are insignificant. When an overvoltage occurs, the suppressor's resistance is drastically reduced. It is able to pass a large amount of current in this mode, thus holding the surge voltage to a safe predictable level. The change in resistance between the two modes of operation for a suppressor rated at 2 amperes, 30 volts rms, for example, is from approximately 6000 ohms at the steady-state condition to 37.5 ohms or less when discharging a surge current.

The volt-ampere characteristic of a nonpolarized suppressor (one that accepts surge currents of either polarity) is shown in Fig. 1. At rated steady-state voltage of 30 volts rms (42.4 volts peak), hardly any current flows through the suppressor. As the applied voltage increases above the steady-state point, the curve bends sharply and the suppressor begins to pass large amounts of current without much increase in voltage. From roughly 10 percent to 100 percent of rated current—a 1000 percent change—voltage increases only about 15 percent. Discharge current ratings are so chosen that there is a substantial margin between the clamping voltage and the cell sparkover point.

When a surge voltage is applied to a Voltrap suppressor, current flows through it with no observable delay. The variable-resistance characteristic of the suppressor is enhanced by an appreciable amount of inherent capacitance, so that on a steep wave front the initial current is the charging current of the suppressor capacitance. As this current reaches maximum and starts to decay, the discharge current continues through the suppressor resistance. This effect has been observed on voltage rise rates up to 100 volts per microsecond. Clamping voltage at rated current is unchanged over the normal range of operating cell temperature, say from 0 degrees C to 100 degrees C.





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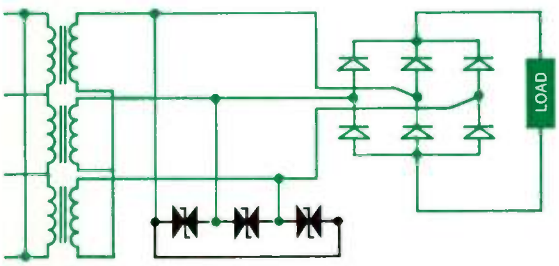

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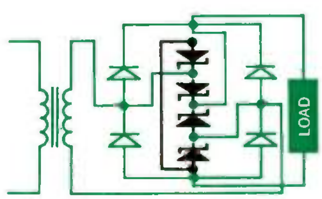

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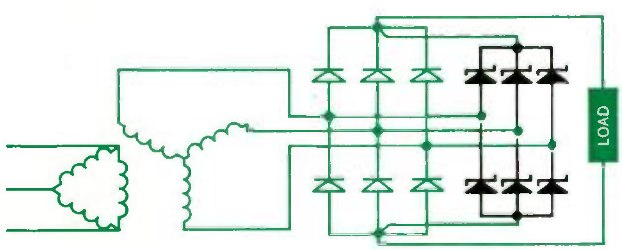

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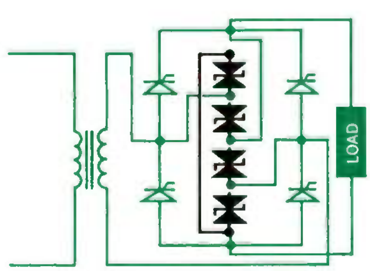

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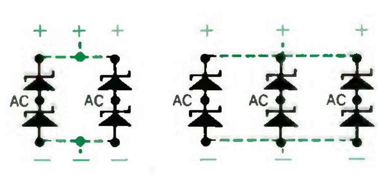

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The basic design of the unit assemblies is shown in Figs. 2 and 3. All cell surfaces are exposed to assure clearing of sparks that may occur if the unit is subjected to a discharge far beyond its rating. (It would have been cheaper, at least for the smaller sizes, to stack the cells solidly. This would leave no way for a spark to clear, however, and shorting could result on large overvoltages.)

The open construction has the additional advantage of better cooling, which reduces steady-state temperature rise and increases the unit's energy-absorbing capability for repetitive surges. Also, the spring contacts against each cell surface give constant contact pressure at all times, regardless of temperature changes.

circuit applications

Voltrap suppressors are designed for both polarized and nonpolarized operation. The nonpolarized type clamps surge voltages of either polarity. Thus, a single-element suppressor can be used across the ac input to a single-phase bridge rectifier as shown in Fig. 4. This protects against surges originating anywhere in the ac supply to the rectifier.

For a three-phase circuit, a three-element (delta-connected) nonpolarized suppressor can be used as shown in Fig. 5. Again it protects against surges from the ac lines.

Polarized suppressors, which clamp surge voltages of one polarity, are used to protect rectifier cells against surges from both ac and dc circuits. A Voltrap suppressor unit connected as a single-phase bridge and protecting a single-phase rectifier bridge is shown in Fig. 6. Only four connections have to be made. A three-phase rectifier bridge can also be protected by a single suppressor, as shown in Fig. 7, with only five connections.

Silicon controlled rectifiers require protection in both directions, so nonpolarized suppressors must be used. A single-phase bridge of controlled-rectifier cells is protected by a four-element nonpolarized suppressor as shown in Fig. 8. It is applied as a unit, with only four connections.

Four- and six-element suppressors are not built in single units in some of the higher voltage ratings because they would be excessively long. Instead, two-element units are employed to make up the bridge connections as shown in Fig. 9. The units may be either polarized or non-polarized.

application factors and ratings

Correct selection of a surge suppressor requires a knowledge of four factors:

a. Maximum applied rms ac voltage.
b. Maximum surge discharge current.
c. Clamping voltage at maximum discharge current.
d. Energy of surge and rate of repetition.

Figs. 4 and 5 Nonpolarized surge suppressors are shown protecting, respectively, a single-phase and a three-phase bridge rectifier against surges in the ac supply lines.

Figs. 6 and 7 Polarized suppressors can be applied as shown here to protect single-phase and three-phase rectifiers against voltage surges from both ac and dc circuits.

Fig. 8 A nonpolarized suppressor affords protection in both directions for silicon controlled rectifiers.

Fig. 9 In the higher voltage ratings, two-element Voltrap suppressors are combined in bridge arrangements. The dashed lines in this illustration indicate the user's connections.

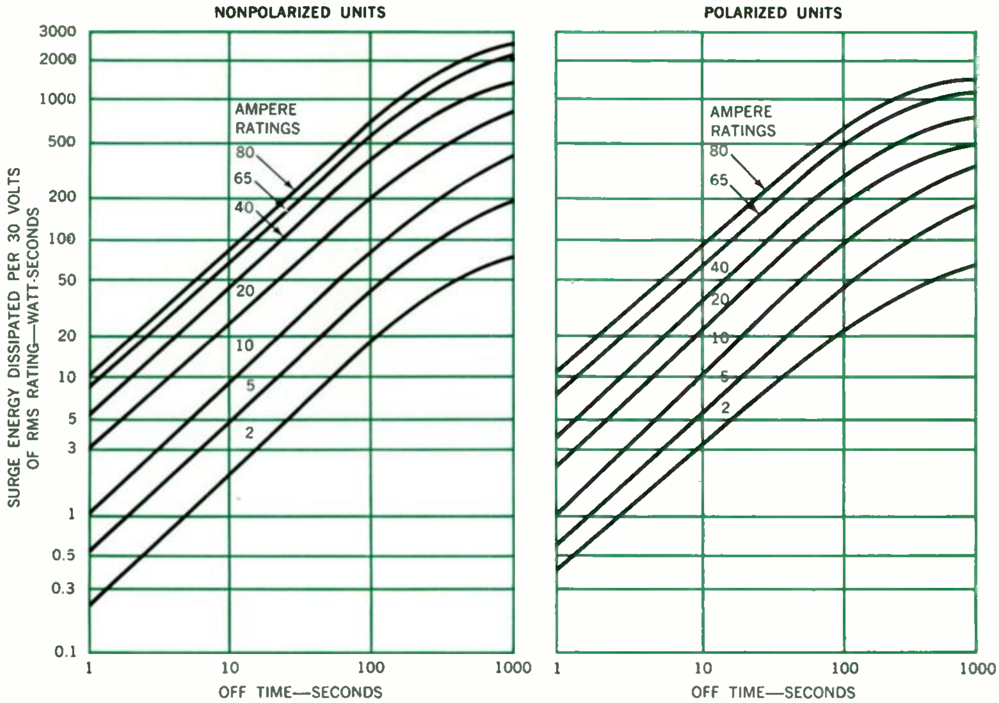


Fig. 10 The amount of surge energy that can be dissipated increases with the time interval between surges. This relation is illustrated graphically here for both polarized and nonpolarized Voltrap surge suppressors. The graphs are drawn for 30 volts of rms voltage rating; values for higher ratings can be found by ratioing the ratings.

Suppressor rms ac *voltage ratings* begin at 30 volts and increase in 30-volt steps to 480 volts for standard units. Special units are supplied for voltages above 480. The steady-state current that flows at the rated voltage is typically about five milliamperes per square inch of total surface area.

The *maximum current to be discharged* is often difficult to determine. For the most common and troublesome case —interruption of transformer magnetizing current with no load on the rectifier—the following relationship gives a conservative value for the required surge-suppressor current rating:

$$\text{Discharge amperes} = 0.7 \times (\text{secondary full-load ac amperes}) \times K,$$

where K is percent magnetizing current.

For example, a 2-kw 125-volt dc rectifier operating from single phase with 10 percent magnetizing current would have a secondary full-load current of approximately $1.2 \times \frac{2000}{125} = 19.2$ amperes. The required suppressor rating then is $0.7 \times 19.2 \times 0.10 = 1.34$ amperes.

If percent magnetizing current is not known, it may be estimated from the following table with sufficient accuracy to apply Voltrap surge suppressors:

Transformer Rating (kva)	Magnetizing Current (percent)
less than 1	15
1 to 5	10
5 to 25	5
above 25	2

When the unit must handle the stored energy of a magnetic load, its current rating should be about half of the continuous dc load current rating.

Discharge currents considerably higher than the listed ratings can be dissipated safely if pulse duration and rate of repetition are properly limited. For example, a pulse of 250 percent of rated discharge amperes, having a width of 25 milliseconds, can be dissipated if it is not repeated for at least 90 seconds. A pulse width of 10 milliseconds at 400 percent of rated amperes can be dissipated, again with 90 seconds off time. At these higher currents, however, the rated clamping voltage may be exceeded.

Clamping voltage ratings are in two grades. Grade C suppressors clamp at a voltage not more than 2.5 times the rated rms voltage of the unit. Thus, a 210-volt Grade C unit clamps at 525 volts. This provides ample protection for a diode rated at 600 volts prv. Grade A suppressors clamp at not more than 2.8 times the rms voltage rating; a 210-volt Grade A suppressor, for example, clamps at about 585 volts.

The clamping voltage rating selected should be safely below the prv rating of the silicon cell being protected. The greater this margin, the greater the safety factor against possible discharge currents above the rating of the suppressor. The suppressor should be placed physically adjacent to the diodes being protected to keep the leads as short and direct as possible.

The *surge energy* that can be dissipated by the Voltrap suppressor obviously is greater for surges occurring once an hour than for surges occurring once a second. The relation between the surge energy that can be dissipated and the time that should elapse between surges is illustrated in Fig. 10. The figure shows, for example, that a nonpolarized 30-volt suppressor having a discharge rating of 40 amperes can dissipate surges of 100 watt-seconds if the off time between surges is about 30 seconds. Values for higher voltage ratings are obtained by ratioing the rms voltage rating. Thus, for the same 30-second off time, a 210-volt unit could dissipate 7 × 100, or 700, watt-seconds of energy.

DESIGNING ASSEMBLED SWITCHGEAR BY COMPUTER

H. B. WORTMAN, Advisory Engineer
Assembled Switchgear and Devices Engineering

M. H. WALLER
Advanced Systems Engineering and Analytical Department
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

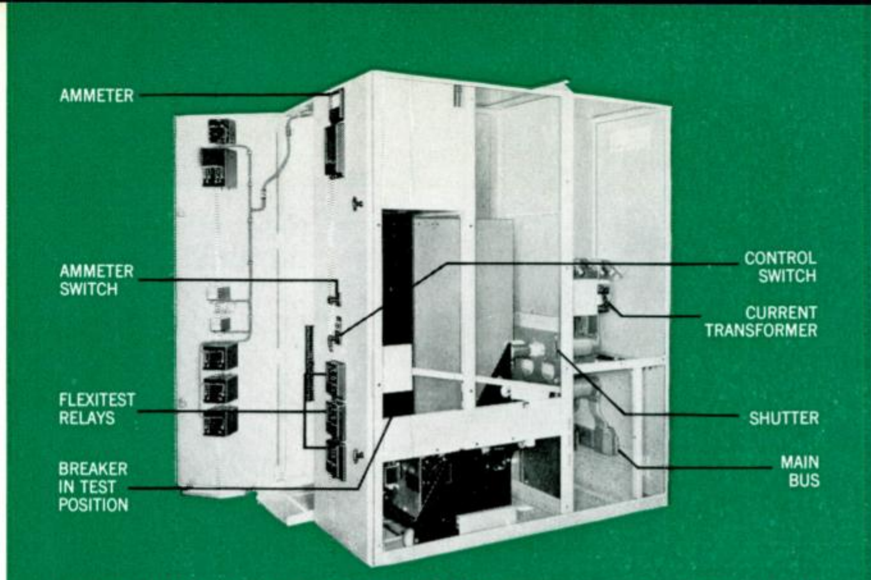


Fig. 1 Metal-clad units are assemblies of previously designed components.

Automated machine tools, tape-controlled punches, and programmed testing have advanced the manufacture of metal-clad switchgear far from its beginnings thirty years ago. Developments in electronic data processing equipment are making possible similar advancements in engineering design methods. Equipment that is taking much of the clerical work out of accounting, banking, inventory control, and scheduling also can contribute to the more efficient use of engineering talent. The value of human creativeness demands serious consideration of the possibilities.

metal-clad customer order development defined

Metal-clad equipment is essentially an assembly of predesigned components. Two typical units are shown in Fig. 1. Each started with the same steel housing, and was equipped with bus, current transformers, switches and breakers which were already designed. In fact, many of these parts were in stock long before the order was received.

Customer order development engineering consists of interpreting the customer's requirements in manufacturing terms, and providing the customer with information about the equipment he will receive.

The abilities essential to this work are an understanding of power switching and equipment protection. The engineer must determine short-circuit current to select the proper breaker interrupting capacity. He must understand transients as found in motor inrush currents or voltage surges. And, he must properly apply the equipment according to these electrical phenomena.

The draftsman interprets the engineer's analysis in available breakers, units, and components. Each order is likely to be a unique arrangement of previously designed parts. The draftsman must know the physical significance of these parts and distribute them according to certain practical dictates. For example, meters are best located at eye level, relays must be accessible for maintenance, etc.

However, in addition to these fundamental decisions, engineers and draftsmen are presently required to convert their ideas into completely artificial part numbers and record them on traditionally established formats. It is these duties of catalog searching, form filling, and interminable redrawing of unchanging outlines on established panel faces that appear to be the kind of information computers are capable of processing.

general method of parts selection

The ideal computer design program will permit the engineer or draftsman to describe the purchaser's functional needs and let the computer select the parts.

Metal-clad parts selection is largely a matter of inevitable choice, dependent on conditions of rating, unit application, and unit position. Most parts have fixed dimensions and well defined uses, so that it is possible to code the conditions for their selection. If a switchgear application is then described with the same coding, the standard parts can be selected.

Two general methods are available for automatically producing parts lists—the *branching method* and the *condition-pattern method.* In most applications, as in the one described here for metal-clad switchgear, a combination of the two systems is the most practical approach.

Both methods are based on the assumption that the functional or descriptive specifications for a unit of equipment contain all the variable information needed to prepare the parts list. *Functional specifications* concern the job the unit is to perform, while *descriptive specifications* concern the characteristics of the unit.

Both functional and descriptive specifications divide into what will be called parameters. A parameter has two or more possible conditions, exactly one of which must apply in every case.

The differences between the two methods of parts selection can be readily illustrated by using an automobile for a hypothetical example. The preparation of a parts list for this automobile demonstrates the selection process. The descriptive specification for this automobile example has three parameters: style, line, and power-pack (Fig. 2). Two significant facts about such a specification structure are: (1) All conditions of a parameter are mutually exclusive, i.e., no two can apply to the same unit; and (2) some condition of every parameter will apply to each possible unit. In the example, this means that a specification must include exactly three conditions, one for each parameter.

Branching Method—This method resembles a tree-like structure, whose branches represent all possible conditions of the parameters (Fig. 3). The parts are placed in the structure, as near as possible to the base, according to their use (Table I).

The branching structure can be simplified by merging branches whose subbranches are identical. For example, the convertible and station wagon branches (Fig. 3) can be merged just before the selection of part 9 (heavy-duty frame). Many other mergers are also possible in this example.

With the branching method, the number of possible units is the product of the number of conditions for each parameter. In the example it is $3 \times 4 \times 2$, or 24. In an actual application the number of possible units is much larger. Since each unit has a unique path, the branching structure can become extremely cumbersome even for computer application, and would require expensive programming, maintenance, and computer time.

Condition-Pattern Method—The condition-pattern method is the inverse of the branching method: where the branching method lists the parts required for each set of conditions, the condition-pattern method lists the sets of applicable conditions for each part.

Essentially, the condition-pattern structure consists of a listing of parts; each part will have one or more *part patterns* (Fig. 4a). A part pattern contains some or all of the sets of conditions, coded in binary (0 and 1), which require the part. Thus, a part pattern exists for each use of each part. Since the number of condition sets is much larger than the number of parts, and the condition sets may be efficiently coded and combined, the condition-pattern structure is easier to handle than the branching structure.

Part Patterns Table—The first step in applying the condition-pattern method is a listing of part patterns for each use of each part, as shown in Fig. 4a. This table is prepared from the information given in Table I. Rules for coding and combining this list are:

(1) When a parameter does not affect the selection of a part, 1's are used for all of that parameter's conditions.

(2) All patterns for one part are alternates in that any one is sufficient to select the part. Boolean algebra allows many such alternate patterns to be combined according to the following rule: Two patterns for the same part may be combined if they are the same for all parameters except one, by placing a 1 in the result for each position that contains a 1 in either or both patterns. For example, the first two patterns for part 15 (four-barrel carburetor) in Fig. 4a are the same for line and power-pack, but different for style. Therefore, they may be combined as shown in Fig. 5b. The result may not be combined with the third part pattern because of a difference under *two parameters*, style and line. The combined list of part patterns in Fig. 4b results from applying this rule in all possible cases.

(3) If two or more parts have the same set of patterns, they may be combined and called one part since each is used only with the other.

Parts Selection—To select parts from a parts pattern table, an input pattern is prepared for the unit to be manufactured. A 1 is placed (in the same format) under the chosen condition of each parameter and a 0 under all other conditions. For example, the input pattern for a two-door special without power pack is shown in Fig. 6. To select parts, the input pattern is matched against part patterns; a part is selected if all positions which are 1 in the input pattern are 1 in the part pattern.

A parts list is prepared by starting at the top of the parts pattern table and proceeding as follows:

(1) Compare the input pattern with the first part pattern.

(2) If the input pattern is contained in the part pattern, select the part and go on to the *first pattern of the next part*.

(3) If the input pattern is not contained in the part pattern, go on to the *next pattern*.

In actual applications there are many more parameters than are usually needed for selecting any one part. Therefore, most of the parameters for a part pattern are 1's. Such parameters, or fields, contribute nothing to the selection of these parts and may be conveniently eliminated if they occur in blocks such as at the top of Fig. 4b. Such blocks may be formed by varying the order of parts and parameters. The fields are eliminated by dividing the parts pattern table into several tables or categories, each with its own pattern format. In the example, category 1 would consist of positions four through seven of the first eight lines from Fig. 4b. Category 2 would contain the remaining lines of the table. Then, when searching category 1, it would be necessary to compare on only four positions instead of nine. Since the condition-pattern method is practical only on a computer, this field elimination technique is quite significant. It means that less information is read into the computer and stored internally, and fewer comparisons are necessary.

In the example, the first column of the parts pattern table contains only part number and name. Actually, it may contain any information about the part. Some applications may use only a part number, which will serve as a key to files containing other information about the part. Other applications may use such data as part name, cost, quantity, storeroom or supplier, and routing, along with part number.

If the class of units breaks easily into subclasses, it may be advantageous to use a combination of the branching and condition-pattern methods. In such a combination, one or two levels of branching serve to break the problem into subproblems.

application to metal-clad switchgear

Metal-clad switchgear is divided into five major types according to voltage and interrupting ratings. The branching method is used to route each order according to type and the remainder of the processing is then done with the condition-pattern method.

Coding of Metal-Clad Parts—Parts are accumulated in 17 different categories, based on common parameters. Parts with similar or related uses tend to appear in the same category. No category contains more than 36 conditions. This 36-bit pattern length was chosen to conform to the word length of the available computer.

Various parts may have the same or different bit patterns in the 36 condition positions. The breakdown of a typical coded part description (a current transformer primary bar) is illustrated in Fig. 7. Bit positions are assigned to parameters and conditions that apply to the particular part. For example, positions 7 and 8 define the type of secondary winding of the current transformer in Fig. 7. The 1 in position 7 identifies the part as applicable to a single secondary. All relevant conditions are specified to develop a part pattern; the irrelevant parameters are filled with 1's.

Many parameters appear in several categories. However, it is not necessary that they appear in the same position in the code words for different categories. In fact, it is not necessary to maintain, in any category, all the conditions of a parameter which appear in another category. For example, category *A* may require specific rating entries for 200, 300, 400, and 600 amperes. Category *B* may require only a single entry for all current ratings equal to or less than 400 amperes.

Code Word Generation—Input pattern words for selecting parts from the part pattern catalog are generated through

PARAMETERS	CONDITIONS
Line	Regular Special Deluxe
Style	Two-door Four-door Convertible Station wagon
Power-Pack	With Without

Fig. 2 Specification structure for automobile example.

Table I USE OF PARTS IN AUTOMOBILES

Part Number and Name	Use
1. Front doors	All cars except convertibles
2. Rear doors	Four-door automobiles
3. Convertible doors	Convertibles
4. Station wagon rear doors	Station wagons
5. Two-door body	Two-door automobiles
6. Four-door body	Four-door automobiles
7. Convertible body	Convertibles
8. Station wagon body	Station wagons
9. Heavy duty frame	Deluxe line and all convertibles and station wagons
10. Regular frame	All cars not using part 9
11. Six-cylinder engine	Regular line and two- and four-door specials
12. Eight-cylinder engines	All cars not using six-cylinder engine
13. One-barrel carburetor	Six-cylinder engines without power-pack
14. Two-barrel carburetor	Six-cylinder engines with power-pack and eight-cylinder without
15. Four-barrel carburetor	Eight-cylinder engines with power-pack
16. Special trim	Special and deluxe cars
17. Deluxe trim	Deluxe cars

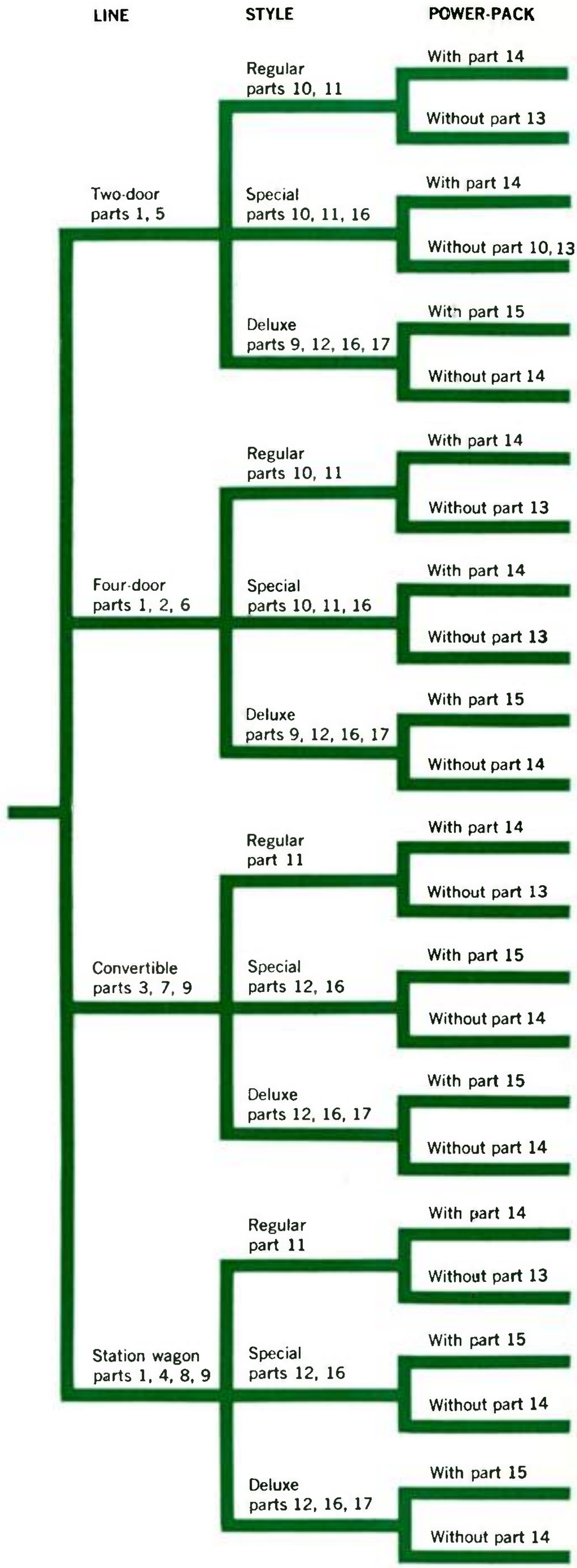


Fig. 3 Branching method applied to automobile example.

4a

Part Number And Name	Line			Style				Power-pack	
	Regular	Special	Deluxe	Two-door	Four-door	Convertible	Station Wagon	With	Without
1. Front doors	1	1	1	1	0	0	0	1	1
	1	1	1	0	1	0	0	1	1
	1	1	1	0	0	0	1	1	1
2. Rear doors	1	1	1	0	1	0	0	1	1
3. Convertible doors	1	1	1	0	0	1	0	1	1
4. Station wagon rear doors	1	1	1	0	0	0	1	1	1
5. Two-door body	1	1	1	1	0	0	0	1	1
6. Four-door body	1	1	1	0	1	0	0	1	1
7. Convertible body	1	1	1	0	0	1	0	1	1
8. Station wagon body	1	1	1	0	0	0	1	1	1
9. Heavy duty frame	1	1	1	0	0	1	0	1	1
	1	1	1	0	0	0	1	1	1
	0	0	1	1	0	0	0	1	1
	0	0	1	0	1	0	0	1	1
10. Regular frame	1	0	0	1	0	0	0	1	1
	0	1	0	1	0	0	0	1	1
	1	0	0	0	1	0	0	1	1
	0	1	0	0	1	0	0	1	1
11. Six-cylinder engine	1	0	0	1	1	1	1	1	1
	0	1	0	1	0	0	0	1	1
	0	1	0	0	1	0	0	1	1
12. Eight-cylinder engine	0	1	0	0	0	1	0	1	1
	0	1	0	0	0	0	1	1	1
	0	0	1	1	1	1	1	1	1
13. One-barrel carburetor	1	0	0	1	1	1	1	0	1
	0	1	0	1	0	0	0	0	1
	0	1	0	0	1	0	0	0	1
14. Two-barrel carburetor	1	0	0	1	1	1	1	1	0
	0	1	0	1	0	0	0	1	0
	0	1	0	0	1	0	0	1	0
	0	1	0	0	0	1	0	0	1
	0	1	0	0	0	0	1	0	1
	0	0	1	1	1	1	1	0	1
15. Four-barrel carburetor	0	1	0	0	0	1	0	1	0
	0	1	0	0	0	0	1	1	0
	0	0	1	1	1	1	1	1	0
16. Special trim	0	1	0	1	1	1	1	1	1
	0	0	1	1	1	1	1	1	1
17. Deluxe trim	0	0	1	1	1	1	1	1	1

4b

Part Number And Name	Line			Style				Power-pack	
	Regular	Special	Deluxe	Two-door	Four-door	Convertible	Station Wagon	With	Without
1. Front doors	1	1	1	1	1	0	1	1	1
2. Rear doors	1	1	1	0	1	0	0	1	1
3. Convertible doors	1	1	1	0	0	1	0	1	1
4. Station wagon rear doors	1	1	1	0	0	0	1	1	1
5. Two-door body	1	1	1	1	0	0	0	1	1
6. Four-door body	1	1	1	0	1	0	0	1	1
7. Convertible body	1	1	1	0	0	1	0	1	1
8. Station wagon body	1	1	1	0	0	0	1	1	1
9. Heavy duty frame	1	1	1	0	0	1	1	1	1
	0	0	1	1	1	0	0	1	1
10. Regular frame	1	1	0	1	1	0	0	1	1
11. Six-cylinder engine	1	0	0	1	1	1	1	1	1
	0	1	0	1	1	0	0	1	1
12. Eight-cylinder engine	0	1	0	0	0	1	1	1	1
	0	0	1	1	1	1	1	1	1
13. One-barrel carburetor	1	0	0	1	1	1	1	0	1
	0	1	0	1	1	0	0	0	1
14. Two-barrel carburetor	1	0	0	1	1	1	1	1	0
	0	1	0	1	1	0	0	1	0
	0	1	0	0	0	1	1	0	1
	0	0	1	1	1	1	1	0	1
15. Four-barrel carburetor	0	1	0	0	0	1	1	1	0
	0	0	1	1	1	1	1	1	0
16. Special trim	0	1	1	1	1	1	1	1	1
17. Deluxe trim	0	0	1	1	1	1	1	1	1

Fig. 4 (a) List of part patterns (uncombined) for automobile example. (b) Same part pattern list combined.

Fig. 5 (a) Justification for placing 1's under all conditions of irrelevant parameters; (b) combination of first two patterns of part 15 from Fig. 4a.

5a

	1	0	0	1	0	0	0	1	0
OR	1	0	0	1	0	0	0	0	1
OR	0	1	0	1	0	0	0	1	0
OR	0	1	0	1	0	0	0	0	1
OR	0	0	1	1	0	0	0	1	0
OR	0	0	1	1	0	0	0	0	1
=	1	1	1	1	0	0	0	1	1

5b

1st pattern	0	1	0	0	0	1	0	1	0
2nd pattern	0	1	0	0	0	0	1	1	0
Result	0	1	0	0	0	1	1	1	0

Fig. 6 Input pattern for a two-door special without power-pack.

Line			Style				Power-pack	
Regular	Special	Deluxe	Two-door	Four-door	Convertible	Station wagon	With	Without
0	1	0	1	0	0	0	0	1

an interpretative program. The designer supplies a functional description of the assembly: This includes such data as general order information, functional information on the overall station, and unit descriptions peculiar to each specific cell. All of this information is coded on punched cards for input to the computer. The various types of descriptive input and the technique for defining the card punching required are illustrated in Fig. 8.

To facilitate changes in the parameter-condition structure, the computer program for generating code words for parts selection must be easily modified. This requirement is satisfied with an input monitoring and control program that uses a system of modular subroutines. The control program interrogates input and establishes the sequence in which the necessary subroutines are executed. Each subroutine is independent of both the control program and other subroutines. A subroutine contributes (to the generated code words) a binary pattern that represents the conditions of its associated parameter.

Some input information applies to all cells (units) in a metal-clad switchgear lineup—for example, voltage, inter-

7a

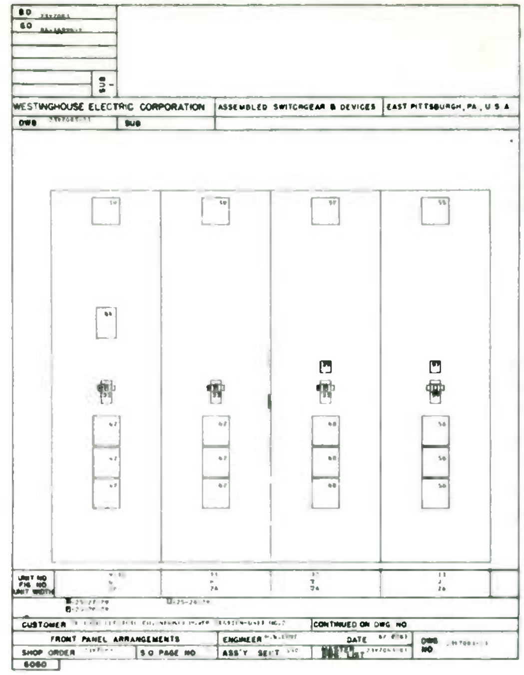
PARAMETER	CONDITION	CODE	BIT POS.
Unit width (inches)	20″ or 26″	(irrel-	1
	36″	evant)	2
Type of current transformer	None	0	3
	RCT	1	4
	CT	0	5
	UP	0	6
Current transformer secondary	Single	1	7
	Double	0	8
Primary current (amperes)	150	0	9
	200	0	10
	300	1	11
	400	0	12
	600	0	13
	800	0	14
. . . .	. . . .	(irrel-evant)	. . . 36

7b

PART NO. 116D506G03, CURRENT TRANSFORMER PRIMARY BAR

Relevant Conditions	010010001000
Relevant and irrelevant conditions	110100100010001111111111111111111111
Generated code word of unit	100100100010000000001000111000110001

9



8

STATION DESCRIPTION

5 KV | 15 KV

SYSTEM VOLTAGE (LINE TO LINE) (1) : 2400 [0], 4200 [1], 4800 [3], 7200 [4], 12000 [5], 14400 [6].

BREAKER M.V.A. (2) : 75 [0], 150 [1], 250 [2], 350 [3], 500 [4], 750 [5], 1000 [6].

BUS CURRENT (3) : 1200 [0], 2000 [1], 3000 [2].

FREQUENCY (4) : 25 [0], 60 [ ]

SHELTERFORM (5) : SINGLE AISLE [1], COMMON AISLE [2].

CONTROL VOLTAGE (CLOSE) (6) : 125 VDC [0], 250 VDC [1], 230 VAC [2].

CONTROL VOLTAGE (TRIP) (7) : 125 VDC [0], 250 VDC [1], 230 VAC [2], 24 VDC [3], 48 VDC [4], TIME DELAY [6], INSTANTANEOUS TRIP [7]

Fig. 7 Illustration of the development of coded descriptions and their use: (a) Conditions are assigned bit positions; part patterns are coded according to the pertinent conditions. (b) Parts are coded by first recognizing the relevant, then the irrelevant conditions. This last pattern is compared with the generated code word of the unit; if the part pattern contains the generated code word, the part is selected.

Fig. 8 Input data sheets are designed to permit the transcription of functional and descriptive data to punched cards. Typical portions of input data are shown for station description. [(1) are columns and [0] are punches.]

rupting capacity, and main bus current. The conditions of these parameters are tested once and the resulting pattern inserted in the generated code words for all cells. Other parameters pertain to individual cells; these parameters are interrogated and the appropriate bit patterns inserted in the applicable generated code words.

In addition to interrogating individual cell input parameters, the computer program must develop cell lineup continuity. For example, main bus must be selected to extend into adjacent cells. To select proper bus lengths, the widths of both the cell being processed and adjacent cell must be taken into consideration. The high degree of standardization in both cell widths and bus bar lengths permits the selection of the proper bar length based on the particular combination of cell widths.

Adjacent cell correlation may alter cell code words. For example, assume cells 1 and 2 are oriented left to right. Cell 1 is a circuit breaker housing, cell 2 is an auxiliary housing. Assume it necessary to mount a set of potential transformers in cell 2, which are connected to the line side of the circuit breaker in cell 1. The code word developed for cell 1 must be changed, to select not a solid steel barrier, but one with an appropriate number of holes through which the potential transformer connecting cables may pass.

The examples cited above are peculiar to switchgear. However, the facility for appending checks to the system of subroutines indicates the ease with which the condition-pattern method may be applied.

After cell input interrogation and adjacent cell correlation is completed, it is desirable to eliminate the duplicate code words in each of the 17 categories. Two cells may require the same part for the same application. The code words which will select the part may be exactly the same, but only one selection is desired. The elimination of duplicate code words reduces the catalog-tape searching time by the computer.

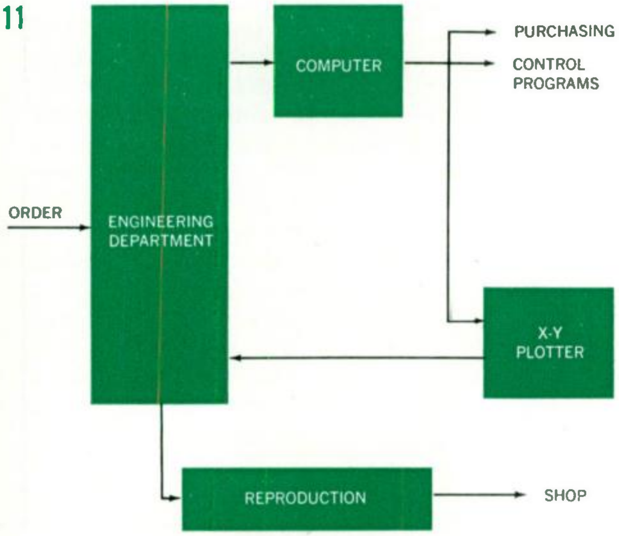
INPUT		OUTPUT
FUNCTION	TIME	MATERIAL
Customer Order Section	4 Hours	Cell Parts Description
		Meter and Transformer Sheets
Punch and Verify	1 Hour	
7090 Computer	1.5 Minute	Stock Assignment Cards
1401 Computer	10 Minutes	Front Panel Drawings
Data Plotter	30 Minutes	Bills of Materials
		Punch Sheets
		Preform Wiring Layout Guides
		Nameplate Charts

Fig. 9 Front panel drawings are prepared by first printing the variable typed information, then drawing the outlines with a coordinate plotter.

Fig. 10 Time required to prepare and process the selection of standard parts for a typical metal-clad switchgear order.

Fig. 11 Assembled switchgear orders are interpreted and processed as shown in this chart.

11



searching the catalog tape

The interpretative program produces a condensed code word table containing generated code words (GCWs), segregated into 17 separate parts categories. The part code word (PCW) catalog, also separated into 17 parts categories, is contained on tape. The catalog-tape search is accomplished by comparing the PCWs of the tape catalog with the GCWs in the condensed code word table. This comparison is made as follows:

(1) The first PCW in category 1 of the tape catalog is compared with each GCW in category 1 of the condensed code word table.

(2) If the PCW does not contain all of the one bits found in at least one of the GCWs the part is not selected.

(3) If, on the other hand, the PCW of the catalog part is found to contain all of the one bits of some GCW, the part is selected. In this event, no further comparisons are made using that PCW.

(4) This process is repeated using successive PCWs until the last PCW of the last part in category 17 of the catalog-tape has been compared with the GCWs in category 17 of the condensed code word table.

The search produces a complete parts list for the order. Each selected part will have the following information listed: Style number; preassigned item number; quantity of the part required by the particular application for which the part was selected; the PCW associated with the part; the number of the category from which the part was selected; and a note code for those parts that are to be applied in some nonstandard manner.

Note codes are selected from the tape-catalog in the same manner that parts are selected.

An individual part may appear more than once in the selected parts table. The number of times such a part is selected is determined, in general, by the number of different uses for which that part is required. Also, the part may be duplicated because of a note requirement.

The next step in the computer program is the preparation of the quantity distribution of the parts, i.e., the quantity of each part required for each cell. Duplicate parts entries are combined, where possible.

searching the parts data catalog

The information needed for processing thus far is available in the PCW tape catalog. Since a part may appear several times in the PCW tape catalog, a minimum of information is stored here. However, the part style number is used to locate additional information in a parts data catalog. This catalog includes such information as the part name, its type number, rating, storeroom location, etc. Similarly, the note code is used to locate notes in a note catalog. Upon completion of the parts data and note catalog search, all information needed to produce a complete bill of material, interworks requisitions, and stock assignment cards is contained in the computer's primary storage. From here on, essentially routine programming is required to produce these and other output documents.

program output

The output information is converted to printed and punched card data. Printed output is in the form of requisitions, manufacturing information, and base information for manufacturing and customer drawings. Much of the output material is printed on drafting quality vellum. This permits the designers to supplement program-selected parts with pieces or arrangements too unusual to justify storage. Two sets of punched cards are produced. One set is a deck of stock assignment cards for the inventory control program, and the other directs the X-Y plotter.

The front panel drawings are prepared on a card-controlled X-Y plotter. A typical set of panel drawings is shown in Fig. 9. Titles and item numbers, where possible, are first printed on the paper as part of the computer printed output. The panel and device outlines are then added by the plotter.

Other program output includes panel punch sheets for use with a turret punch. A machine control tape could be prepared if one were required. The punch sheet program includes the calculation of values incidental to the preparation of pay cards.

Cell and circuit nameplate charts are also developed. The cell nameplates depend on a routine that determines a breaker interchangeability pattern from such pertinent facts as a breaker rating and current transformer ratio.

Requisitions are prepared if the stored information indicates their need. Delivery dates for these items are developed from the contract shipping date and the "lead time" requirements.

A typical metal-clad switchgear order consists of an assembly of five breaker units and one auxiliary compartment. The time required to prepare and process such an order is detailed in Fig. 10.

effect of computer program output on established operations

The computer program is oriented in the order processing system as shown in Fig. 11. The order is interpreted in the engineering department. Communication with the computer is by punched cards. The output is in the form of requisitions, material lists, inventory control cards and panel data cards for the plotter.

A significant opportunity arises from the ability to select the pertinent part number and print it with a preassigned drawing item number. In this way the same item number always applies to a standard part in a standard location. This is a convenience to assembly groups and permits the use of the same section drawing for many orders.

Presently, wiring for metal-clad panels is preformed. The program provides a guide to wiring fixture locations.

Before program runs were available long delivery items were ordered several weeks before locally produced parts. Now, it is possible to identify and order most of the components for metal-clad assembly much earlier.

The study described has established that a program can be written to convert descriptive input into parts lists, panel drawings and other conventional information media familiar to purchaser and manufacturing personnel.

This is most significant in situations where relatively few statements define an application and a great many parts must be processed. In the metal-clad problem, the parts for each cell are chosen from over 6500 parts and assemblies. Over half of these items are instruments, relays, meters, transformers and similar devices that are available for a range of ratings and have a different part number for each interval.

Two factors that contributed significantly to the feasibility of the computer program were the highly standardized components and the thoroughly organized parts files. Although the parts usage definitions well known to experienced designers permitted effective manual design of metal-clad switchgear, automation of design procedures required more explicit definitions.

The use of the program is reasonably limited to parts considered active enough to warrant cataloging. Thus, unusual arrangements and superseded or foreign equipment must be supplemented by normal design and drafting procedures.

Westinghouse ENGINEER Mar. 1962

The authors wish to acknowledge the important contributions to this article made by H. K. Gallimore of the Advanced Systems Engineering and Analytical Department, Robert H. Davis of the East Pittsburgh Divisions Business Systems Department, and Ralph Waltemire and George R. Ramsey of the Assembled Switchgear and Devices Department.

Eyes for Typhon

The Typhon Weapons System, a ship-based anti-air warfare system, is getting the first test of its radar "eyes." Named after the hundred-headed monster in Greek mythology, Typhon will be an integrated shipboard radar and armament-control system. It is designed to provide the fleet with a greatly improved anti-air warfare capability and also with offensive capability for engaging enemy fleet units and conducting shore bombardment. The system will fire missiles from launchers mounted on fast-moving warships in strategic fleet locations around the world. Radar, computer, and weapon-direction subsystems will be an integrated design produced by Westinghouse.

The "eyes" of the system will be an advanced long-range search, track, and guidance radar. Westinghouse engineers are presently engaged in the development, design, and production of a prototype model of this long-range radar portion of the system. The new radar concept, originated by scientists at the Applied Physics Laboratory of the Johns Hopkins University at Silver Spring, Maryland, incorporates high data rate and high power features far in excess of present designs. The radar will employ a phased transmitter array to provide electronic scanning.

The first step in the radar development is an experimental model, which is a scaled down version of the Typhon radar system. This model, built in conjunction with the Applied Physics Laboratory, is now in operation. The model combines the search and track functions of the radar and uses a similar antenna system although at greatly reduced power. Experimental weapon-direction equipment has also been built; it can do the things that the prototype will be designed to do, but only one function at a time. This model equipment will be used as a design tool during the development of the prototype system and equipment. System changes can be tried on the experimental model before being incorporated into the prototype design.

Westinghouse received its first contract for the long-range radar portion of the system in April 1960. The contract for development and production of the weapon-direction equipment was awarded in March 1961.

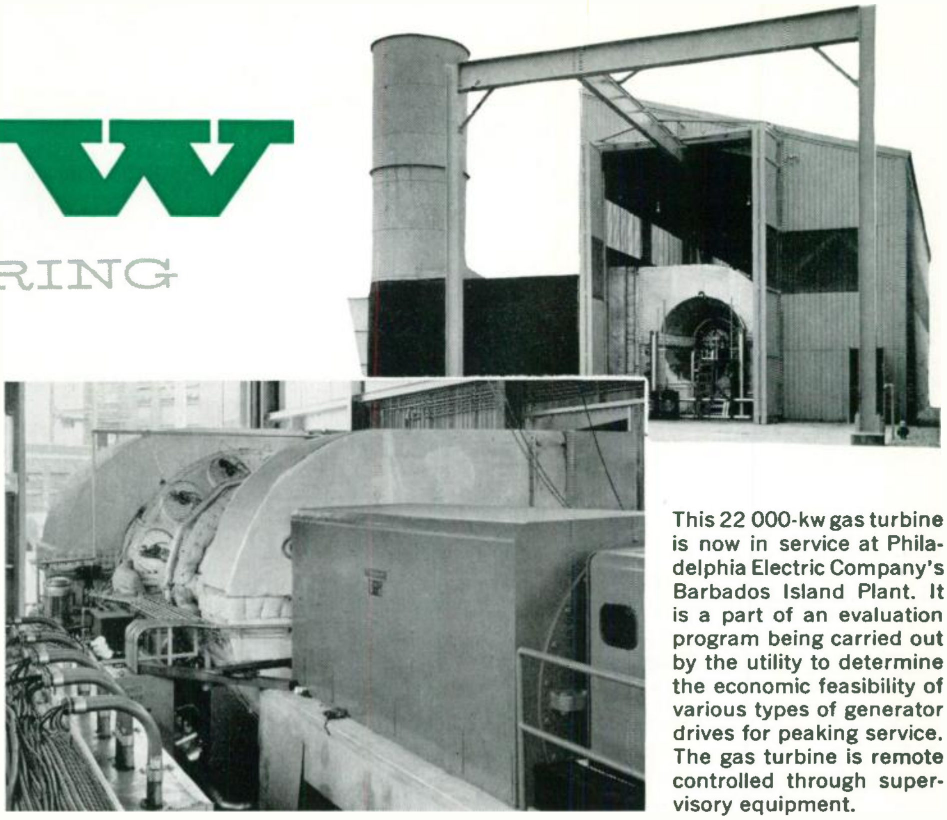
WHAT'S NEW IN ENGINEERING

Thousands of Eyes—The phased array concept consists of driving a number of transmitters in parallel and adding their outputs in space. This technique not only permits the phased addition of radiated power in space but also provides directive characteristics not unlike those obtained with the dish-type reflectors of present-day radars. This means that literally thousands of "radar eyes" will be required to cover the complete horizon. A key element in each radar "eye" will be a traveling-wave tube (TWT), which is a special kind of a microwave amplifier.

In the TWT tube, energy in the form of an electron beam is injected through a series of resonant cavities in such a way that the electron-beam energy is converted into an amplified rf field signal for transmission. During this process, a signal amplification of 20 000 is accomplished.

As in most microwave devices, the tube has extremely tight tolerance requirements for physical dimensions. In this case the tolerance problem is much greater than it is in most applications because each tube must have exactly the same gain and frequency characteristics. Each tube is literally a "high-fidelity" microwave device, where the output signal must be a faithful, undistorted reproduction of the input, but amplified by a factor of 20 000.

The electrical performance design on the tube is being done by the Watkins Johnson Company of Palo Alto, California. This is the first time that a development program has been aimed at the production of such a large number of tubes with such uniformity in characteristics, along with extreme reliability requirements. Where the traveling-wave tube in the past has been made in quantities of tens per year, this new application will require the production of thousands of traveling-wave tubes per year. ■ ■ ■



This 22 000-kw gas turbine is now in service at Philadelphia Electric Company's Barbados Island Plant. It is a part of an evaluation program being carried out by the utility to determine the economic feasibility of various types of generator drives for peaking service. The gas turbine is remote controlled through supervisory equipment.

230-Kv Shunt Reactor

Reactive kva to compensate for capacitive charging reactance of high-voltage lines is normally provided by low-voltage reactors placed across the tertiary windings of transformers. A large 230-kv shunt reactor now applies the reactance where it is required.

The 25 000-kva unit is installed near the mid-point of the new 300-mile 345-kv transmission line of Arizona Public Service. This line, the longest 345-kv line yet built in this country, will deliver the 800-mw capacity of the utility's Four Corners plant in northwestern New Mexico to the load centers of southern Arizona.

The new shunt reactor consists of an air-core winding completely shielded magnetically phase to phase and phase to tank. The winding uses a shell-form coil and Insuldur insulation. ■ ■ ■

Universal Tungsten Welding Electrode

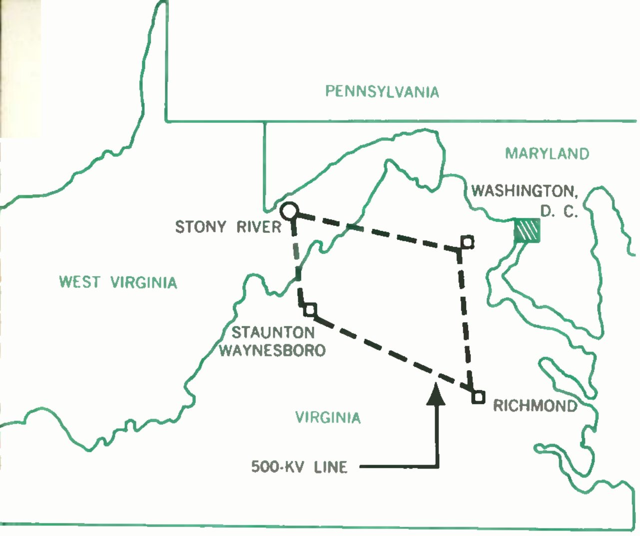
Tungsten inert-gas welding has become one of the most valuable precision welding methods, especially in the aircraft, missile, and atomic-power industries. The arc is drawn with a nonconsumable tungsten-alloy electrode, and the work area is shielded by an inert gas to prevent contamination from the air. Four different electrode alloys have been needed in the past, each performing better than the others for specific applications.

Now, a universal electrode developed by Westinghouse Lamp Division engineers serves for all situations and is better than the earlier compositions in some respects. For example, it is superior where arc "fluttering" cannot be tolerated, as is often the case in complex shapes. It also minimizes contamination of the weld with tungsten, an especially important factor in fabricating uranium fuel elements. The new electrode eliminates the risk of selecting an improper electrode for a job and also simplifies ordering and stocking of electrodes. ■ ■ ■

Nation's First 500-Kv Transmission System

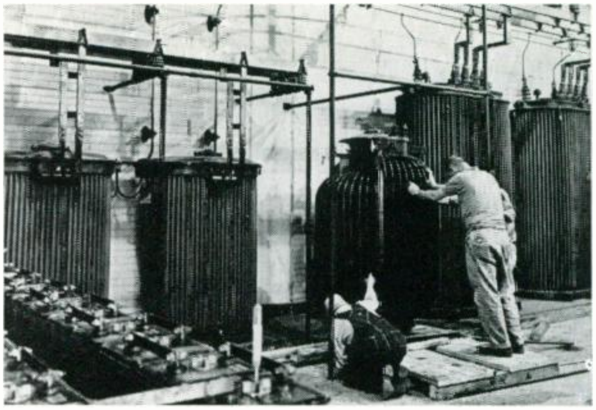
The Virginia Electric and Power Company has awarded a contract to Westinghouse to supply engineering and equipment for the nation's first commercial 500-kv transmission system. This marks the first move in America to construct lines of this voltage to transmit large blocks of electric power from remote coal fields to distant load centers.

The $45-million project will extend



Left The Virginia Electric and Power Company's planned 500-kv transmission system.

Right This 500-kva three-phase T-connected transformer saved floor space when modernizing the St. Louis (Missouri) Post Dispatch building. It replaces three older single-phase transformers (at left) and is identical in rating to the larger transformer at right.



from a new mine-mouth power station in Grant County, West Virginia, forming a 350-mile loop from the station to the Washington, D. C. suburbs in Northern Virginia, south to Richmond, and back to the station by way of the Waynesboro-Staunton area. Construction of the first legs of the line will be completed in 1964, and the entire project is expected to be in operation by early 1966. Engineering and surveying will begin at once.

The new power station from which the 500-kv lines will originate will be located in the coal fields of West Virginia. It will have two generating units of 500 megawatts each.

The contract provides for an engineering team composed mostly of Westinghouse engineers, with representatives of Vepco, its consultants, and power line equipment suppliers, to make extensive studies of all data from existing high-voltage lines and EHV experiments to arrive at optimum design for the new line. After these studies are completed, Westinghouse will design and manufacture the major equipment for the line terminals and Vepco will construct the 350-mile transmission loop. This will be the first time that a transmission system has been engineered and designed as a complete unit in advance, rather than as an assembly of separately engineered parts. ■ ■ ■

T-Connected Transformer

By combining an old principle with a highly developed transformer design, engineers have come up with a tremendously improved three-phase distribution transformer. The old principle is the T connection; the new three-phase transformer uses two single-phase transformers connected in T and assembled in one tank. The design enables transformer engineers to incorporate in a three-phase transformer the many improvements that have been made in the more widely used single-phase design.

The most significant thing about this design is its net advantage over the conventional three-phase design. In the 225- to 500-kva range, both no-load and total losses are lower. In the 500-kva size, for example, the no-load loss of the T-connected transformer is 1350 watts, compared to 1800 watts for the previous design; total loss is 6900 watts for the new design, 7720 watts for the previous unit. Impedance is also lower—3.1 percent as compared to 4.9 percent for the 500-kva unit, and an even greater reduction in the smaller ratings. Total weight is also reduced, from 6000 pounds to 4270 pounds for the 500-kva unit.

All this adds up to less operating cost. Annual operating costs for a 300-kva unit operating at an average load of 240 kva are about $131 a year less for the T-connected unit compared with the previous type SL.

One potential disadvantage of the T connection is voltage unbalance. However, the low-impedance design keeps unbalance to less than 0.5 percent, which is below the accuracy of most panel-type meters; voltage unbalance is therefore of no consequence in the new design.

The T connection also permits flexibility in physical design. Core and coils can be placed one on top of the other and fitted in a round tank design; alternatively, the core and coils can be placed side by side for a pad-mounted design. ■ ■ ■

Superconductors Provide Super Magnetic Fields

Research scientists and engineers have long sought a way of harnessing the large currents that flow in superconductors near absolute zero. The difficulty was that one of the most desirable applications—loss-free windings for generating powerful magnetic fields—seemed to be ruled out by the fact that strong magnetic fields destroyed superconductivity.

A breakthrough came in 1960 with the discovery by J. E. Kunzler and his associates at Bell Laboratories that short composite wires made of the niobium-tin intermetallic compound Nb_3Sn continued to carry supercurrents in very high fields.

Unfortunately, the niobium-tin compound is brittle and hard to form, so scientists at the Westinghouse Research Laboratories turned their attention toward developing ductile high-field superconducting materials. Their work led to development of a one-pound solenoid wound with wire made of a niobium-zirconium alloy and rated at 43 000 gauss—twice as strong as a conventional iron-core electromagnet weighing 20 tons. Since then, they have produced coils developing 60 000 gauss. (See inside front cover.)

Commercial versions of the solenoids are now being made available to industrial, governmental, and academic laboratories as powerful tools for research in superconductivity, magnetics, plasmas, nuclear fusion, and other fields. Westinghouse supplies the superconducting wire, wound coil, or complete solenoid system including cryogenic components. The magnet is rated at 50 000 gauss.

ABOUT THE AUTHORS . . .

R. J. CREAGAN is engineering manager for the Atomic Power Department, which is responsible for the development and design of nuclear power plants for commercial applications. Creagan was graduated from Illinois Institute of Technology in 1942 with a bachelor of science degree in engineering. He later obtained his master's degree and his doctorate in Physics at Yale University.

He worked at the Argonne National Laboratory in 1946 on the experimental breeder reactor and later at Argonne as a Westinghouse employe in 1950 on the first criticals for the *Nautilus* prototype. After returning to Westinghouse at the Bettis Laboratory, he headed the group which did the initial reactor design studies for what later became the Shippingport Project. He later moved to the Atomic Power Department as manager of reactor engineering and in 1961 became engineering manager.

REUBEN LEE and HENRY F. DEFRANCESCO, both engineers by profession, have more than a casual interest in the field of education. Reuben Lee became significantly involved in education in 1958 when he instigated the rebirth of Stratovision for educational television. DeFrancesco's interest in education began when he taught mathematics during his graduate studies.

Lee joined Westinghouse on the Graduate Student Course in 1924 after graduating from West Virginia University with a BSEE. He was appointed a design engineer at the Electronics Division in 1938. In 1945, he became an advisory engineer, and was made a consulting engineer in 1957.

In June 1960, Lee was awarded the Westinghouse Order of Merit, the company's highest award for achievement.

DeFrancesco came with the company in 1956 from the Department of Defense. His first position was a Fellow Engineer in the advanced development engineering group at the Electronics Division. In 1958 he was appointed supervisor of a study group in advanced development engineering, and in 1960 became an engineering section manager responsible for design of special purpose military computers. DeFrancesco is a graduate of the University of Virginia, with a BEE in 1947 and an MA in 1950.

A. M. LOCKIE was given a tough assignment for this issue: clarify a sometimes confusing subject, transformer loss ratios.

Lockie has been dealing with distribution transformer designs and problems since he first joined Westinghouse. He graduated from Rensselaer Polytechnic Institute with an EE degree in 1931, and an MEE in 1934.

Lockie started work on development and application of protective devices for distribution transformers in 1936 and continued in this field until 1953. Then he joined the long range major development section and became an Advisory Engineer.

A. J. BAESLACK entered the Graduate Student Course in 1944 after receiving his BSEE from the University of Pittsburgh. He worked in the electro-physics section of the Westinghouse Research Laboratories for a year and then was appointed an instructor at Carnegie Institute of Technology. He earned his MSEE there in 1948 and joined Alcoa in 1949. Baeslack returned to Westinghouse in 1954 as a design engineer in the Arc Welding Department. He transferred to the Systems Control Engineering Department in 1956.

J. G. PETERSEN, JR. earned his BSEE at Case Institute of Technology in 1951 and then joined Westinghouse on the Graduate Student Course. He was assigned to the Systems Control Engineering Department, where he has helped create drive control designs for applications ranging from mine hoists to missile launchers.

EDWARD T. SPIRES, JR., earned his BS in physics at Carnegie Institute of Technology in 1948 and immediately joined the Westinghouse Materials Engineering Department. In 1951 Spires transferred to the General Purpose Control Department's rectifier section and was made general foreman in 1956. The following year he became section manager and also received an MBA degree from the University of Buffalo. He moved to Headquarters in 1961.

I. R. SMITH began his technical education in 1916 at Worcester Polytechnic Institute. It was interrupted in 1918 by service in the U. S. Army, but he returned to Worcester in 1919 and received his BS in electrical engineering in 1921. He joined Westinghouse on the Graduate Student Course and then was assigned to the lightning arrester section of the Supply Engineering Department. In 1928 he became a section engineer in the rectifier section. Smith is now engineering manager of the selenium products section.

HERMAN B. WORTMAN and MILTON H. WALLER headed up the team that developed the program for designing assembled switchgear by computer. Wortman, an Advisory Engineer in design programming, began the initial study in 1958. He joined the Switchgear Division in 1936 after graduating from Drexel Institute with a BSEE.

Waller, a Senior Engineer in the Advanced Systems Engineering and Analytical Department, is a member of CASE (Computer-Advisory Service in Engineering), and assists Company divisions with computer applications.

Waller came with Westinghouse in 1953 to work in the switchboard engineering department of the Switchgear Division. He helped set up the Univac computer operation for the East Pittsburgh divisions in 1955, and a year later, he transferred to the Analytical Department. Waller is a graduate of the University of Kansas with a BS in EE in 1948.

This is the *Enterprise,* world's mightiest ship, as it went to sea for the first time. Her eight reactors were designed and developed by Westinghouse Electric Corporation under the direction of and in technical cooperation with the Naval Reactors Branch of the Atomic Energy Commission. The huge aircraft carrier has a displacement of 85 000 tons.