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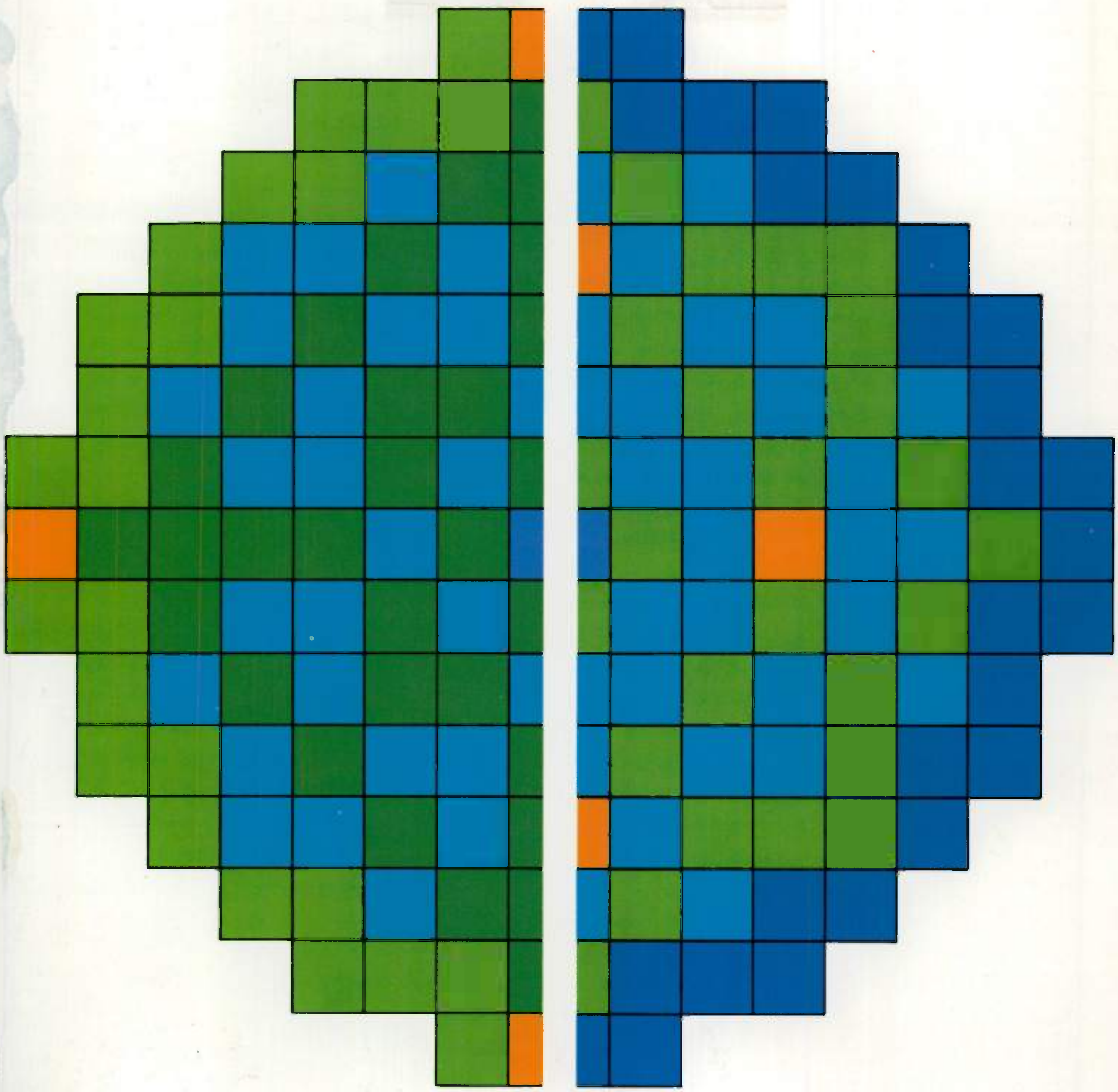


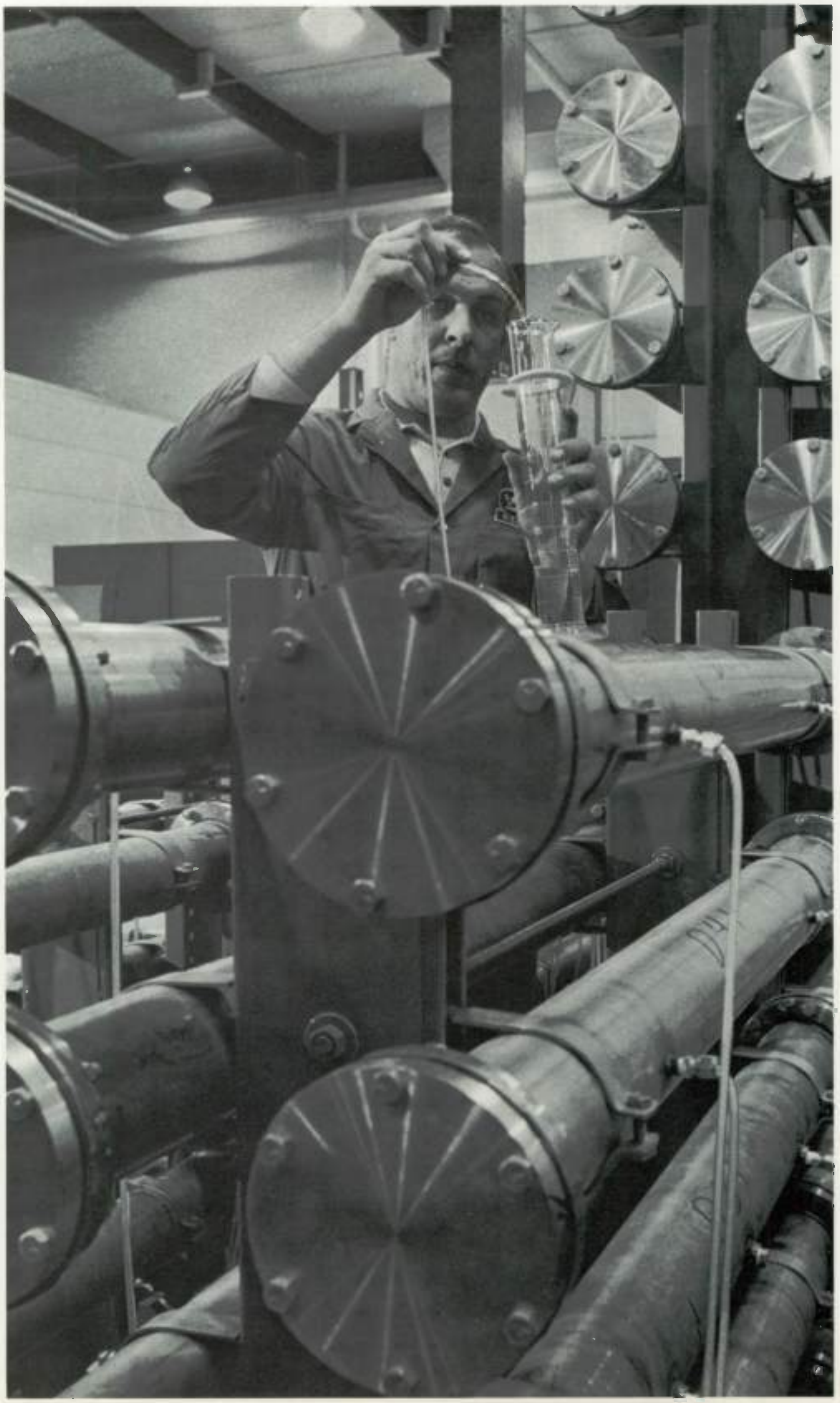
Modular Water Purifying System Employs Reverse Osmosis

An improved reverse-osmosis type of water purifying system is based on a newly formulated semipermeable membrane that provides high product-water flow rate and high impurity rejection rate. Membranes are housed in tubular modules that can be combined in various numbers to achieve the capacity desired—from very small units up to plants of a million or more gallons per day capacity.

Reverse osmosis works by applying enough pressure on the feedwater side of the membrane to reverse the natural osmotic flow of water, which is from the dilute to the concentrated side. Water is forced through the membrane to the product side, leaving behind all the undissolved solids suspended in it and most of the dissolved solids.

Each module has several tubular membranes firmly supported by a porous matrix of resin-bonded sand, which is housed in a steel shell that supports the matrix and collects the product water. The system is best suited for treating brackish and polluted water having up to 5000 milligrams per liter of dissolved solids.

One important use foreseen for the new system is treatment of brackish water to provide drinkable water for municipal systems because, in addition to removing the required amount of dissolved salts, it also removes bacteria and viruses. Others are purification of boiler feedwater, reclamation of treated municipal waste water, treatment of water for beverage manufacture, treatment of industrial waste liquids, and reclamation of industrial process liquids. The system was developed by the Westinghouse Research Laboratories and Product Transition Laboratory for the company's Heat Transfer Division.



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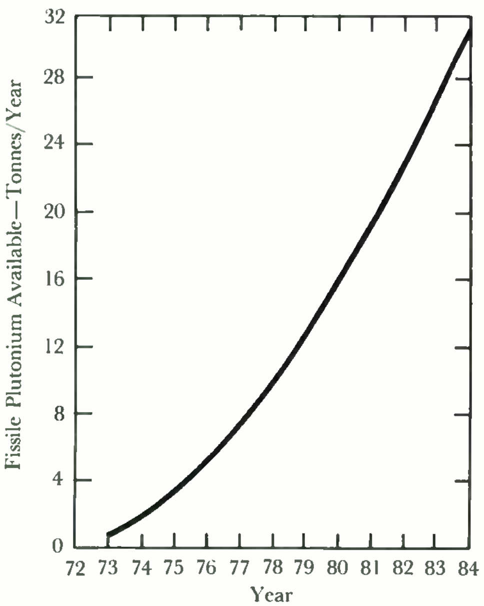
Front Cover: The half-core representations on this month's cover illustrate typical checkerboard loading patterns for pressurized-water reactors. Shown at left is the first reload of uranium fuel (region 4) for cycle 2 operation, which includes four demonstration assemblies containing plutonium enrichment. For cycle 3 operation, shown on the right, the irradiated region 4 assemblies (including the four plutonium assemblies) have been moved inward and fresh region 5 fuel assemblies are positioned on the outside of the core. For further identification of the core loading pattern, see Figs. 4 and 5 of the article on plutonium recycle.

Preparations for Commercial Plutonium Recycle

J. Haley

The termination of the AEC buyback in December 1970 signaled the beginning of commercial plutonium recycle. To ensure the design, fabrication, and operation of plutonium recycle fuel on a commercial basis, utility-government-industry joint development programs, augmented by individual company efforts, are developing the required technology and production facilities.



1—Plutonium available for thermal recycle each year.

The concept of plutonium recycle has been with the nuclear industry for a long time because the economics of the nuclear fuel cycle depends upon how well the plutonium generated by thermal reactors can be utilized. The credit for generated plutonium has a potential value of more than 10 percent of total fuel-cycle costs for the light-water reactors *now committed*, but that plutonium must be recycled economically for this credit to be realized. (For a typical pressurized-water reactor, the fuel costs in Table I would be increased by 12 percent if its generated plutonium had no value.)

Nuclear fuel cost analyses have included a credit for plutonium since the 1950's, and today's light-water reactors receive a plutonium credit of about 0.2 mill per kilowatthour. This value has been supported in the United States by the Atomic Energy Commission's guaranteed buy-back, which has been used to supply various research and development requirements and provide for demonstration programs.

But in December 1970, the guaranteed government buy-back of plutonium ended. As more reactors come on the line in the 1970's, substantial quantities of plutonium over and above any requirements for breeder reactor development will become available.

An estimate of the plutonium that will become available annually at the reprocessing plants is shown in Fig. 1. The estimated requirements for breeder development and for early commercial breeders have been subtracted from the total plutonium available, so Fig. 1 represents net fissile plutonium available each year for light water reactor recycle.

There has been a significant delay in the initial plutonium recycle fabrication load from earlier forecasts. The Edison Electric Institute (EEI) Phase I Study (1968) predicted a 200-tonne/year* U.S. recycle fabrication load in 1973. But as a result of subsequent delays in reactor plant construction and orders, it is now estimated that the total U.S. plutonium fabrication load will not even reach 100 tonnes/year until 1975. However, no further delays seem likely in this initial plutonium fabrication load because it is essentially independent of reactors starting up after early 1971.

The plutonium available for recycle will increase appreciably during the 1975-80 period. Each large reactor (800-1000 MWe) generates 150 to 200 kilograms of fissile plutonium annually. At $8 per gram, there will be $130 million worth of plutonium discharged from U.S. reprocessing plants for recycle in 1980 alone. In other words, in 1980, U.S. recycle fabrication load will be more than 500 tonnes/year* or five times the predicted 1975 load.

Present estimates are that the first large-scale commercial fast breeder reactors will go on the line during the mid-1980's. If so, the requirements for fast-breeder inventories will not become a substantial factor in the plutonium market before the early 1990's.

From Fig. 1, it can be seen that without recycle, 160 tonnes of fissile plutonium would accumulate through 1984 (area under the curve). This material would be worth more than $1.2 billion at $8 per gram value. It would clearly be an uneconomic proposition to stockpile such large amounts of plutonium for an extended period of time.

Although the economic significance of plutonium recycle starting in the mid-1970's is generally recognized, the preparations required for developing the necessary recycle capability are not as fully appreciated. One reason for the lack of concern is that future mixed-oxide fuel assemblies will contain less than five percent plutonium oxide, the remainder being uranium oxide. However, that seemingly low figure for plutonium is misleading because plutonium recycle poses a set of problems for which solutions do not automatically result from uranium-fuel experience. Those problems can be grouped in the categories of design, fabrication, and licensing. Significant effort has already gone into solving these problems, and more will be required.

*Metric tons of fuel (U + Pu) assuming a 3-percent fissile plutonium enrichment.

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(since July 1970), the program has two basic objectives: To demonstrate performance of mixed-oxide fuel at linear power and burnup levels consistent with modern PWR technology; and to obtain design information on depletion and transuranic isotope generation characteristics of plutonium fuel at higher burnup.

An extensive Core II post-irradiation program was completed in early 1970. The peak burnup evaluated was 29,000 megawatt days per tonne (MWd/t). Saxton has continued to operate satisfactorily since starting Core III power operations in December 1969. Since then a significant number of plutonium rods have operated at 19 kW/ft. Currently, peak burnup for the mixed-oxide fuel is about 44,000 MWd/t.

By late 1971, the Saxton plutonium fuel should achieve 50,000 MWd/t peak burnup and will have demonstrated the peak power and burnup levels required for modern PWRs.

Plutonium Utilization Study[2]

The next part of the overall program was the EEI-Westinghouse Plutonium Utilization Study combined with the ESADA-Westinghouse Critical Experiments (1966-68). This EEI Project RP72 Phase 1 program was primarily an analytical feasibility study of the technical and economic parameters influencing the use of plutonium in a PWR. These studies dealt with nuclear parameters, fuel fabrication, fuel cycle analyses, physics methods development, and nuclear design.

The subjects emphasize the diverse nature of the individual programs that are being fully developed in preparation for commercial plutonium recycle. For example, physics methods development in the EEI Phase I Study centered on the analyses of eleven ESADA critical experiments conducted by Westinghouse in 1966. As a result, the initial criticality of plutonium-fueled PWRs can now be calculated as accurately as for uranium-fueled systems. Physics method development work, however, which includes analyses of depletion characteristics and transuranic isotope generation data from the high-burnup Saxton fuel, must be continued.

The Plutonium Utilization Study also concluded that adequate control rod worth and power distribution control are the principal concerns in plutonium recycle applications.

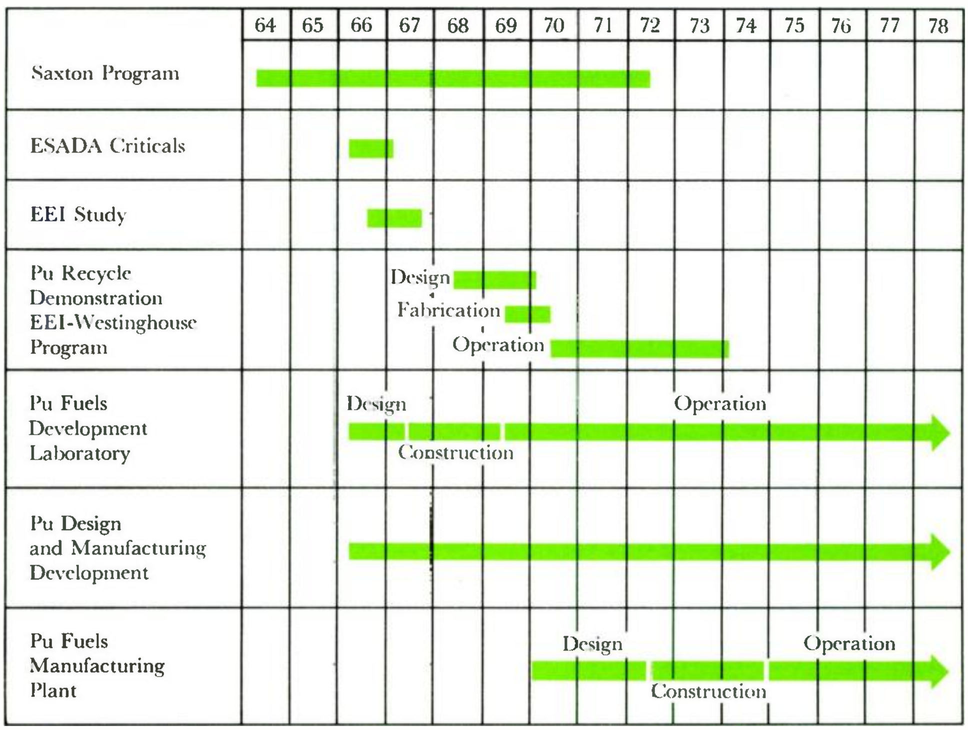
Plutonium Recycle Demonstration Program[3]

After the Phase I Study, the next step was to demonstrate plutonium recycle in a large PWR of today's design. To accomplish this, the EEI-Westinghouse Plutonium Recycle Demonstration Program has been undertaken (EEI Project RP-72). The purpose of this program is to license, operate, and evalute a representative number of plutonium fuel rods in the San Onofre reactor. This demonstration experience under actual utility operating conditions will complement the material and design recycle information being generated in the Saxton test reactor. In order to achieve a meaningful demonstration, Westinghouse first determined the characteristics of future commercial recycle fuel, and then selected a prototypical recycle configuration for the demonstration fuel. To accomplish these design tasks (Preliminary Region Design and Demonstration Assembly Design), Westinghouse utilized proprietary codes developed outside this program for normal PWR reload fuel applications.

In mid-1968, Westinghouse started the Preliminary Region Design effort for this program. Technical and economic comparisons of various recycle methods were made for a large PWR of the Indian Point Unit 2 design. The comparisons included core power distribution calculations, plus an in-depth analysis of reactivity coefficients and control requirements.

The primary Region Design and the previous Phase I Study indicate that commercial PWR recycle fuel can be expected to have these characteristics:

1) A reload region having the same mechanical design for both the plutonium recycle and the enriched uranium fuel assemblies;



2— Plutonium recycle program schedule.

2) The plutonium recycle assemblies for PWR reload regions consisting entirely of mixed-oxide fuel rods; and

3) A minimum of three different plutonium enrichments in each recycle assembly. (These multienrichments are required to provide the necessary power distribution control—solving the problem reported in the earlier EEI Phase I Study.)

The above characteristics should maximize plutonium recycle capabilities for a specific PWR. However, each reactor has different reactivity requirements, available rod worth, and associated recycle capabilities. Therefore, each reactor will require additional analyses to investigate fuel management techniques, modes of operation, and control capability.

The demonstration assembly design included the necessary studies in nuclear, thermal-hydraulic, and mechanical design. These were carried out in parallel with that for the first reload uranium fuel (region 4) for San Onofre. The demonstration assembly design configuration was selected to be prototypical of future commercial recycle fuel. As a result, each of the four demonstration assemblies consists entirely of mixed-oxide fuel rods and has three different plutonium enrichments. This enrichment pattern is shown in Fig. 3.

In April 1970, Westinghouse completed fabrication of the 720 plutonium-bearing Zircaloy-clad fuel rods required for these assemblies. The plutonium rods were fabricated in the Westinghouse PFDL starting with plutonium nitrate leased from the AEC. In August 1970, the demonstration assembly fabrication was completed when the assemblies were shipped as part of the San Onofre Region 4 reload fuel.

The four demonstration assemblies were loaded in the San Onofre reactor in October and the reactor returned to full power on November 21, 1970. The current reactor loading pattern is shown in Fig. 4 with the demonstration assemblies located in the four corners. The demonstration assemblies will be operated during three reactor cycles. Periodic measurements and tests will be made as a check on analytical predictions. At the end of their first and second cycles (the second and third San Onofre cycles), selected plutonium fuel rods will be removed, examined, and returned to the core. Some of these rods will be replaced and then shipped from San Onofre for post-irradiation examinations.

The planned locations for the demonstration assemblies during the San Onofre third cycle, which begins in early 1972, are shown in Fig. 5. This quarter-core representation illustrates the typical checkerboard loading pattern for PWRs. The irradiated region 4 (including the demonstration assemblies) and region 3 fuel assemblies are positioned in a checkerboard pattern inside the core. The fresh region 5 fuel assemblies are located on the outside of the core for cycle 3 operation.

The four San Onofre demonstration assemblies contain 45 kilograms of plutonium, five times the current Saxton loading, which had previously been the largest U.S. commercial application of recycle plutonium.

Other Westinghouse Plutonium Development Programs

An essential part of our overall plutonium recycle program is the proprietary work being conducted by Westinghouse. This design and fabrication development work is required to integrate the overall recycle program. For example, the design data from high burnup Saxton fuel will be used to improve nuclear codes and techniques. This includes additional materials evaluation of Saxton fuel which the AEC made available for industry purchase. During 1971-74, Westinghouse will fabricate plutonium fuel reload assemblies in PFDL. Besides providing utility customers with early commercial recycle fabrication during this period, it will allow check-out of advanced equipment and processes.

The final element in the overall program is the development, design, construction and operation of the Westinghouse Plutonium Fuel Manufacturing Plant (PFMP). Experienced personnel, who are currently designing this facility, will form the nucleus of the factory which should start full scale production in 1975. The project is on schedule, and is cur-

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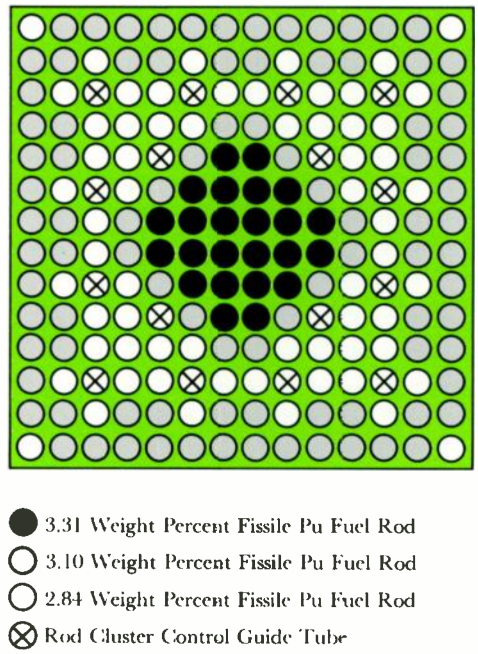
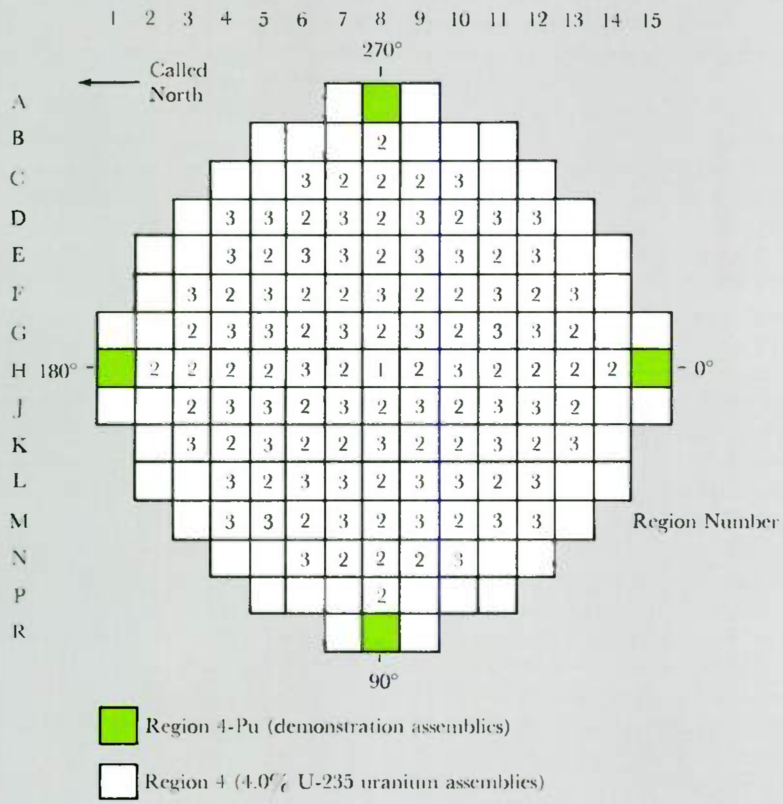


3—Enrichment pattern for demonstration assemblies.

4—San Onofre current (Cycle 2) loading pattern.

5—San Onofre Cycle 3 nominal relative power at beginning of life.

4



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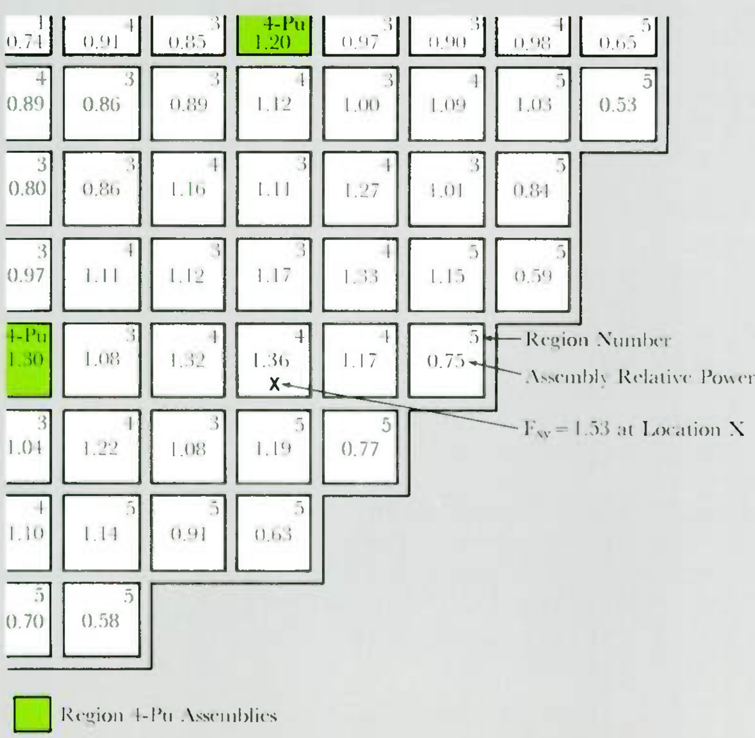

rently in the preliminary design and final development stage.

Conclusion

In summary, commercial plutonium recycle capabilities must be available starting in 1975 when the first significant amount of plutonium is available for recycle. However, plutonium recycle presents a set of problems for which solutions have not been provided by uranium experience. Much has been accomplished to solve these problems by joint industry-utility-government programs, but there is much to do which is not within the scope of these programs. An integrated, overall development program, such as the one being conducted by Westinghouse, is essential to achieve commercial plutonium recycle.

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[1]Saxton Plutonium Program. Semi-Annual Progress Reports. Westinghouse Electric Corporation. *WCAP-3385-1* through *WCAP-3385-24*. 1965-1970. USAEC Contract AT(30-1)-3385.

[2]Economic Utilization of Plutonium in Pressurized Water Reactors. Final Report. EEI Project RP-72. Westinghouse Electric Corporation. *WCAP-7160*. February 1968.

[3]Plutonium Recycle Demonstration Program. for the period ending December 1970. J. Haley. EEI Project RP-72. Westinghouse Electric Corporation. *WCAP-4167-2*. February 1971. EEI Project RP-72. USAEC Contract AT(30-1)-4167.

Fuel for Fast Test Reactor Being Developed in Pilot Line

Methods are being worked out for large-scale manufacture of mixed plutonium- and uranium-dioxide fuel.

One of the basic parts of the U. S. Atomic Energy Commission's Liquid Metal Fast Breeder Reactor (LMFBR) program is development of mixed plutonium- and uranium-dioxide fuel for the Fast Test Reactor (FTR). Consequently, fuel-fabrication development work is in progress at the Fast Flux Test Facility (FFTF) pilot line at the AEC Hanford Project, Richland, Washington.* The facility is operated by WADCO Corporation, a subsidiary of Westinghouse.

The present FTR fuel design consists of subassemblies containing 217 fuel pins, which are about 7½ feet long and contain a 3-foot column of the mixed-oxide fuel pellets (approximately 144 pellets). Development work at this time consists mainly of devising pellet-forming processes to meet specifications for such pellet qualities as density, homogeneity, ratio of oxygen to metal, grain size, porosity distribution, fissile content, impurity level, gas and moisture content, and surface condition. The specified ratio of oxygen to metal is 1.970 ± 0.020, and required pellet density is in the range of 87.3 to 93.5 percent of theoretical.

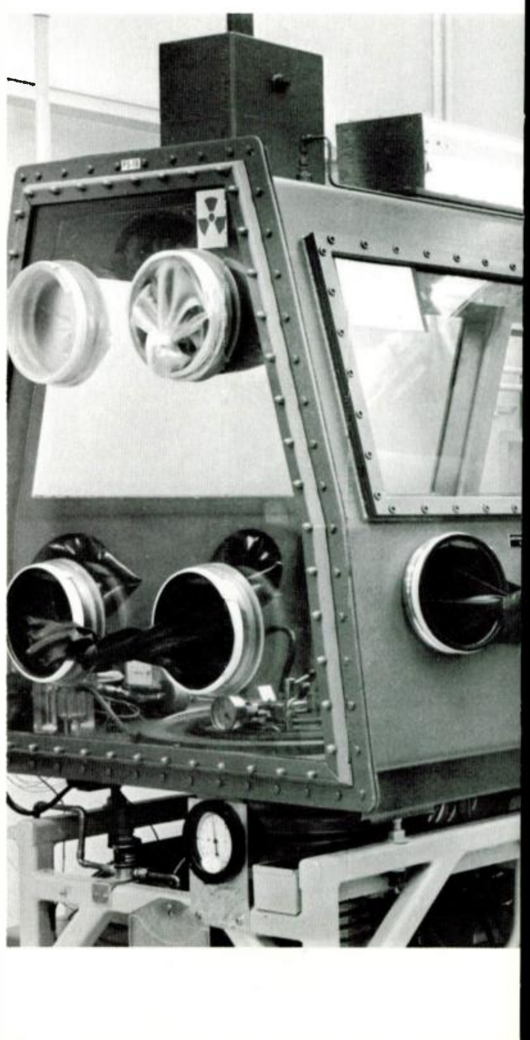
The present pellet design diameter is 0.1945 ± 0.015 inch. Length is to be selected within the range of 0.205 to 0.283 inch, with a tolerance of ± 0.020 inch on the selected length.

Conventional ceramic processes are being used to fabricate the prototype fuel pellets. They include mechanically mixing the plutonium and uranium dioxides, adding an organic binder, prepressing, granulating, cold pressing into pellets, removing the binder, sintering the pellets, and centerless grinding if necessary.

Because plutonium is toxic, all plutonium-oxide processing steps are performed inside gloveboxes maintained at a negative pressure with respect to the ambient atmosphere. Among the equipment adapted for glovebox use is the automatic hydraulic press shown in the photograph. For ease of operation and servicing, the controls, pump, and fluid reservoir are located outside the glovebox, with hydraulic and electric lines passing through the wall to the press. This press is used both to prepress half-inch-diameter slugs with pressures in the 50,000-psi range and then to form fuel pellets with pressures in the 30,000-psi range. This prepressing at high pressure followed by granulation and pellet forming at lower pressure has been the most successful technique evaluated to date for producing pellets with the desired density.

Exposure to gamma and neutron radiation can best be controlled by minimizing

1—*(Above)* **Prototype fuel pellets for the Fast Test Reactor consist of mixed plutonium and uranium dioxides. Processes are being developed to mass-produce pellets with the required physical properties.**



2—*(Right)* **Gloveboxes enclose the hydraulic press and sintering furnace used to make pellets at the fuel-fabrication demonstration facility. The boxes prevent escape of fuel materials.**

*E. R. Astley and J. C. R. Kelly, Jr., "Fast Flux Test Facility for Developing Breeder Reactor Technology," *Westinghouse ENGINEER*, Nov. 1969, pp 162-9.

H. T. Blair is a development engineer at WADCO Corporation, Richland, Washington.

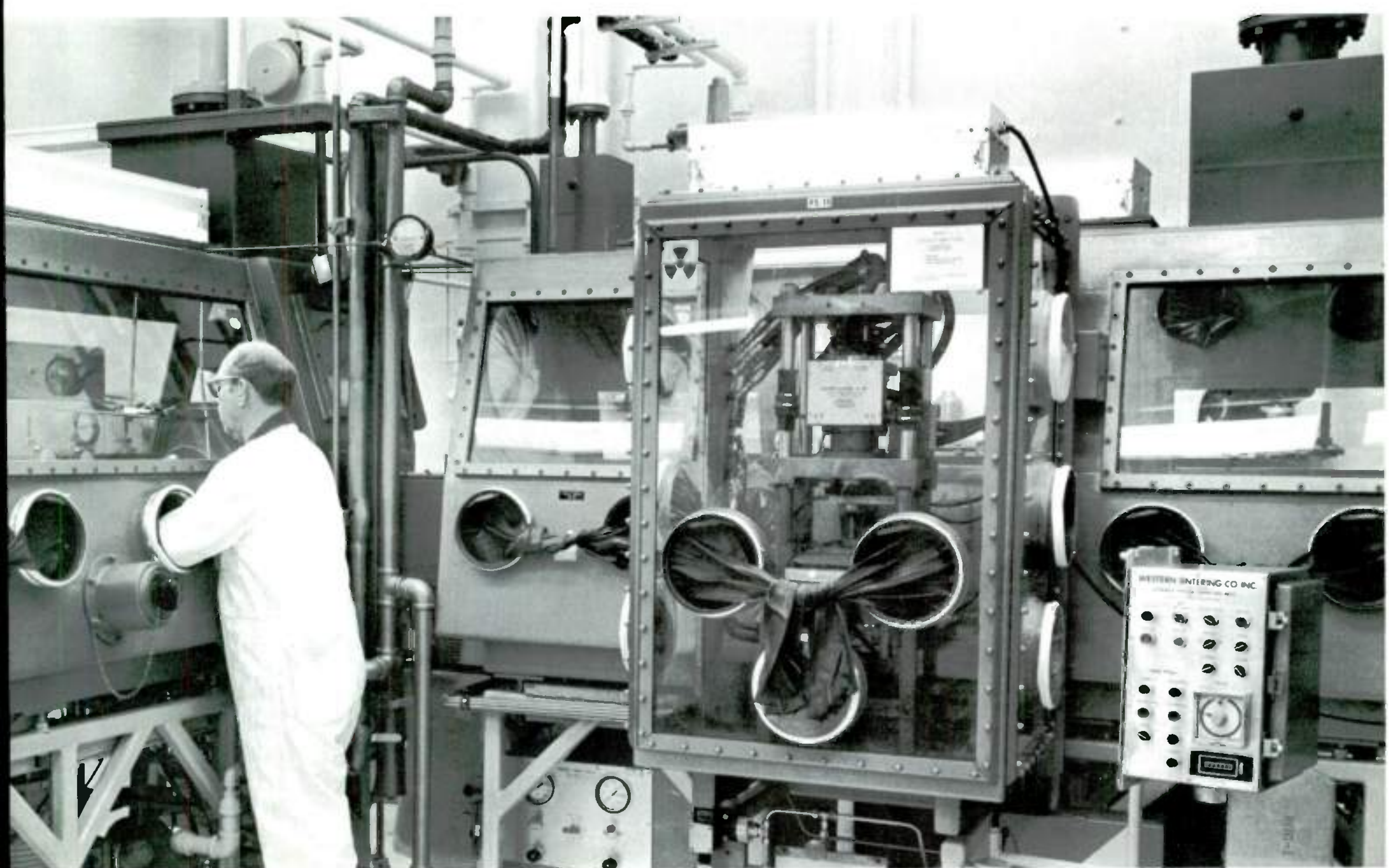
hand operations and reducing oxide dust accumulation on glovebox surfaces, so mechanization and automation are being emphasized. Semiremote techniques will be required in the future to fabricate fuel from materials recovered from spent breeder-reactor fuel because of the accumulation of heavy-isotope radioactivity in those materials.

Measures taken to prevent accumulation of a critical mass of fissile material in the pilot facility include the setting of mass limits on glovebox fissile-material and moderator content, fissile-material spacing, and container volume. (Without these precautions, such process materials as water and organic binders could act as moderators and, theoretically, permit a chain reaction to occur if a critical mass were allowed to accumulate.) These limits make batch processing most practical at present, but continuous processing is feasible with complete mechanization, careful control of moderators, and control of the volume and spacing of process equipment.

A computerized data system is being developed to monitor the movement of all fissile material in the pilot facility for both criticality control and accountability purposes.

The need to control moderators also affects the design of the vacuum sintering furnace used: its cooling coils are on the exterior shell to prevent any break in the coils from filling the furnace with water. The cooling coils on the lid of the furnace are the only coils inside the glovebox, and they are supplied with water from a closed recirculating cooling system of known volume. The furnace is used to sinter pressed fuel pellets at 1700 degrees C in a dynamic reducing atmosphere of argon and hydrogen, and for outgassing the sintered pellets at 850 degrees in a vacuum to control their gas and moisture content.

The technology being developed in the pilot facility, and in supporting research and development programs, ultimately will be adapted to large-scale commercial manufacture of fuel in support of the FFTF. A need of approximately 20,000 fuel pins a year is anticipated for the FFTF program.



Motors for Vibratory Applications

Z. A. Tendorf

Shaker motors have their particular application principles that, when followed, provide both trouble-free service and effective utilization of the vibratory force that is produced.

Electric motors ordinarily are built to be as free as practical from vibration, but one type of motor is built to allow shaft unbalance for the specific purpose of producing vibration. This is the shaker motor, also known as exciter motor.

Shaker motors are used to impart a desired exciting force and frequency to various kinds of vibrating equipment, including feeders, conveyors, shake-out screens, hoppers, grinders, finishers, and mixers. Vibrating equipment provides a more positive flow of the material being handled than gravity feed does, especially when the material is sticky, and it often can perform jobs that would be difficult for other kinds of conveying and feeding equipment.

For example, the equipment can readily be designed to handle very hot materials, such as fresh iron castings, and abrasive materials such as sand, steel scrap, rock, and coal. (One application is shake-out screens that separate hot castings from the sand used for molds.) The equipment can withstand heavy impacts, and materials can be dried or cooled (even water quenched) while being conveyed. Dust-tight covers are easily added to the vibrating "pans" that support and convey the material being handled.

A shaker motor is basically a squirrel-cage ac motor, but with its shaft extended at each end and an eccentric weight attached to each shaft extension. Bearings and other features also may differ considerably from those of ordinary motors, depending on the type of duty the shaker motor is intended for. In addition to this common type of shaker motor, a new "vibration energizer" is being developed to provide unbalance ratings considerably beyond what has heretofore been feasible.

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There are two basic approaches to the design of vibrating equipment: the brute-force approach and the resonant, or natural-frequency, approach.

Vibratory Systems

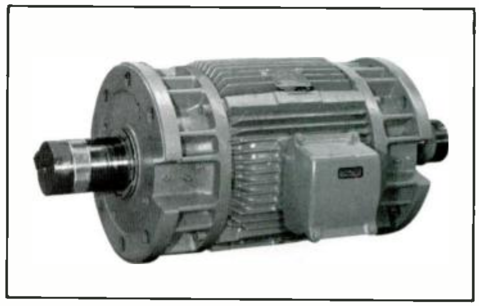
Brute-Force Design — In this approach, almost all of the force necessary to vibrate the equipment is derived from the shaker motor. The motor is attached directly to the vibrating equipment, which is supported on springs that isolate the equipment from the floor or support structure. (See *Vibration Principles,* following pages.)

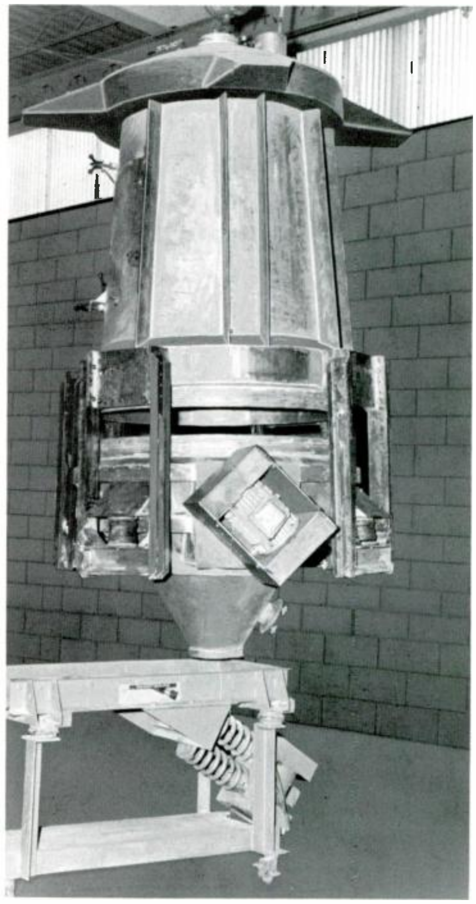
The brute-force design can be subdivided into two categories: free-free and partially restrained.

In a free-free system, there are no restrictions on motion in the *X-Y* plane; that is, a point on the shaker motor or on the vibrating equipment has a circular or elliptical motion as in the example of Fig. 1 in the "box." Free-free systems are used for such equipment as gyratory hoppers, grinders, and finishers.

In a partially restrained system, motion is made rectilinear by rotating two eccentrically loaded shafts in opposite directions as shown in the diagram. The shafts may be geared to a single drive motor, or they may be the shafts of two synchronized shaker motors. In the latter method, variations in the motion produced can be had by choice of the mounting angle of the shaker motors and their position with respect to the center of gravity of the system. Hoppers and shaker screens are typical applications.

Resonant Design—In this approach, coupling springs (commonly called reactor or magnification springs) are employed, and isolation springs may or may not be used. Resonance or near resonance is achieved by designing the spring system in such a way that the natural frequency of the vibrating mass with its spring system is equal to the frequency of the driving force. The principal advantage is that the driving force is amplified and thus produces the desired amplitude of motion at lower applied force; therefore, lighter-duty motors can be used than would be needed for equivalent brute-force systems.





Top—Standard heavy-duty shaker motor is a totally enclosed nonventilated ac motor with special bearings and shaft. This one is rated 7.5 hp, 900 r/min, 30,000 pounds maximum total centrifugal force. The shaft is extended at both ends for attaching two unbalanced weights.

Bottom—Two heavy-duty shaker motors are mounted on the hopper in a brute-force configuration to shake material down through it. The feeder below the hopper is a two-mass resonant system, its light-duty shaker motor coupled to the pan by reactor springs. (Photo courtesy Carman Industries, Inc.)

Resonant designs can be classified as single-mass/spring systems or as two-mass systems with the masses coupled by reactor springs.

Single-mass/spring resonant systems have the shaker motor attached directly to the vibrating equipment, as in brute-force systems, but the unit is mounted on a stiffer reactor spring system instead of on the soft isolation springs (see Fig. 2). There are many reactor springs in parallel along the conveyor, each handling a fraction of the force. Thus, the vibrating force is distributed along the length of the pan, and that is the main advantage of the system. Long conveyors are typical applications.

Two-mass resonant systems employ two vibrating masses—the pan and the shaker motor (Fig. 3). The two are coupled with reactor springs, and the entire system is supported on isolation springs from one of the masses (normally the pan). This excitation method is often used for feeders.

Two-mass systems are further subdivided into fixed-feed-rate and adjustable-feed-rate types.

A *fixed-rate* feeder is set ("tuned") at the desired magnification level, which is the factor by which the spring force is amplified by the system's resonance. The system is so designed that headload (the weight of the material being handled) is not likely to detune it.

Adjustable-rate feeders have provision for control of the stroke (the double-amplitude length of motion). Control can be effected by at least three methods—variable exciting frequency, variable spring rate, and variable exciting force.

For variable exciting frequency, the feeder coupling spring is designed to operate at or near resonance when the shaker motor is running at maximum speed at full applied voltage; when applied voltage is reduced, the motor "slips," that is, it reduces speed because motor torque decreases as the square of the applied voltage. The reduced shaker frequency causes simultaneous change in stroke and frequency as the feeder is detuned (Fig. 4).

The squirrel-cage ac induction motor is not overheated at reduced voltages under load. As will be shown later in the section on motor power and torque, the most work is done by the motor when the system is in resonance; as it departs from resonance, less motor horsepower is required.

The simplest way of varying voltage to the shaker motor is by use of an autotransformer. The more sophisticated method is SCR solid-state control, which allows only a portion of the full sine wave of the ac voltage to pass through to the motor. Since the timing of an SCR's firing can be controlled to microseconds, the solid-state system gives not only accurate voltage control but also ability to follow variable process signals. It is applicable to such jobs as bag filling, where both feed rate and cutoff can be controlled by the changing weight of the bag being filled.

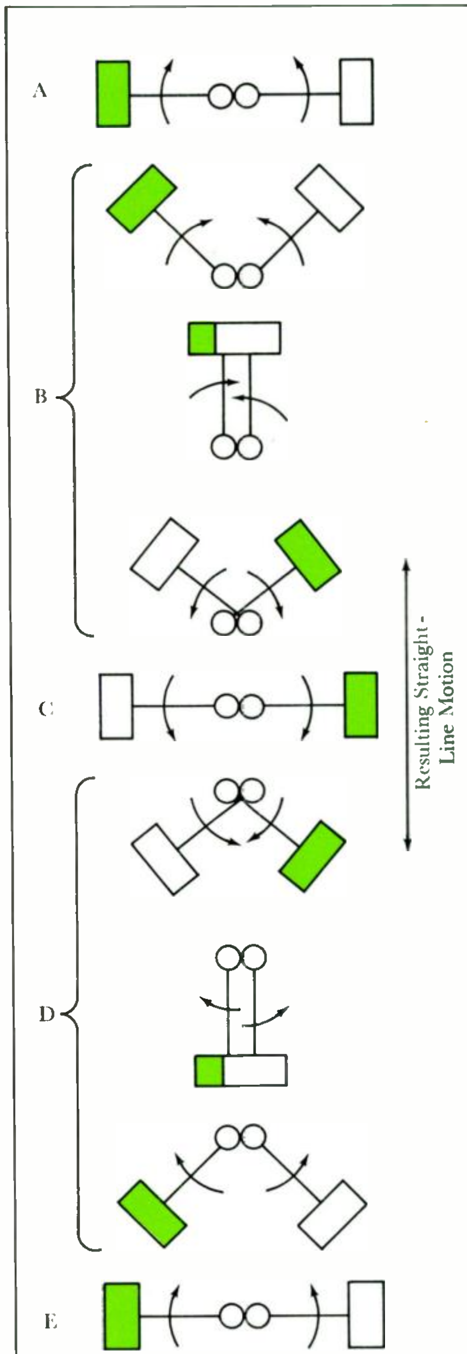
Variable spring rate is accomplished by use of pneumatic springs as the resonant coupling medium. Air pressure control accurately varies the spring rate (stiffness). The change in spring rate alters the natural frequency of the system, resulting in a change in stroke and a consequent change in feed rate.

Variable exciting force is achieved by adding unbalance weight to, or subtracting it from, the exciter shaft. The method used is movement of mercury in the weights by regulated air pressure. Feed rate changes linearly in response to the air pressure control. Like the SCR variable-frequency system, this one is easily adaptable to control for a variable process by means of signals from the process.

Shaker Motors

A shaker motor is basically a totally enclosed nonventilated squirrel-cage

Text continued on page 78.



A	Weights (and centrifugal forces) opposed. No motion produced.
B	Forces in common direction produce motion in that direction.
C	Forces opposed. No motion produced.
D	Forces in common direction produce motion in that direction.
E	Forces opposed. No motion produced.

Motion is limited to a linear direction in the partially restrained type of brute-force system, instead of being circular or eliptical as it is in the free-free type. Two eccentrically weighted shafts are rotated in opposite directions, synchronized so that system motion is possible only in the directions of the resultant forces; all other force components are mirror reflections and so cancel each other.

Vibration Principles

Brute-Force Design—The shaker motor is attached directly to the vibrating equipment, which is supported on isolation springs. Centrifugal force developed by the eccentric weight excites vibration at forced oscillating frequency, ω_f. This frequency is the speed of the motor and is always more than two times the highest resonant frequency of the vibrating equipment.

An ideal brute-force design can be represented by a single-mass/spring system (Fig. 1). The differential equation for the vibration in the X direction of a symmetrical system is

$$M\frac{d^2x}{dt^2} + C\frac{dx}{dt} + Kx = F\sin\omega_f t, \qquad (1)$$

where M is the mass of the vibrating system, x is displacement at time t, C is the coefficient of damping, K is the spring rate constant, $(d^2x)/(dt^2)$ is acceleration in the X direction, and $(dx)/(dt)$ is velocity in the X direction. F, the magnitude of the force necessary to sustain mechanical oscillation, is given by

$$F = me\,\omega_f^2, \qquad (2)$$

where m is mass of the eccentric weight, w, e is length of the arm from the center of rotation to the center of gravity of the eccentric weight, and ω_f is, as before, rotational speed of the motor shaft (in radians per second).

Thus, equation 1 becomes:

$$M\frac{d^2x}{dt^2} + C\frac{dx}{dt} + Kx = me\,\omega_f^2\sin\omega_f t. \qquad (3)$$

The complete solution of this equation is given in any textbook on differential equations or on vibration. Of interest is the steady-state amplitude, A, of the forced vibration since that is the useful parameter. The relationship of A to the other system parameters can be written in the following nondimensional form, which is known as the transmissibility (tr) equation:

$$tr = \frac{AK}{F} = 1\Big/\sqrt{\left[1-\left(\frac{\omega_f}{\omega_n}\right)^2\right]^2 + \left(\frac{C}{M\omega_n}\frac{\omega_f}{\omega_n}\right)^2} \qquad (4)$$

where ω_n (which is equal to K/M) is the undamped natural frequency of a single-mass/spring system and $C/M\omega_n$ may be regarded as a damping factor. The plot of this transmissibility equation in Fig. 1C shows that, for $\omega_f/\omega_n > 2$, tr approaches zero. This means that only a small fraction of the force, F_{tr}, is being transmitted into the foundation, which is the desired condition. ($F_{tr} = F \times tr$.)

Equation 4 may be rewritten in the following form to provide a design relationship for calculating the amount of unbalance needed to obtain the desired motion:

$$\frac{MA}{me} = (\omega_f/\omega_n)^2\Big/\sqrt{\left[1-\left(\frac{\omega_f}{\omega_n}\right)^2\right]^2 + \left(\frac{C}{M\omega_n}\frac{\omega_f}{\omega_n}\right)^2}. \qquad (5)$$

From Fig. 1D, which is a plot of equation 5, it is readily seen that, for a ratio of forcing frequency (ω_f) to natural frequency (ω_n) greater than two, the ratio of MA/me approaches 1. This is a very useful design relationship for single-mass/spring brute-force systems:

$$(MA)/(me) = (WA)/(we) \cong 1, \qquad (6)$$

where W is the effective weight of the vibrating system and we is the amount of unbalance (in lb-in.) needed to obtain the desired amplitude of vibration.

Resonant Design—The single-mass/spring resonant system differs from the brute-force design mainly in having a reactor spring system (Fig. 2). The same equations of motion apply (3, 4, and 5). Equation 4 is also the magnification-factor equation:

$$MF = A/(F/K).$$

A two-mass resonant system has the pan and shaker motor coupled by reactor springs (Fig. 3). Vibrating force from the shaker motor is magnified by the coupling spring because of the system's resonance.

A *fixed-rate feeder* of that type is tuned at some magnification level (Fig. 3C). The pan is usually made two to three times heavier than the motor so headload will be applied to the heavier mass; detuning of the system then is less likely to occur. Since amplitudes are inversely proportional to weights, it follows that the motor may move at two to three times the amplitude of the feeder pan. However, both weights vibrate at the same frequency.

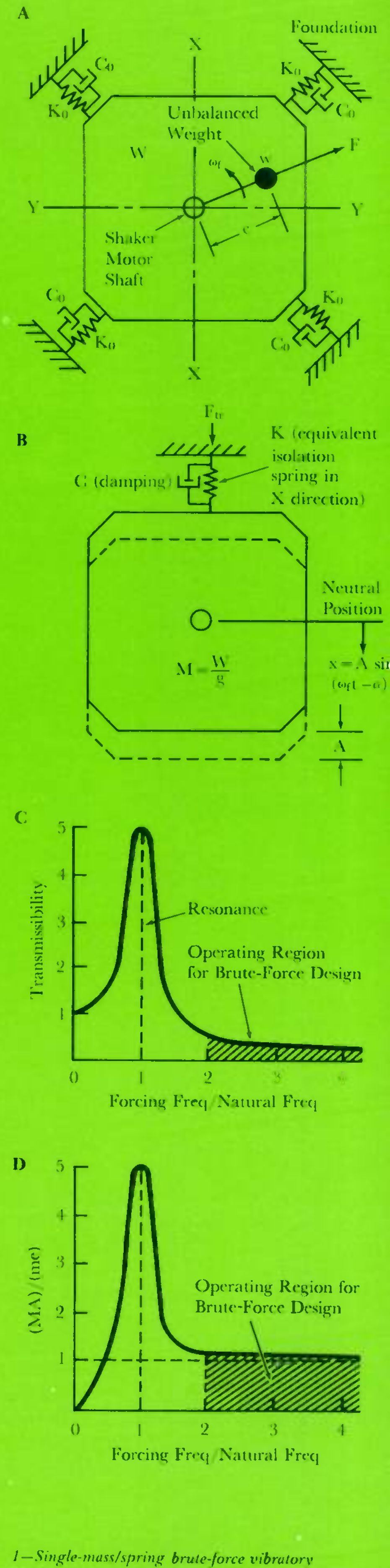
If the isolation spring in Fig. 3 is eliminated in an ideal system's analysis ($K_0 = 0$), the effect on the higher-mode natural frequency is negligible. This unsupported two-weights-one-spring system hanging in space would approximate the natural frequency equation for the vibratory feeder:

$$\omega_n = \sqrt{[K/(W_1/g)] + [K/(W_2/g)]}, \qquad (7)$$

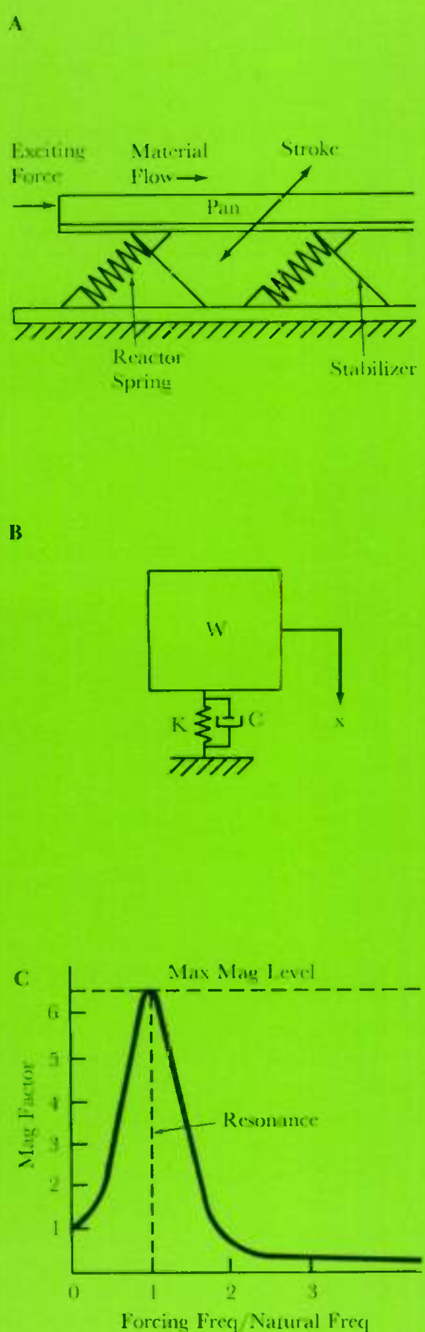
where K is the rate constant of the reactor spring coupling the two weights, W_1 is weight of feeder pan plus effective headload, W_2 is weight of the motor, and g is earth gravity. Equation 7 shows that the lighter mass has considerably greater effect on natural frequency, so any change in it would alter the ratio of exciting force frequency to natural frequency (ω_f/ω_n) of the system and at the same time the feed rate.

If the system operates in the subresonance region ($\omega_f/\omega_n < 1$), any additional headload assures a nearly constant feed rate. The reason is that the additional load in the denominator of the natural-frequency equation results in decrease of natural frequency, so the ratio of the exciting force frequency to the natural frequency increases in the direction of larger magnification factor (for example, from 5 to 6 in Fig. 3C). The larger magnification factor, when applied to the constant exciting force, results in maintaining a nearly constant stroke (and thus nearly constant feed rate) under the increased headload. If the system were to operate in the superresonance region, the magnification level would be on a down slope and feed rate would decrease under additional load. Therefore, the subresonance region is commonly used.

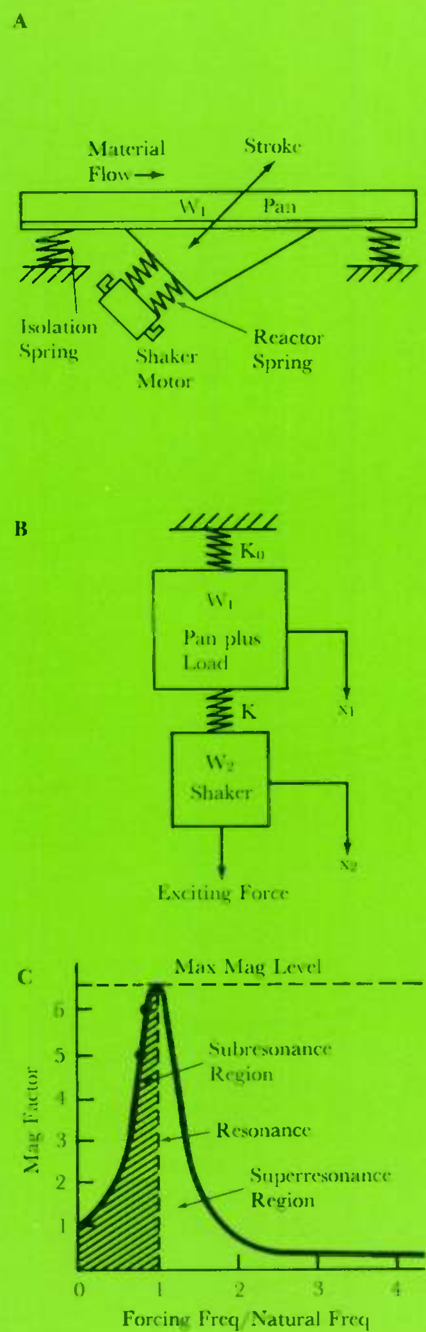
An *adjustable-rate feeder* is similar except for having provision for detuning the system to reduce stroke and frequency and thus reduce the rate at which material is moved. Variable exciting frequency is one detuning method used (Fig. 4). It is achieved by reducing motor speed by voltage control. Fig. 4A is similar to Fig. 3A except that it shows the important phase angle relationships. Fig. 4B shows typical ac motor speed-torque curves, plus torque demand curves for different percentages of rated voltage. Phase angle relationships (Fig. 4C) are shown as functions of a system's response in terms of magnification factor (Fig. 4D) for three typical damping factors.



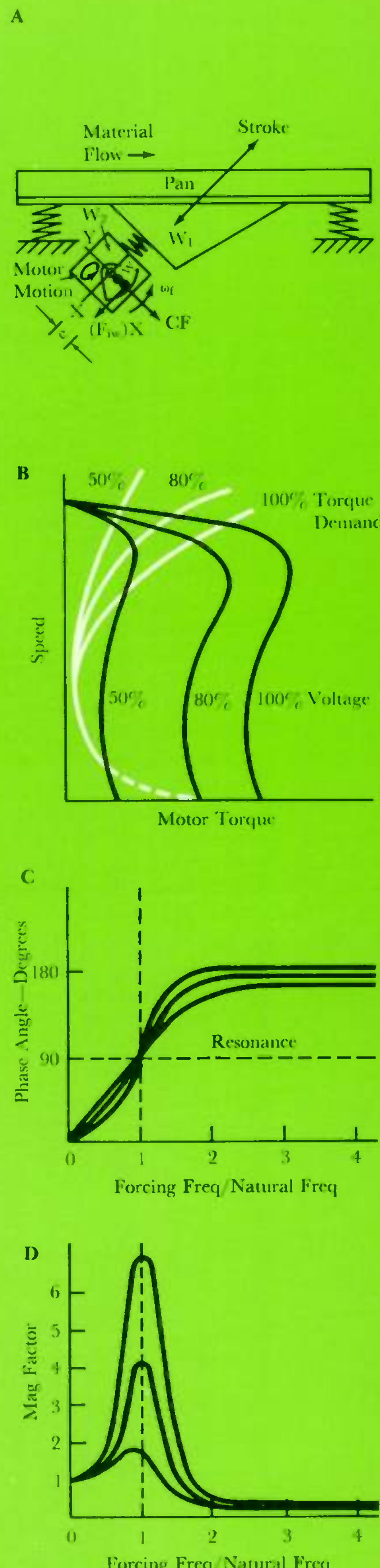
1—Single-mass/spring brute-force vibratory system. The model vibrates in the X-Y plane.



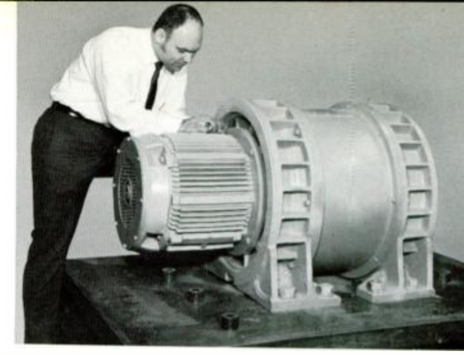
2—Single-mass/spring resonant system.



3—Two-mass resonant system with masses coupled by reactor springs.



4—Variable-frequency method of varying the stroke in a two-mass resonant system.



A new type of vibration energizer is being developed to provide more unbalance force than is feasible with the standard shaker motor. In the laboratory installation shown, the energizer was mounted on a steel table supported by isolation springs. The ac motor in the energizer was equivalent to a 324T TEFC motor rated 20 hp, 900 r/min; total weight of energizer and table was about 12,500 pounds. Steady-state stroke was about half an inch.

ac induction motor, but with special (rather than NEMA standard) double-extended shaft, bearings, and bearing fits. Those special mechanical features, along with the electrical design, are dictated by the loads on the shaft.

In brief, the motor rotating parts, including the eccentric weights, do not vibrate with respect to the bearing supports; instead, they whip about an imaginary axis at the shaft rotational speed. The principal load, centrifugal force, is a steady undirectional radial load on the shaft—identical to the effect of applying a load of equal magnitude to the stationary shaft. (See *Shaft Loading*, page 79.)

Thus, the radial load on the bearing outer ring rotates around the ring, while that on the inner ring is stationary with respect to the ring. It has been found best with such a load to fit the outer ring tightly in the bearing housing, while the inner ring is fitted loosely on the shaft to permit assembly and to allow thermal expansion of the shaft. If the outer ring were fitted loosely in the housing, the varidirectional load of centrifugal force with respect to that ring would tend to make it first creep in the housing and then rotate, generating heat and spelling bearing disaster.

Two types of shaker motor are presently made by Westinghouse, the heavy-duty type and the light-duty type. (See Table I for rating information.)

The heavy-duty motor is especially constructed to handle heavy mechanical loads. It has relatively large self-aligning spherical roller bearings designed for vibratory equipment, shake-proof hardware, winding and leads protected against chafing, and high starting torque. Heavy-duty motors are generally used in brute-force vibratory systems.

The light-duty motor is designed primarily for use in resonant systems, where mechanical loads are lighter. It closely resembles the standard totally enclosed nonventilated motor, except that shakeproof construction is used. The ball bearings have internal clearances larger than normal to allow for thermal expansion. NEMA B speed-torque performance is usually satisfactory.

Motor Power and Torque

The power required to drive a vibrating system is important to both the designer and the user of the system: to the designer because knowing the horsepower is essential for design of the machine elements and choice of the shaker motor, to the user because power demand per unit production of material largely determines the cost of his process. The motor designer is concerned with the size of the eccentric weight necessary to develop the desired motion. It and the operating speed dictate the type and size of bearings and shaft, as already noted; the size of the eccentric weight is also part of another concern, the maximum inertia that the motor can accelerate without overheating.

The most important consideration, however, is starting and accelerating torque, especially for brute-force applications. Because those applications normally require large unbalance, the exciter motor must overcome considerable resisting torque (due to the unbalanced weight) and then come to speed in a matter of seconds so as to pass quickly through system resonance due to the isolation springs.

Motor losses and the energy dissipated in bearing friction depend on the design and loading and are readily calculable; the energy dissipation can be considerable. On the other hand, power dissipated in hysteresis and friction losses of springs and other machine parts is probably very small (and can be neglected) compared with power consumption due to transporting and working on materials, since all materials have friction (damping) and mass.

Analytical determination of power required to handle materials in vibration is extremely difficult, if not impossible. In the first place, it is difficult to evaluate the effective mass of the working material, i.e., the quantity of mass in contact with the vibratory system and thus affecting its response to periodic oscillation (equation 1). The mass of the material during a portion of each cycle loses contact with the body of the vibratory equipment, posing a very difficult theoretical problem. A second difficulty is the damping: does the material have the characteristics of a Newtonian fluid; that is, must the damping force be proportional to the velocity of motion? Power consumption

Table I—Allowable Loads for Shaker Motors

	Frame Size	Nameplate Horsepower	Maximum Centrifugal Force (lb)*	
			900-r/min Motors	1200-r/min Motors
Light-Duty Motors	184T	1.0	684	621
	215T	2.0	872	792
	256T	5.0	1405	1276
	286T	7.5	1910	1736
Heavy-Duty Motors	184T	1.0	3100	2860
	215T	2.0	6000	5500
	256T	5.0	9000	8200
	286T	7.5	14,600	13,000

*Maximum centrifugal force (CF) permitted on each shaft extension. The values are based on one year (8750 hours) of B-10 bearing life; that is, 90 percent of bearings subjected to the maximum loads should run continuously for one year without fatigue failure. B-10 bearing life (in hours) for loads other than maximum is approximately: $[(\text{Maximum CF from table})/(\text{Actual CF per shaft extension})]^n \times 8750$, where n is 3 for light-duty motors and $10/3$ for heavy-duty motors.

Shaft Loading

Three basic load systems act on the shaft: weight of the rotating parts, centrifugal force of the rotating unbalance, and inertia force caused by vibration.

A typical shaker motor shaft has two identical unbalanced weights, which are in line and symmetrical with respect to two bearing supports. (See figure.) Each weight, w, is eccentric by the amount of e: that is, e is the distance from the axis of rotation to the center of gravity of the eccentric weight. The motor is attached either rigidly or through a coupling spring to a vibrating equipment at a mounting angle, ϕ, from vertical position. The initial or "normal" shaft position is with eccentrics hanging downward due to gravity.

The load on the nonrotating shaft due to weight may be radial or axial, or both, depending on the mounting angle. At mounting angles between 0 and 90 degrees, the radial components of the weights produce steady radial load and the components along the shaft axis produce steady axial load. In addition, the axial component of each eccentric weight produces a steady bending moment:

$$M_B = we \sin \phi.$$

When the motor is running at steady-state full speed, and if for a moment the assumption is made that it is rigidly attached to a body having infinite stiffness (that is, the system does not vibrate), the radial component of any rotating weight still produces steady unidirectional radial load relative to the motor housing, but the load alternates relative to a point on the shaft. In addition, each radial component of unbalanced weight produces an alternating torque, T_w, on the shaft:

$$T_w = we \cos \phi \sin \omega_f t.$$

The axial load, F_a, due to total weight of the rotating assembly, W_{RA}, essentially remains unchanged; that is, its magnitude and direction do not change as functions of speed:

$$F_a = W_{RA} \sin \phi.$$

The rotation of unbalanced weight develops a centrifugal force, CF. This force for any fixed speed, ω_f, is a steady unidirectional radial load relative to a point on the shaft, but it alternates relative to the motor housing:

$$CF = (we/g)\, \omega_f^2.$$

Now, if the vibratory system is free to vibrate (that is, if the shaker motor is coupled through springs to the vibrating equipment and/or the equipment is mounted on isolation springs), the rotating unbalance weight produces vibration of the equipment due to centrifugal force, CF. In addition to the loads already accounted for, inertia force is introduced. This force acts through the center of gravity of any mass subjected to accelerated motion. The magnitude of inertia force, F_{iw}, depends on the mass (weight, w, divided by earth gravity, g), the amplitude of vibration, A, and the square of the speed, ω_f^2:

$$F_{iw} = (w/g)\, A\, \omega_f^2.$$

Inertia force, like centrifugal force, rotates at the shaft speed (ω_f, in radians per second) and produces unidirectional radial load on the shaft. For any fixed speed, the phase angle, α, between inertia force and centrifugal force remains constant. The phase angle and the amplitude depend on the system's response to the excitation. These relationships are further explained in the section *Motor Power and Torque*.

Because of the fixed phase relationship, the inertia force acting on the center of gravity of an eccentric weight can be added vectorially to the centrifugal force developed by it. The resultant force is unidirectional relative to the shaft; that is, the shaft sees the same force as if a static force of the same magnitude were acting on the stationary shaft. The inertia force acting on each eccentric weight, w, depending on phase angle, α, may produce torque, T_{iw}.

$$T_{iw} = (w/g\, A \omega_f^2 \sin \alpha)\, e.$$

In summary, the motor rotating parts including eccentric weights do not vibrate with respect to the bearing supports; they whip about an imaginary axis at the shaft rotational speed. The principal load, centrifugal force, causes steady unidirectional radial load on the shaft, identical to the effect of applying a load of magnitude equal to the centrifugal force to the stationary shaft.

Fundamental Relationships

Bearing Loads—(1) A radial load that is unidirectional relative to a point on the rotating shaft produces a unidirectional inner-ring radial load and a rotating outer-ring radial load.

2) A radial load that alternates in direction relative to a point on the rotating shaft produces a rotating inner-ring radial load and a unidirectional outer-ring radial load.

3) When the radial loads are in phase and symmetrically overhanging at each shaft extension with respect to the bearing supports, the bearing radial load is equal to the overhung load applied at each shaft extension.

4) When the radial load is symmetrically located between two bearings, half the load is carried radially by each bearing.

5) Bearings are so arranged that downward axial load produces thrust on the bottom bearing.

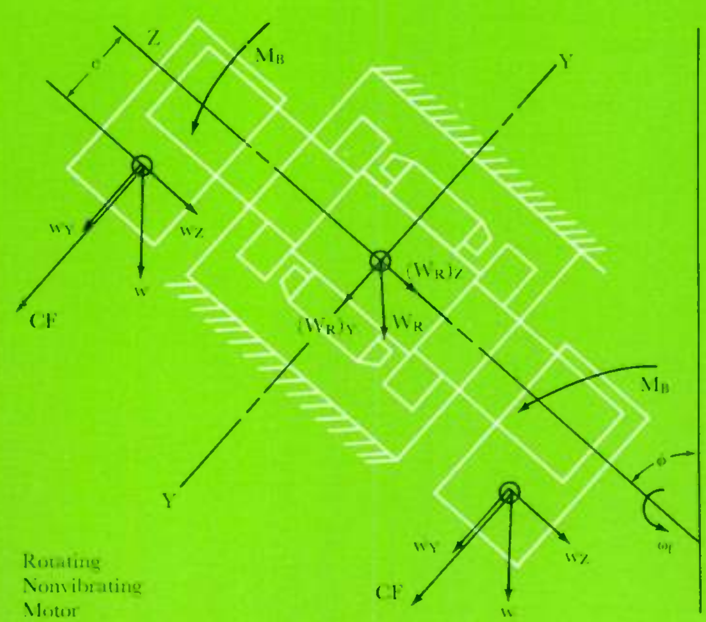
Shaft Stress—With respect to a point on the shaft:

1) Constant-magnitude unidirectional radial loads cause steady bending stresses in the shaft.

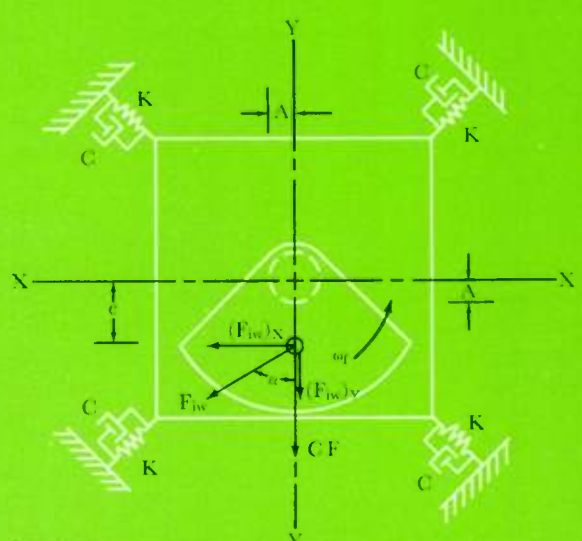
2) Variable-magnitude unidirectional radial loads cause alternating bending stresses in the shaft.

3) Constant-magnitude rotating radial loads cause reversal of bending stresses in the shaft.

Shaft loads may be steady or variable in magnitude and unidirectional or varidirectional relative to a point on the shaker motor's shaft. The selection of shaft and bearings largely depends on the magnitude and direction of the various loads.



Rotating Nonvibrating Motor



End View, Rotating Vibrating Motor

can be determined, but, unfortunately, only by measuring it in actual service.

Since the forcing of the equipment to vibrate arises from rotation of an eccentric weight at a certain motor speed, the vibration frequency of the equipment must be the same as that of the motor shaft angular velocity, ω_f (in radians per second). However, there is a phase difference, α, between rotation of the centrifugal force, *CF*, and the vibrational displacement of the equipment; α is an angle by which the displacement of the vibration lags the force producing the vibration. (See *Shaft Loading*, page 79.)

Damping (friction) in the system causes the lag. Since the inertia force due to vibration of the equipment acting through the center of gravity of each vibrating mass is in the opposite direction to the acceleration of simple harmonic motion, which is at 180 degrees to the displacement, it follows that the inertia force through the eccentric weight lags the centrifugal force by an angle, α. Thus, this inertia force can result in torque, T_{iw}, opposing rotation of the shaft. The amount of opposing torque depends greatly on the frequency ratio, ω_f/ω_n, for a particular system.

In a brute-force system, for example, where $\omega_f/\omega_n > 2$, α approaches 180 degrees (Fig. 4c). The component of inertia force acting on the eccentric weight at right angles to the centrifugal force is negligible and thus does not cause torque. On the other hand, in resonant systems, where ω_f/ω_n is approximately 1 and the phase angle, α, is approximately 90 degrees, the torque due to inertia force caused by accelerated motion of vibration through the center of gravity of the eccentric weight is significant and accounts for the occurrence of maximum load on the shaker motor when at resonance. Since $T_{iw} = (w/g)\ eA\omega_f^2 sin\ \alpha$, the maximum torque is $(T_{iw})_{max} = (w/g)\ eA\omega_f^2$ when α is 90 degrees.

It is now seen why it was said earlier that the shaker motor does not overheat at reduced voltage. As the system is detuned (ω_f/ω_n made less than 1 by variable voltage control), torque demand on the motor is decreased because phase angle, α, and amplitude, A, decrease rapidly, regardless of the value of damping factor, $C/(M\omega_n)$, for small decreases in the ω_f/ω_n ratio.

Finally, the work done to lift the eccentric weight, and the associated change in potential and kinetic energy, can generally be neglected from engineering consideration, although it is considered irreversible because of power dissipated into heat in the motor during the work part of the cycle.

Lubrication

Bearing lubrication is the most difficult and frequently occurring problem in design and application of shaker motors. Bearings have generally been grease lubricated because of design advantages and because of the operating conditions of most shaker motors. The principal design advantage of grease lubrication is the simpler bearing-housing construction that it permits. As for operating conditions, shaker motors are usually mounted vertically or at an angle; mounting angle matters with oil lubrication, but it doesn't with grease.

Westinghouse shaker motors are designed and greased for long trouble-free service. However, the motor manufacturer's recommendations must be followed in regreasing. The most frequent causes of grease lubrication problems are overgreasing or undergreasing, use of improper grease (such as types that are nonchanneling or have low-viscosity oil), relubrication not frequent enough, and loss of lubricant through use of the wrong grease.

Heat generated in bearings can make grease lubrication unsatisfactory, so problems with grease would become serious if bearings were increased in size or speed much beyond present values or if loads became much higher. That is why a new concept in vibration exciters is being developed at the Medium AC Motor and Gearing Division.

New Development

The new product being developed is a self-contained "vibration energizer." It is planned as an extension of the present line of heavy-duty shaker motors, providing unbalance force ranging in small steps from 30,000 to 60,000 pounds.

However, it differs greatly in design from the present shaker motors. It consists of a housing completely enclosing the unbalanced shaft extension and its bearings, and of a totally enclosed fan-cooled motor mounted on one end of the housing. The relatively large housing permits use of large heavy-duty bearings. Moreover, the system is simple in construction because only two bearings support the force developed by the shaft unbalance and also support the motor rotor overhung on the common shaft.

Since the bearings will share approximately 60,000 pounds load at 900 r/min, lubrication is the most important consideration in the development. The load is supported by two spherical roller bearings sized for 10,000 hours of minimum ("B-10") life (the life that 90 percent of a group of bearings will exceed without fatigue failure). The bearings are lubricated by circulating oil to them under low pressure; an oil system was developed to positively control the flow to each bearing regardless of mounting position. The unit can be either foot mounted or double-flange mounted at any angle.

The greater cost of the oil lubrication system is justified. Circulating oil lubrication is ideal for spherical roller bearings: it removes heat rapidly, resulting in lower bearing operating temperature and keeping the oil at the viscosity needed to prevent bearing distress leading to premature failure. Moreover, maintenance requirements are less since there is no need for periodic greasing.

The level of unbalance force provided could be achieved by locating a shaft with unbalance weight in the vibrating equipment and belt-driving it from a motor; however, such an arrangement would lack the new vibration energizer's advantage of being a single unit that can be quickly replaced if trouble develops.

Recent Developments in Low-Light-Level Camera Tubes

A. B. Laponsky
V. J. Santilli

Two major types of charge-storage camera tubes are being applied to a variety of low-light-level imaging tasks. The choice of tube for a given application will be determined by the performance characteristics required.

Advances in electronic imaging were publicized world-wide during the Apollo flights, beginning with Apollo 9, when earth-bound viewers saw televised coverage of life aboard the Apollo command modules and astronaut's views of the moon and the earth. Actually, the Apollo camera systems are just two examples of a number of recent accomplishments in low-light-level imaging made possible by a highly sophisticated television camera tube that uses the SEC (secondary electron conduction) charge-storing and amplifying target. This unique target used with various imaging tube configurations, as shown in Fig. 1, has provided camera tubes for a wide variety of special imaging tasks, ranging from military underwater television systems to ultraviolet mapping of the heavens. Recent development of another charge-amplifying target (called EBS for electron bombarded silicon) provides even further flexibility in the design and application of these ultrasensitive charge-storage camera tubes.

The basic charge-storage camera tube can be considered in three sections: an image section converts the incoming optical image to a focused electron image; a charge-amplifying target changes this electron image to an amplified charge pattern; a readout gun transforms the charge pattern to a video signal for further processing by the television system (Fig. 2).

Additions and refinements to this basic camera-tube configuration provide the particular capabilities required for each application. Image intensifier modules (which are basically additional image sections) can be placed in front of the image section to provide additional light

1—Charge storage camera tube configurations include the following, from top to bottom: electrostatically focused 25-mm camera tubes with SEC target (WL 30691) or EBS target (WX 31792); electrostatically focused 40-mm camera tube with SEC target (WL 30654) or EBS target (WX 31841); magnetically focused 3-inch SEC camera tube (WX 5419B) characterized by superior performance in resolution and geometrical fidelity; electrostatically focused 3-inch SEC camera tube (WX 31366) with image zoom capability of 2 to 1.

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intensification for extremely low-light-level situations; zoom electrodes can be inserted in the image or intensifier sections to provide variable magnification. Gating electrodes can be added to provide electronic shuttering when this feature is required. Image section focusing can be electrostatic or magnetic, depending on the requirements of the application. Two basic types of charge-storage targets, the SEC and EBS, are now available, each with its particular advantages. Special faceplates and photocathodes can be used to transform electromagnetic images from outside the visible range, such as X-rays or ultraviolet, to be used for imaging purposes. The one element that is essentially unchanged for all charge-storage camera tubes is the readout section, which is basically a vidicon gun.

Image Sections

The incoming light image is focused optically on the image section faceplate, activating the photoemissive material (photocathode) on the rear surface of the faceplate. Electrons that come off the photocathode are focused electrically by the image section onto the target, providing an electron density pattern that corresponds to the variations of light intensity on the faceplate.

The conventional image section has an electron trajectory pattern similar to an optical lens in that the image is reversed from input to output. Most camera tubes develop this trajectory with electrostatic focusing, produced with a diode configuration. The primary advantage of electrostatic focusing is that the field shape (and thus electron trajectory) is a function of electrode geometry and is independent of photocathode voltage. Magnetic focusing is another type of image focusing that can be employed. However, although magnetic focusing gives better resolution than electrostatic focusing, it requires more weight and it adds focusing complications. The trajectory of an electron in a magnetic field is a function of its velocity, so when photocathode voltage is changed, the magnetic field must also be changed.

The use of a high photocathode potential (relative to the anode electrode) permits high electron gain to be achieved by accelerating electrons to high speeds. By altering this voltage, image section gain can be changed. Thus, gain control circuits provide automatic light-level control by altering photocathode voltage within a range of —2.5 kV to —8 or —10 kV, depending upon the type of target used.

Because the target is the most fragile of the elements in a camera tube and since its size influences the size of the readout section of the tube, limitations are often imposed on target diameter. To achieve the best sensitivity, however, a large area photocathode is desirable. Thus, most of the Westinghouse camera tubes employ minifying image sections in which the photoelectrons from a large-area photocathode are imaged onto a smaller-area target. For example, a typical camera tube type developed for military and commercial television has an input diameter of 25 millimeters and an active target diameter of about 20 mm, providing a minification of 0.64.

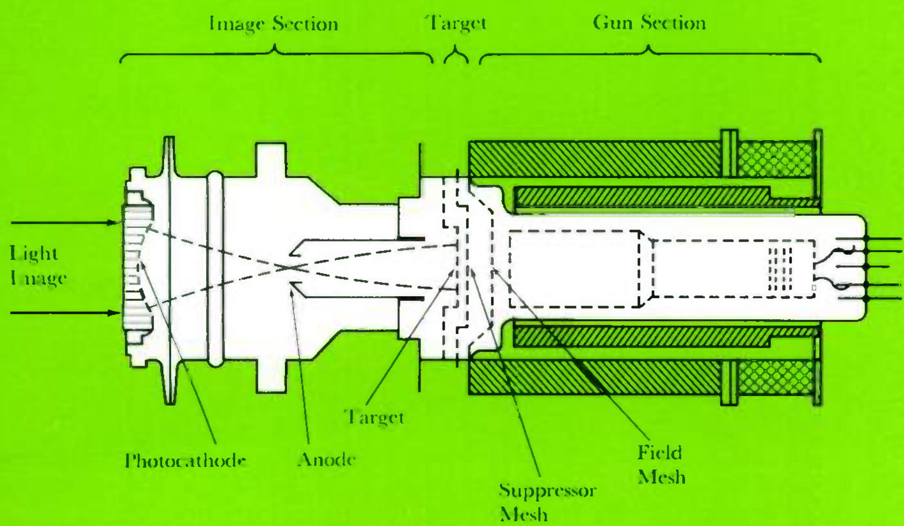
For another type of image section, used on a recently developed Westinghouse tube called the Proxicon camera tube, a brute force method of focusing is used rather than the complicated electron trajectory of conventional electrostatic or magnetic focusing. The input face and target are placed in extremely close proximity (about 1 mm), which, in combination with a high field (4 kV/mm), cause electrons to move directly from the photocathode surface to the target surface before they can spread (Fig. 3). The tube is physically the same size as the vidicon, which permits it to be used as a retrofit for certain vidicon types and provides the additional gain of a charge-amplifying SEC target, which cannot be used directly in a conventional vidicon configuration.

Charge-Storage Targets

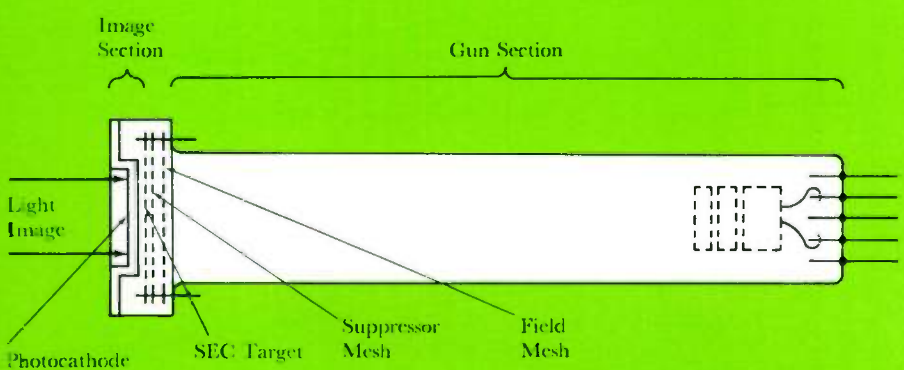
The key to the performance of these camera tubes is the target, which receives the focused electron pattern from the image section and converts it to a charge pattern on its rear (reading) surface.

The first of the two types of targets which are now being used in Westinghouse charge-storage camera tubes, the SEC, was developed several years ago before the technology for making the silicon-diode EBS target was perfected. The SEC target nominally provides a gain of 100, compared to the more recently developed EBS target, which provides gains of 2000 or more. That high gain is the most impressive characteristic of the EBS target. For very low-light-level imaging of the television type, such as some military applications might require, high gain is particularly desirable because it can often eliminate the need for additional stages of image intensification. However, for applications such as commercial color television, the high gain of the EBS target is often more than necessary. For example, most broadcasters prefer camera tube gains of about 20 to 50, so much of the advantage of the EBS target is lost. Although an EBS tube can be operated with reduced gain by reducing photocathode voltage, target performance deteriorates. Actually, most of the deterioration is presently due to quality problems (minor blemishes, etc.), so eventually low-voltage operation of EBS tubes may become feasible. An EBS target would be desirable because the achievable EBS target signal currents are relatively high due to the high target capacitance compared to the SEC target. For a given pretarget gain, the EBS target is able to store more information than the SEC target and thus offers greater dynamic range, improved grey scale rendition, and better signal-to-noise ratio than the SEC type.

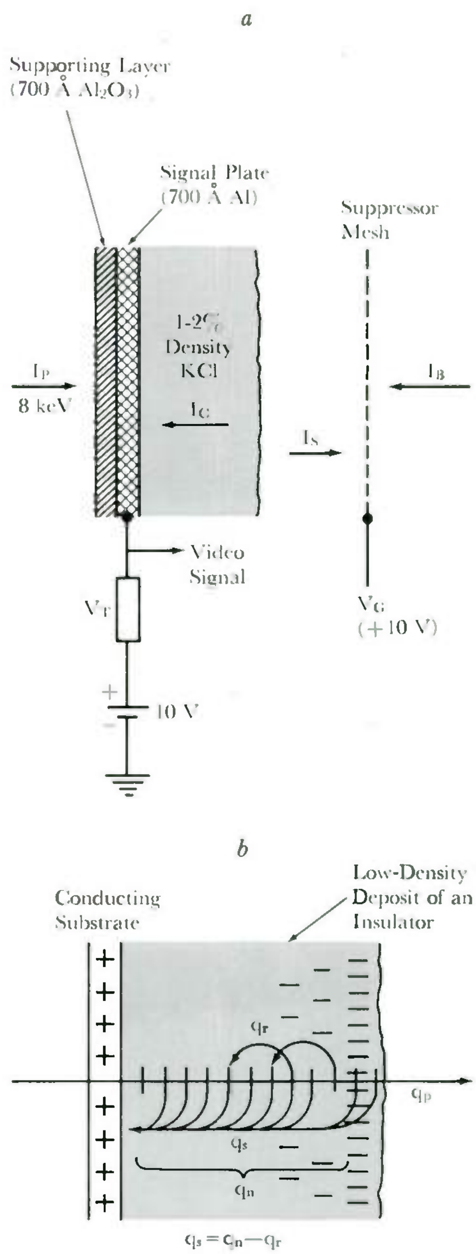
The unique advantage of the SEC target is that it operates with virtually no dark current (leakage current). Thus, it can store charge patterns on the target surface for long periods, or integrate extremely weak signals over long periods (16-hour integration has been demonstrated). The EBS target, with its relatively high dark current, can store or integrate for only a few seconds, which is more than adequate for normal television frame rates but unsuitable for scientific applications that require longer integration or storage periods. Although there are ways of accomplishing integration



2—Schematic drawing of SEC camera tube and focusing coils.



3—Schematic drawing of Proxicon camera tube.



4—Simplified sketch of SEC target structure (*a*) and target operation (*b*).

and storage externally to the target, the task is considerably more complex.

The dark current of the EBS target also causes it to be temperature sensitive, whereas the SEC target is insensitive to temperature variations over normal ranges up to values in excess of 65 degrees C. However, the temperature sensitivity of the EBS target is not a serious handicap over moderate temperature ranges because dark-current compensating circuitry is not difficult to develop.

Another differing characteristic of the two targets is lag, which is related to image smear. For a given signal current, the SEC target exhibits the least lag (or image retention) of any of the present camera-tube targets. Under certain conditions, the EBS target can provide lag performance equivalent to the SEC, but low lag is more difficult to achieve, primarily because of the higher capacitance of the EBS target. However, at very low light levels, the higher gain of the EBS target provides sufficiently greater signal current to offset its nominally poorer lag characteristic and thereby provide better overall performance than an SEC target.

Another difference is that the EBS target is less prone to burn from overexposure than the standard SEC target, and it is a more rugged target physically. A new version of the SEC target has much improved burn resistance and, under certain conditions, is almost as good as the EBS target.

The choice of target for a given imaging task depends upon fitting these various target characteristics to the requirements of the application.

SEC Targets

The original SEC target has a supporting aluminum-oxide film about 700 angstroms thick (Fig. 4a). A 700-angstrom layer of aluminum is deposited on the oxide film to provide a conducting electrode or signal plate, and the resulting backplate assembly is covered with a low-density potassium-chloride (KCl) film 10 to 20 microns thick.

Primary electrons (q_p) from the image section are focused on the aluminum-oxide side of the target. The high energy of the primary electrons (approximately 8 keV) enables the electrons to penetrate the backplate and dissipate their energy in the low-density layer of KCl (Fig. 4b), creating low-energy secondary electrons (q_n). The electric field across the target causes most of these electrons to be transported through the layer in the form of a secondary conduction current. Some of the low-energy secondary electrons recombine (q_r) at positive charge sites within the low-density layer, leaving a resultant net positive charge accumulated ($q_n - q_r$). Since secondary conduction electrons are free electrons traveling in the interparticle volume of the layer, rather than electrons in the conduction band, the response of the low-density film is much faster than for solid-state conduction, and essentially no time lag is observed at normal target operating voltages.

The electric field is imposed on the target film by applying a positive voltage (about +10 V) to the aluminum backplate and stabilizing the rear surface of the low-density film at ground potential (cathode gun potential) by scanning the surface with an electron beam.

When an electron image is focused on the target, secondary electron conduction caused by incoming primary electrons results in electron flow towards the signal plate, leaving the rear surface of the KCl film at a more positive potential, thereby building up a charge pattern that conforms to the incoming optical image. Each time the scanning electron beam sweeps the rear (reading) surface, the beam replenishes the electrons and returns the positively charged surface to ground potential. This replenishing action generates a video current, which is proportional to the replenished charge, through the video resistor.

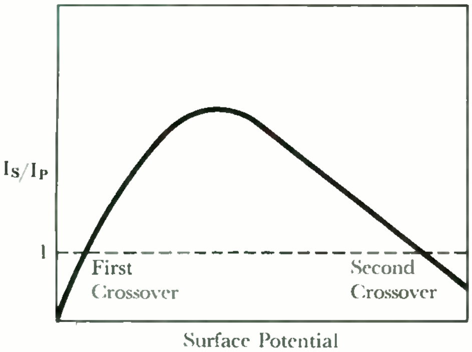
The recently developed burn-resistant SEC target uses fine wire mesh to provide film support in place of the aluminum-oxide film. Both the mesh and the aluminum layer can be considered the signal plate. The wire mesh protects the target in two ways: its thermal capacity is much greater than that of the aluminum-oxide film, so the initial rate of temperature rise is not as great; and it conducts heat away efficiently to keep the target's maximum temperature lower than that of a standard target, which must rely on radiation cooling only.

The fundamental difference in operation in the two targets is that the wire mesh screens some of the incoming primary electrons. This doesn't hurt the image from an optical standpoint because the mesh is too small to be visible. However, if the mesh has a transparency of say 50 percent, half of the incoming electrons are lost. On the other hand, although the original target has almost 100 percent transparency, a certain minimum electron energy is required to penetrate the aluminum-oxide supporting layer; with the screen, electrons that do penetrate the mesh do not have to penetrate the aluminum oxide and therefore can have less energy. This permits the wire-mesh target to be operated with a lower photocathode voltage than can be used with the aluminum-oxide supported target.

For most television imaging applications suitable for SEC camera tubes, the burn-resistant target has replaced the original version because the loss of electrons to the wire mesh causes no problem. The photon flux is such that a good charge pattern can be integrated over the normal television frame time, and the loss of electrons to the screen poses no serious drawback.

One exception where the mesh loss is undersirable involves astronomical observations. For example, when viewing a distant star, the flux of photons from the star is very low, and to build up an image with the original SEC target, the picture photoelectrons must be integrated for a period of perhaps 10 hours. If a mesh-supported target with a transparency of 50 percent is used, only 50 percent of the photoelectrons can penetrate the mesh; therefore, to provide an equivalent image, the picture must be integrated for twice as long, or in this example, 20 hours. Even if the SEC target can integrate successfully for a 20-hour period, only half as many pictures can be made over a given time span.

The reading-gun section performs essentially as in a conventional vidicon camera tube, but certain aspects of its



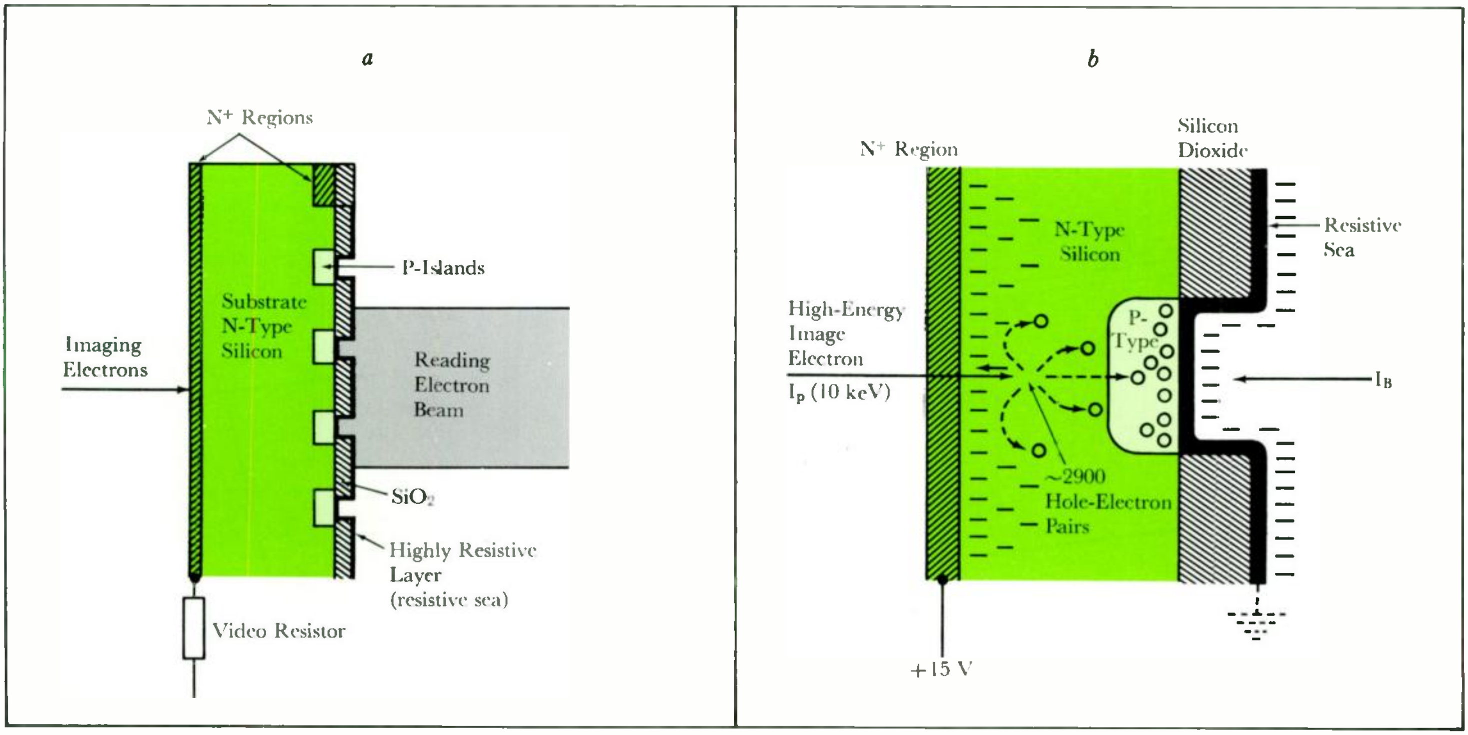
5—*(Above)* **Typical curve of secondary electron emission ratio versus target surface potential.**

6—*(Below)* **Simplified sketch of EBS target structure (*a*) and target operation (*b*).**

performance are unique to SEC target operation. In most SEC target-gun sections, two meshes are used. The *field mesh* (Fig. 2) serves an electron optical purpose of producing a plane equipotential surface and has the highest potential (+300 to +1000 V) on the gun side of the target. The other mesh is the *suppressor mesh*, a protective device with a potential of about +10 V. This low mesh potential prevents the target reading surface from charging up too positively when intense incoming signals are applied.

Low Incoming Signal Response—If the electrons of the reading beam struck the target reading surface with zero velocity, they would charge the surface down to the gun cathode potential. But in fact, beam electrons do have a velocity greater than zero, so they have energies also greater than zero. Thus, some electrons can land on the reading surface even after its potential becomes negative. These electrons cause the target reading surface to go slightly negative, typically about −2 V. This negative charge is the reason for higher target lag for extremely low incoming signals. As previously described, the application of an input signal causes secondary electrons to be released in the low-density film, and as they are conducted away from the reading surface to the signal plate, the reading surface assumes a positive potential. However, if very few secondary electrons are produced due to an extremely weak incoming signal, the charge pattern on the reading surface is altered very little, and the surface potential perhaps raised from −2 V to only −1 V. All reading-beam electrons have energies of 0 or greater, so if the surface potential were charged to +1 V, all electrons in the reading beam would potentially contribute to recharging the reading surface instantly. However, with a surface potential of −1 V, only those electrons with energies greater than 1 eV can land. Since this allows a much smaller fraction of the electrons to land, the process of recharging is slower and may require several scans of the reading beam.

In some types of integrating operations where a sequential reading arrangement



can be used, it is possible, just before reading out, to apply a positive biasing potential to the target (for example, increase it by +2 V) so that potentially all beam electrons can land and most of the charge pattern can be read out with one beam scan. But in a normal television operation, such a sequential system cannot be used.

High-Signal Response—When very bright optical images are applied, another phenomenon occurs with an SEC target, usually referred to as *crossover.* As primary electrons strike an insulating surface, secondary electrons are released. The ratio I_s/I_p (secondary emission ratio) is a function of the surface potential, and a curve of this relationship has the typical shape shown in Fig. 5. The surface potential at which the secondary emission electrons first equal the primary incident electrons is called the first crossover; the voltage at which it recrosses the unity ratio line is the second crossover.

The SEC target is normally operated at a potential (+10 V) much less than the first crossover voltage (+30 to +50 V). Thus, very few secondary electrons are released compared to the number of incident primary electrons in the reading beam, and the surface accumulates electrons. However, if the target is bombarded with an extremely bright image signal, many charge carriers are excited, and cause the target surface to charge highly positive. If the reading surface were allowed to become more positive than the first crossover potential, the reading beam would cause the surface to become even more positive through the generation of secondary electrons ($I_s/I_p > 1$). This is the reason a suppressor mesh (Fig. 4a) is used with the SEC target. By keeping the suppressor-mesh potential lower than the first crossover voltage, electrons have no place to go once the target potential equals suppressor-mesh potential, so the target reading surface cannot reach the high positive voltages that could cause target breakdown.

Although tubes for special applications that involve very low illumination levels are built without a suppressor mesh, special measures such as sequential write and read schemes are employed in operating these devices.

EBS Targets

The EBS (electron bombarded silicon) charge-storage target is a silicon-diode array, fabricated with the same techniques developed for the manufacture of integrated circuits. Use of an EBS target leads to a tube virtually identical in construction with an SEC camera tube (Fig. 1). The primary difference is that an EBS target is substituted for the SEC target and suppressor mesh (an EBS target does not need a suppressor mesh because it does not work on a secondary electron emission principal). In operation, the two tube types are essentially interchangeable, each offering the advantages and disadvantages determined by the characteristics of its target.

EBS targets are fabricated from thin slices of N-type silicon. Using standard photolithographic methods, P-N junctions are formed on the rear (reading) surface by diffusing boron through windows in an SiO_2 insulating layer (Fig. 6a). The target is thinned to the desired thickness by etching away the N-type material on the opposite surface. An N^+ layer is developed on the front surface to improve the target gain characteristic; a thin film which is highly resistive is deposited over the rear surface to help control the influence of excessive charging of the silicon-dioxide (SiO_2) insulating layer by allowing excess charges to leak away slowly and to effectively increase the beam acceptance area.

In operation, signal electrons from the imaging section penetrate the N-type

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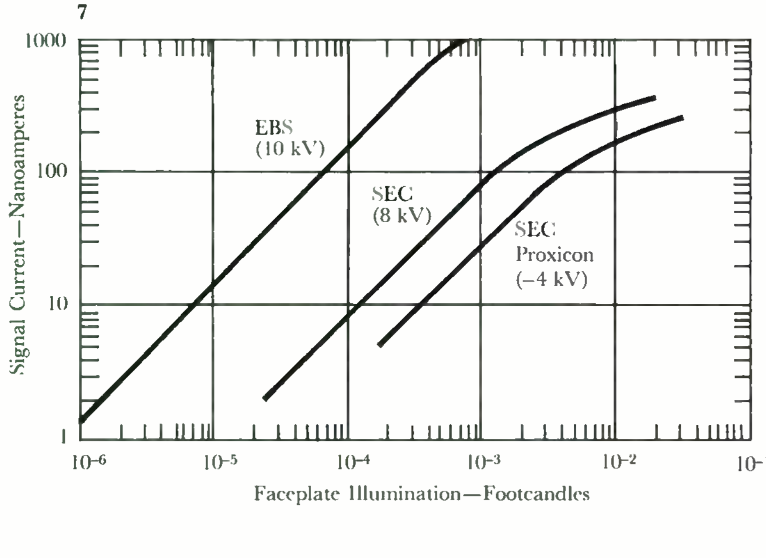

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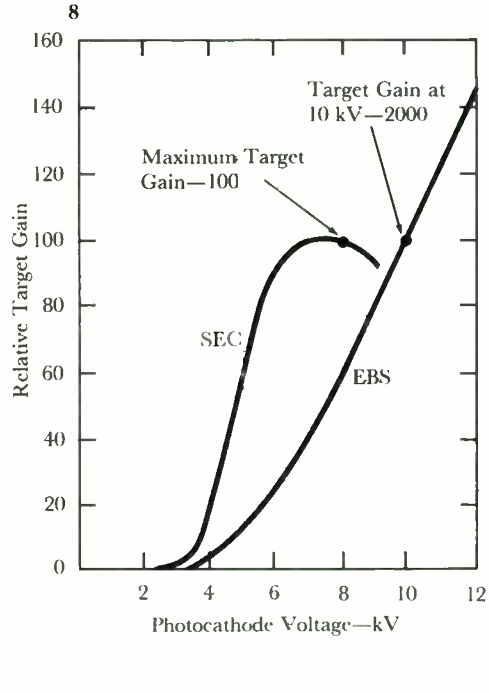

silicon with high kinetic energies, forming electron-hole pairs (Fig. 6b). The holes (which are effectively positive charges) diffuse to and are swept through the diode junctions, and the electrons remain in the N-type wafer. The excitation of charge carriers in the N-type silicon occurs at the rate of about one electron-hole pair for each 3.4 eV of imaging-electron kinetic energy. Thus, an imaging electron with 10 keV energy will theoretically produce some 2900 electron-hole pairs. However, this high potential gain is reduced somewhat by the loss of holes due to recombination at the front surface (although the positive biasing potential of the N^+ layer on the front surface tends to repel hole diffusion) and in the bulk of the target material. Because of the extremely thin target (0.001 cm), holes readily diffuse to the P-type islands on the rear surface; collection efficiencies are about 85 percent, providing typical EBS target gains of about 2000.

The target is read in the same manner as an SEC vidicon type, except that a suppressor mesh is not required. The N^+-type front surface is biased to about +15 V with respect to the reading gun cathode. As the reading beam scans the rear surface, electrons are deposited, dropping the reading surface to the ground potential of the cathode and causing the P-N junctions to be reverse-biased. This bias causes the holes generated by imaging electrons in the N-type silicon to be readily swept through the junction to the P-type islands (discharging the diodes from their full +15-V reverse-bias condition). Each time the reading beam scans the target surface, it recharges the diodes and, in so doing, develops the video signal.

Because of the discrete nature of the silicon-diode array target, resolution capability is limited by diode density. However, as with the screen-supported SEC target, the diode array is too fine to be visible in normal television viewing and an excellent quality picture can be obtained.

Lag and Capacitive Discharge—The lag of a diode array is essentially all due to capacitive discharge. The diode depletion region with no free charges serves as the dielectric of a capacitor. With respect to lag, the diode and reading-beam response is similar to that of a capacitor in series with a high-resistance voltage source. The depth of the depletion region (and hence the value of capacitance) varies with bias voltage. At low biases, the depletion region is relatively shallow; as bias voltage is increased, the depletion region expands (primarily into the N-type region) and capacitance decreases. A decrease in capacitance helps decrease lag because this, in effect, reduces the RC time constant of the reading beam and diode; however, the spread of the depletion region increases dark current which may manifest itself by introducing noise, by requiring additional reading beam current capability, and by restricting the integration capabilities of the target. In most cases, however, dark current poses no problems at normal operating temperatures. A bias voltage that provides a suitable compromise between lag and dark current is about +15 V, which provides a lag of about 15 percent for a signal current of 100 nA. (This compares to a lag of less than 5 percent for an SEC target with a 100-nA signal current.)

Performance Parameters

The relative performance of SEC and EBS targets can be seen by comparing the operating characteristics of two camera tubes that have the same physical configuration except for the charge-amplifying targets. (The WL-30691 uses an SEC target and suppressor grid; the WX-31792 uses an EBS target with no suppressor grid.)

Light-Transfer Characteristic — Perhaps the most important measure of performance of a charge-storage camera tube is its transfer characteristic, which relates the input illumination to the corresponding signal current derived from the target. The transfer characteristics of EBS and SEC camera tubes with conventional electrostatic-focus imaging sections are shown in Fig. 7. The transfer functions shown apply for the standard 1/30-second television frame time with tube voltages adjusted to give optimum performance.

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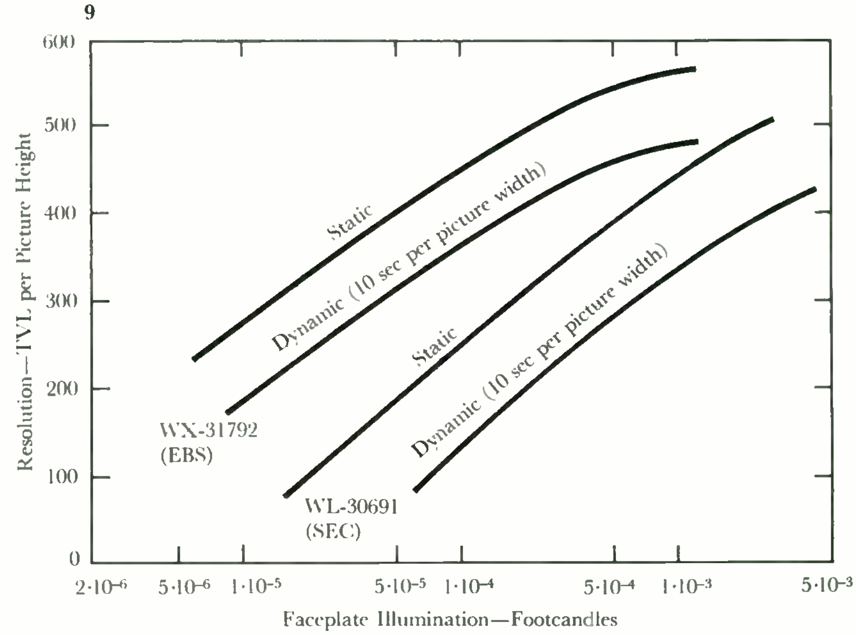
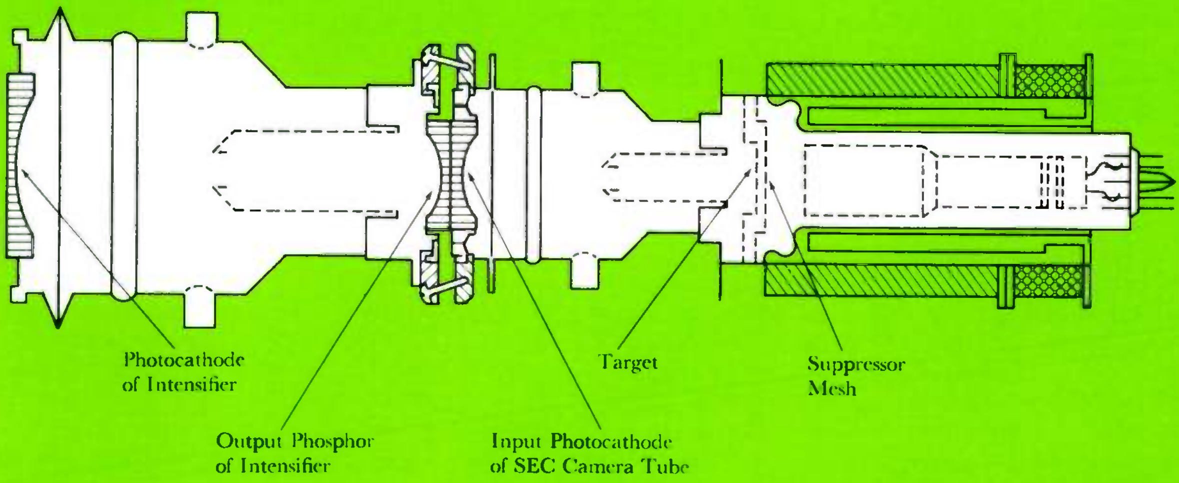


7—Typical light transfer characteristics for EBS, SEC, and Proxicon camera tubes.

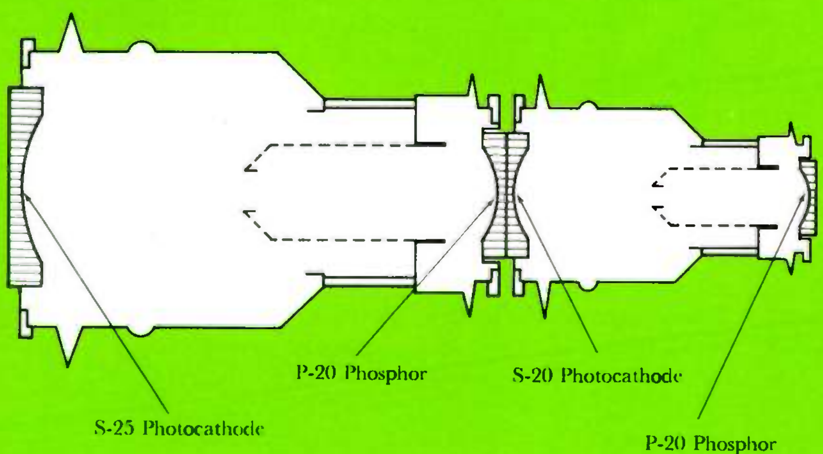
8—Target gain characteristics for SEC and EBS targets.

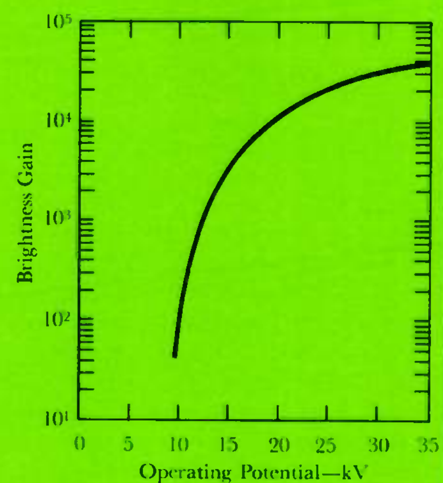
9—Static and dynamic resolution versus light level curves for SEC and EBS camera tubes.

10

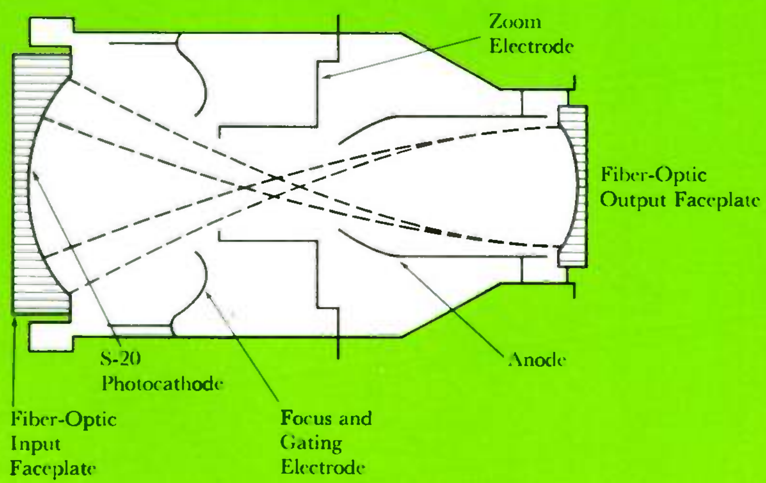

Photocathode
of Intensifier
Output Phosphor
of Intensifier
Target
Input Photocathode
of SEC Camera Tube
Suppressor
Mesh

11


S-25 Photocathode
P-20 Phosphor
S-20 Photocathode
P-20 Phosphor


Brightness Gain
Operating Potential—kV
10⁵
10⁴
10³
10²
10¹
0
5
10
15
20
25
30
35

12


Zoom
Electrode
Fiber-Optic
Output Faceplate
Anode
S-20
Photocathode
Fiber-Optic
Input
Faceplate
Focus and
Gating
Electrode

Both tubes have an S-20 photocathode, and input illumination is 2870 degrees K tungsten radiation.

The outstanding low-light-level sensitivity and high signal current provided by the EBS camera tube are clearly evident. As can be seen in Fig. 7, the SEC camera tube now falls in a sensitivity range overlapped by the EBS camera tube on the low end, and the SEC Proxicon tube (Fig. 3) at the high end. Therefore, in the future, the SEC tube will be used primarily in applications where its other performance characteristics, such as excellent integration and storage capability, can be combined with its low-light sensitivity.

The SEC tube with proximity focusing (WX-31486) at the high end of the illumination scale in Fig. 7 falls in the range desired for color television cameras; in fact, it was designed as a replacement type for the lead-oxide vidicons that have previously filled this need. However, the SEC Proxicon tube provides the additional gain of the SEC target (20 to 50) and better sensitivity because of the low-lag characteristic of the SEC target.

One further advantage of the SEC Proxicon tube is that the resolution of its photocathode is independent of light color, whereas the resolution of vidicon types with direct light excited targets of some thickness is affected to some extent by color because different light wavelengths penetrate the target to different depths.

Gain Control—Effective gain control of the EBS and SEC camera tubes is accomplished by varying photocathode voltage. The relative target gain, as a function of photocathode voltage, is shown in Fig. 8. Automatic gain control is accomplished by sampling the video signal and using a feedback network to regulate photocathode voltage over the ranges indicated in Fig. 8.

Varying photocathode voltages for the EBS tube from 3.5 to 10 kV provides a gain control range of close to 100. As shown by the curve, relative target gain continues to increase with photocathode voltage above this range, and the tube could be operated at higher voltages to extend the range.

Photocathode voltage of the SEC tube is varied over a range of 3.5 to 8 kV for a gain control range of about 15 to 1. Because of the nature of the SEC target, gain falls off above this voltage. Gain-control range could be extended downward by further reducing the photocathode voltage on either tube, but picture quality would be somewhat degraded.

Lag Characteristic—The signal generating mechanism of the SEC target is essentially lagless because conduction of secondary electrons across the storage layer takes place in vacuum rather than in the conduction band. However, lag increases at lower light levels, primarily because of the poorer beam acceptance associated with the lower voltage excursions on the target reading surface. Until recently, SEC tubes were used almost exclusively for extremely low-light-level television, so particular care was taken to reduce lag as much as possible by proper adjustment of target parameters. At normal SEC target operating signal currents of 100 nA, lag in the third field is less than 5 percent. This excellent performance makes it possible to use an SEC tube for such demanding applications as field-sequential color transmission where scan rates are 180 fields per second.

The EBS target has slightly greater image lag than the SEC has, due primarily to the capacitance of the diodes. As previously mentioned, capacitance and lag can be decreased by increasing target biasing voltage, but at the expense of increasing dark current. With signal currents of 200 nA or more, easily obtainable with an EBS target (Fig. 7), typical values of lag in the third field range from 8 to 15 percent.

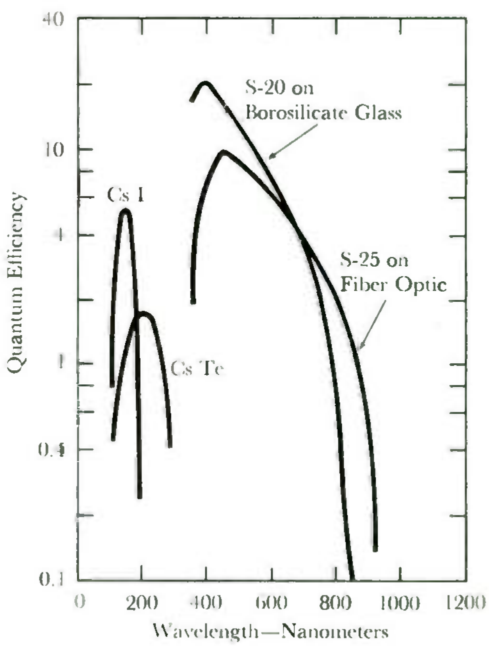
Resolution—The resolution capability of a camera tube is generally assessed by the ability of the tube to present an image of distinguishable, equally spaced black and white bars. The larger the number of distinguishable bars per unit length (often specified as TV lines per picture height where 2 TV lines means 1 white and 1 black bar), the better the resolution (limiting resolution) of the device. The limiting resolution for a given contrast pattern is controlled by the design of the tube and by the signal-to-noise ratio in the image being viewed. In low-light-level viewing applications, the most significant noise source is usually the system preamplifier. Therefore, since this is fixed, the signal-to-noise ratio decreases with decreasing illumination and the limiting resolution drops. This is shown in Fig. 9 by the curves designated *static*, which refer to a static image of a 100-percent-contrast bar chart.

When the bar pattern being imaged is in motion, resolution capability of the system is further reduced. This is the result of two effects, both of which contribute to effective loss of contrast. One of these effects is signal mixing and is due

10—Schematic drawing of intensifier-SEC camera tube combination (WL 32000).

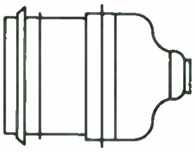
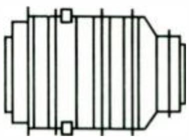
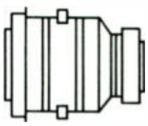
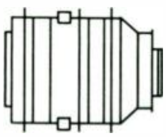
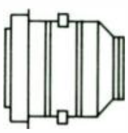
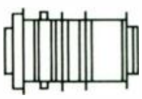
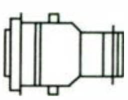
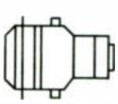
11—Schematic drawing of coupled image intensifiers and the brightness gain curve that results.

12—Simplified schematic drawing of image intensifier with zoom and gating capability.



13—Typical spectral response curves for photocathodes used in SEC camera tubes.

Table I—Principal Design Features of a Family of Image Intensifiers

Tube Silhouette	*Tube Type*	*Photo-cathode Diameter (mm)*	*Phosphor Screen Diameter (mm)*	*Paraxial Image Magnification*	*Gating*
	WX-30946	170	25	0.15	Yes
	WX-30958	80	40	0.5-1.0 Variable	Yes
	WX-30957	80	40	0.5	No
	WX-30956	80	25	0.31-1.0 Variable	Yes
	WX-30836	80	25	0.31	No
	WX-31443	40	25	0.63-1.3 Variable	Yes
	WX-30677	40	25	0.64	No
	WX-30920	25	16	0.63	No

to the transverse motion of the photoelectrons across the charge storage target, caused by the motion of the bar chart. This effect is most pronounced at high light levels where the limiting resolution is normally high and is independent of the nature of the target. The other effect predominates at low illumination levels and is caused by image smear due to lag in the signal read out process. For targets exhibiting high lag, this effect becomes severe. Curves shown in Fig. 9 labeled *dynamic* illustrate the consequences of these effects.

The highest limiting resolutions, which are observable at high signal-to-noise ratios and 100-percent contrast, are limited by the image section, gun section, and target designs. For ideal image and gun sections, the target controls the resolution capabilities.

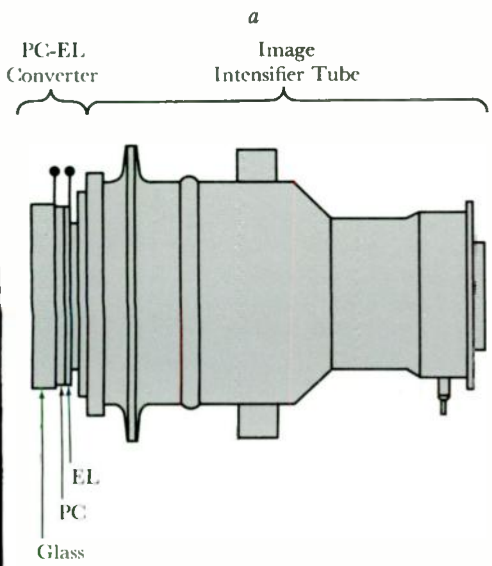
The SEC target is basically capable of providing limiting resolutions in excess of 120 TV lines per millimeter. In actual tubes, this limiting resolution is degraded by the suppressor mesh.

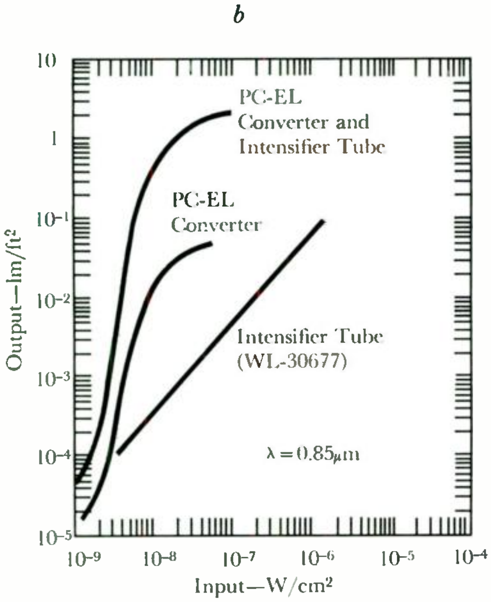
The EBS target is limited in resolution by the discrete nature of the diodes. Thus, a target composed of diodes spaced 12.5 microns apart should be limited in resolution to 80 TV lines per millimeter. However, because the diodes form a regular and periodic array, interference effects between the bar pattern and diode arrays exist and consequently the practical limiting resolution is somewhat less than this.

Image Intensification

When additional image intensification is required for extremely low-light-level applications, an image intensifier is added to the front of the camera tube. An image intensifier is a light-in, light-out device in which the output brightness is increased many times over the illumination falling on its input. It is essentially identical to the basic camera-tube image section and operates in the same fashion except that the photoelectrons, rather than being focused on a charge-storage element, are focused on a phosphor-coated fiber-optic plate (Fig. 10).

With an EBS target, only one image intensification stage is needed to get to





14—Image conversion by use of a PC-EL converter in front of an image intensifier (*a*) combines the transfer characteristics of each (*b*).

what is called the fundamental limit for imaging (the photon noise limit), whereas an SEC tube requires two stages of intensification to reach this level of sensitivity. Thus, at these extremely low levels of illumination, the EBS tube with one stage of intensification will be simpler and somewhat better in resolution than an SEC tube with two stages of intensification.

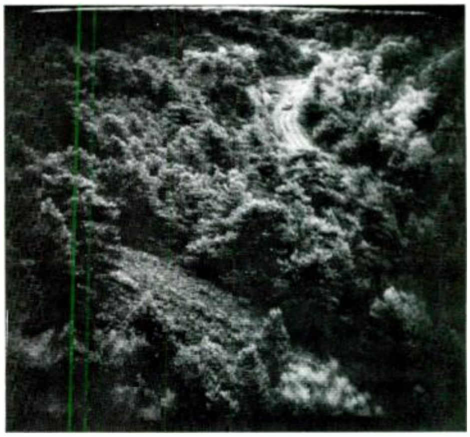
Fiber-optic plates are used for the input and output of image intensification sections for two primary reasons: For all imaging except the proximity focus or magnetic focus situation, the photocathode surface should be curved to provide the best electrostatic focusing, but the input face should be flat to accept the optically focused light image. Thus, a curved glass plate cannot be used because it would cause optical defocusing on the edges, whereas a fiber-optic plate can provide a plane surface on one side and a curved surface on the other without losing focus. The other advantage of fiber-optic faceplates is that by using plane external surfaces, tubes can be directly coupled, one plane surface to another.

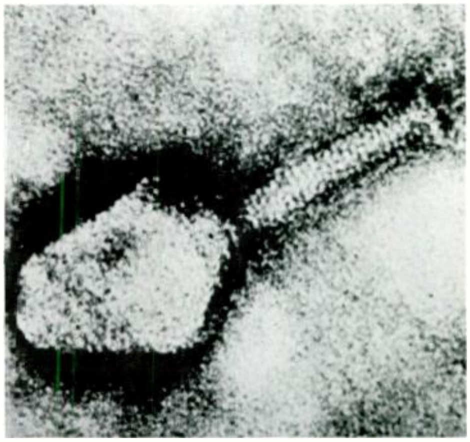
This ability to couple stages makes possible a number of image-intensifier and camera-tube combinations. Image intensifiers are made with input faceplate diameters ranging from 170 mm down to 25 mm, and with output diameters from 40 mm to 16 mm (Table I). All image sections are designed for compatibility in coupling to permit various combinations of image intensifiers and camera tube. A typical combination with its transfer characteristic is shown in Fig. 11.

Zoom and Gating—Two additional features can be incorporated in the image intensification stage when required.

A zoom electrode (Fig. 12) changes the shape of the electrostatic field when a voltage is applied, thereby deflecting electrons along an altered path. An image is extracted from a smaller portion of the faceplate, thereby providing the image-zoom feature. Since the new field shape also requires adjustment of voltages simultaneously on the focus electrode, specific tapped combinations are used to provide various degrees of zoom.

As with straight image intensification





15—*(Top)* This low-light-level television picture of Four Mile Canyon in Colorado was taken at night under moonless clear sky conditions.

16—*(Bottom)* Television micrograph of a T4 bacteriophage; note fine structure in tail.

stages, these zoom stages can be placed in series in front of a camera tube to provide various ranges of image amplification.

The focus electrode (Fig. 12) can also be used for gating by pulsing it with a high negative voltage, which shuts off the electron flow from the photocathode and provides a form of electronic shutter. The gating feature is useful when an auxiliary pulsed illuminator is employed. For example, if the camera tube is used side by side with a laser beam, the tube can be gated off at the instant the laser is pulsed to eliminate picking up unwanted back-scattered light from the laser pulse. In addition, gating can be used for determining object distances and for light-level control.

Light Sensitivity

The determinate of light sensitivity for either an SEC or an EBS camera tube is the photocathode material. For the camera tube characteristics described in this article, the conventional S-20 photocathode has been assumed. Other photocathode materials can be used depending upon the application (Fig. 13).

It may also be necessary to change faceplate material for some applications. For example, since most fiber-optic faceplates do not transmit ultraviolet, it is often necessary to use a lithium-fluoride or magnesium-fluoride faceplate for UV imaging tubes. The photocathode material is applied directly to the rear surface of the faceplate as with the fiber-optic faceplate. If a UV tube is wanted which will respond to UV only, a solar-blind photocathode is required. Such a photocathode will not respond to wavelengths above 3000 A. In most of these cases, any of the camera tube image sections normally employed in the visible spectral range can be used. Most frequently, UV imaging is accomplished with magnetically or proximity focused image sections.

In cases where the SEC tube must respond to a very broad light spectrum for long integration periods, a bialkali photocathode is used. This photocathode is an antimony-sodium-potassium material. Because there is no cesium, the red response is poorer than for conventional photocathodes. However, the elimination of cesium permits longer integration periods by avoiding the electrical discharge that cesium can cause.

Image Conversion—In some imaging applications, such as infrared or X-ray, an image converter in front of the input faceplate is necessary to convert the image to a wavelength that the S-20 photocathode can sense. Infrared imaging may be accomplished by coupling an infrared sensitive vacuum-type intensifier to the camera tube input. X-ray imaging can be achieved by applying an X-ray conversion screen to the camera tube fiber optic input or by imaging the converted picture from a standard fluoroscopic screen. Both X-ray and infrared imaging may be accomplished by use of a photoconductive-electroluminescent (PC-EL) type of image intensifier (Fig. 14a). In addition to wavelength conversion, PC-EL devices also provide high contrast so that a small variation in input will provide a large range of contrast in the output. This feature is useful in some imaging applications, such as radiography, where contrast is normally very low. The transfer characteristic for a PC-EL converter, an intensifier tube, and the combination is shown in Fig. 14b.

Applications

SEC camera tubes have been used most extensively in night-time observation and surveillance. The development of the EBS tube will provide even better low-light-level sensitivity for some of these applications, particularly for military remote-viewing systems. Shown in Fig. 15 is a TV monitor picture obtained with an intensifier-SEC tube combination of Four Mile Canyon in Colorado under moonless clear sky conditions.

Aside from military applications, the SEC camera tubes and intensifier-camera tube combinations have achieved a significant place as a tool in scientific research. For example, the intensifier-SEC package fiber-optically coupled to an electron microscope has proved useful in handling the extremely low current densities developed by the microscope. The desirable features of this application are the large input format and excellent integrating properties of the SEC tube. Shown in Fig. 16 is a television micrograph of T-4 bacteriophage obtained from the monitor of a Siemens Electron Microscope Intensifier SEC System. The 5-million times magnification was obtained with a 20-second exposure at a current density as low as 10^{-12} A/cm^2.

SEC and SEC-intensifier tubes have been employed in ground-based astronomy at the McDonald, Allegheny, and Lick Observatories. At the Lick Observatory (University of California), an SEC camera was used with the 120-inch telescope to study the light flashes of the pulsar embedded in the Crab Nubula. By using a suitable shutter, pictures were obtained at various phases of the pulsar cycle.

SEC and EBS tubes have been selected for and are being employed in a number of space programs. The Apollo camera applications have been well publicized. Another NASA project is the unmanned Orbiting Astronomical Observatory (OAO), which was launched in December 1968 and contains four SEC tubes (designated Uvicons because they were designed to be sensitive to ultraviolet light). Each tube was used in conjunction with a 12-inch optical telescope. From the launch date to the middle of January 1969, the OAO had collected 20 times more ultraviolet information concerning stars than had been accumulated in 15 years of rocket launchings.

The most widespread use of television camera tubes is in broadcast and closed-circuit television applications. The growth of color television has posed increasingly severe requirements on camera tube performance. In this area, acceptance of the SEC camera tubes is increasing rapidly due to the achievable high sensitivity and extremely low lag. SEC tubes have been employed in three-tube color cameras and have demonstrated the improvements achievable with very low lag. The EBS camera tube will find similar applications in color broadcasting where high gain for extremely difficult lighting conditions is the primary requirement.

All-Computer Contouring N/C Applied to Production Tool

Industry's first all-stored-logic numerical contouring control has been successfully married to a machine tool in a production configuration. (A prototype unit had been successfully demonstrated earlier, controlling a 28-inch vertical chucking machine.) The control unit is a New World C20 numerical contouring control made by the Westinghouse Industrial Systems Division and incorporating a Prodac 2000 minicomputer.*

The tool controlled by the C20 unit is a Bullard Dyn-Au-Tape 86-inch vertical turret lathe. (See photograph on back cover.) It is slated for use in the manufacture of turbine components at the new Winston-Salem plant of the Westinghouse Steam Turbine Division.

*John L. Patrick, "Numerical Control for Machine Tools Is Adaptable and Expandable," *Westinghouse ENGINEER*, Sept. 1970, pp. 137-42.

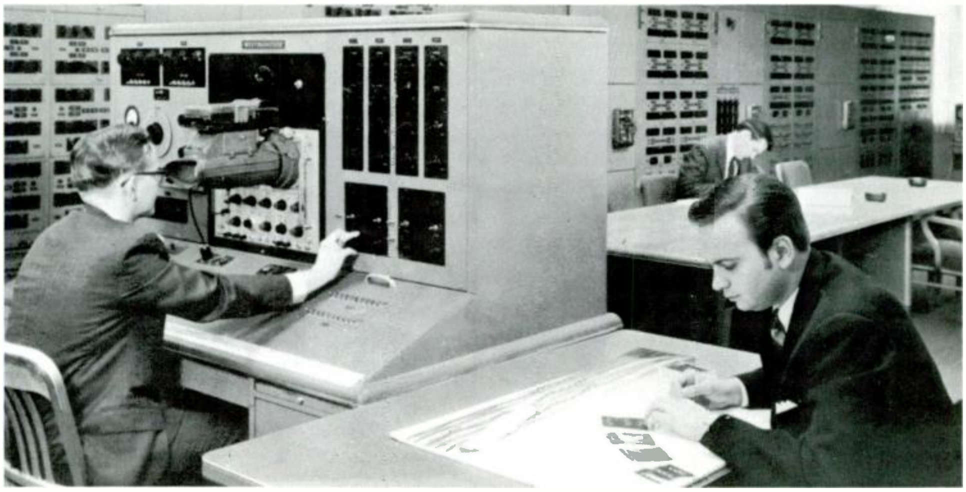
Westinghouse Anacom Enlarged for UHV Transient Studies

The Westinghouse passive-element analog computer (Anacom) has been enlarged to facilitate the study of transient phenomena on UHV transmission systems. Originally designed to study transient problems in all branches of engineering by repetitive simulation, in recent years its main use has been to study switching-surge, lightning, and recovery-voltage transients on electric power systems.

The additions include a set of 18 electronically controlled synchronous switches, two three-phase negative resistor amplifier circuits, and a set of 30 three-phase pi-section circuits to represent approximately 300 miles of EHV or UHV transmission line. With these improvements, the Anacom can represent both present and contemplated transmission systems.

Correct representation of EHV and UHV transmission lines requires a large number of pi sections with low losses to model the distributed-parameter line while correctly modeling the losses of the line at the same time. The new Anacom pi sections were designed to meet these requirements. They can be connected either in a three-phase configuration for representing balanced transposed networks or in a single-phase configuration for representing sequence networks. The pi-section inductors are tapped at 14, 16, and 21 millihenries, which are typical values for representing ten miles of 345-, 500-, and 1100-kV transmission lines. The capacitors for the pi sections can be set in the range from 0 to 0.3 microfarad in steps of 0.01 microfarad. This allows for correct representation of both the surge impedance and travel time of the line.

Although the Anacom has had electronic synchronous switches since 1954, representation of modern circuit breakers, series capacitors with gaps, and other nonlinear elements requires even more precise switching. The new synchronous switches provide for simulation cycle times that range from 0 to 30 seconds with two periods of either 1000 or 2000 degrees of the fundamental frequency during which the switches may be operated. Calibrated dials allow the switches to be set to within one degree, and the repeatability of the switches is within one degree of the set value. The switches can be operated either as 18 independent units or in a gang mode for such simulations as single- or multistep resistor-insertion breakers.



The Westinghouse Anacom (passive-element analog computer) has been enlarged to facilitate studies of transient phenomena on UHV transmission systems.

Study Provides Design Tools for Health Care Facilities

A set of planning "tools" that can be used to help in the design of health care systems is one of the main results of a recent comprehensive analysis of military base-level health care systems. The objective was to lower the costs of patient care through improved effectiveness of the military health systems while maintaining or improving the quality of the care, with the ultimate goal being the design of a new generation of military hospitals. The analysis was conducted by the Westinghouse Health Systems Department under a contract with the U.S. Department of Defense.

Since the needs of civilian health care systems are quite similar to those of base-level military systems, the analysis is significant for the civilian community as well as for the military. It is a step toward meeting the increasing demand for hospital care, while controlling the cost of supplying it, by making facilities more efficient, personnel more productive, and management more effective.

First, a demand model was developed

to specify health care requirements for immediate and future needs as determined by the base mission and other demographic parameters. The primary demand-model input was an extensive data base (which, in itself, is an important result of the study) compiled by a task force of consultants from various groups within Westinghouse as well as consultants in operations research, medicine, nursing, and systems engineering from universities, schools of medicine, and hospitals.

Requirements specified by the demand model were translated into a design configuration that would provide optimal health care for base personnel and their dependents. The design effort employed a systems approach and was under the direction of RTKL, Inc., Architect/Planners, the principle subcontractor in the consortium. The final design calls for a facility with four distinct levels or zones: the ambulatory level, the medical/professional level, the service and mechanical level, and, last, the in-patient level.

Subsystems of the health-care system, such as communications, dietary, and materials-handling systems, were cost analyzed, and an extensive survey was performed to project technological advances in medical care through the next decade. Finally, an auxiliary tool, the dynamic optimization model, was developed. This computerized tool enables planners who make today's cost decisions for medical facilities to take into account required changes in the future, both in demand and in resultant health-resource requirements, and therefore to design a system at lowest life-cycle cost.

X-Ray Tire Inspection Systems for Production-Line Testing

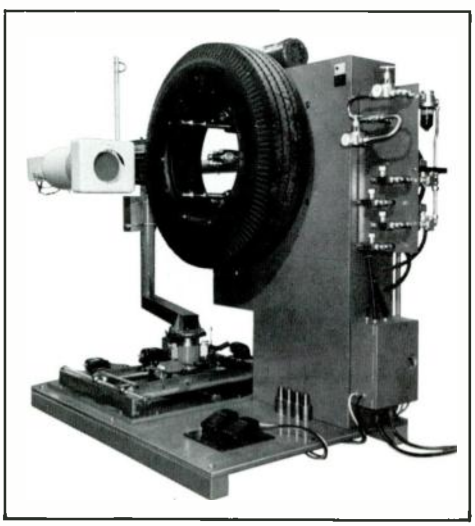
Rubber tires are now being tested nondestructively for breaks, voids, foreign matter, and other structural flaws by inspection systems employing X rays and a television display. The systems reveal the hidden parts of most tires and show the most critical defects commonly known to tire builders and retreaders. Thus, they permit determination of the integrity of a given tire on a semiproduction basis.

A typical system is shown in the photograph. Its manipulator holds a tire vertically while a rotatable X-ray source, positioned within the tire, projects an X-ray view to a high-resolution imaging system. The imaging system moves, in unison with the X-ray source, perpendicular to the tire in an arc up to 180 degrees ("bead-to-bead"). Thus, the entire tire—beads, sidewalls, shoulders, and crown—are inspected from various angles in one operation, without any handling other than placing and removing the tire.

The camera includes an image amplifier. Its output is displayed on a screen at the operator's station.

If a permanent record of a defect is desired, the operator can photograph the video display or load an X-ray cassette into an adapter and expose it to the beam for a high-definition picture. The station also includes controls for rotating the tire, controlling movement of the X-ray source and camera, and controlling beam intensity.

Besides its use in inspecting finished tires, the system can be adapted for inspecting tires in process and used tires for retreading. It also can be adapted to permit viewing from various angles. Changing spindles on the rotating mechanism adapts the unit for different tire sizes.



The mechanism and X-ray equipment are inside a small lead-lined room, while the operator station is outside the room. Interlocks prevent operation of the X-ray source when the room door is open.

The systems are made by the Westinghouse Astronuclear Laboratory; they are outgrowths of the Laboratory's own program of 100-percent inspection of its reactor fuel rods and other components as part of the production process. (The Laboratory is responsible for developing the nuclear reactor in the NERVA rocket engine and has built a number of test reactors for the program.)

Magnetically Shielded Containers Protect Lunar Samples

Some of the lunar rock samples collected by the Apollo 14 astronauts were brought back in special magnetically shielded containers to prevent the earth's magnetic field from changing the lunar field in the rocks. Those samples are being analyzed to determine their magnetic properties.

The magnetic-shield sample container (MSSC) is a double-walled container made of Hipernom magnetic shielding alloy with a Teflon outer sheath. It is 3½ inches in diameter and 6 inches high, and it weighs about a pound.

Hipernom alloy is an 80-percent nickel-iron material designed for applications requiring shielding of stray magnetic fields, or maximum magnetic flux from minimum exciting currents, or minimum losses. Its initial permeability is over 40,000 in the 40-gauss range, and maximum dc permeability is 250,000

Left—**A tire is held for inspection in a nondestructive test system that displays an X-ray picture on a television monitor. As the tire rotates, the X-ray source scans the tire from one bead to the other without any manual handling.**

Right—**Magnetically shielded container was used to prevent the earth's magnetic field from influencing lunar samples. It is made of Hipernom alloy, protected by a Teflon outer sheath.**

to 500,000 at approximately 3500 gauss. It can be so tempered as to permit up to 65-percent deep-draw reductions without intermediate annealing.

The MSSC's were fabricated by the James Millen Company with Hipernom alloy from the Westinghouse Specialty Metals Division. They were supplied to the Apollo program through the Union Carbide Corporation's Nuclear Division.

Security System Will Serve Entire Community

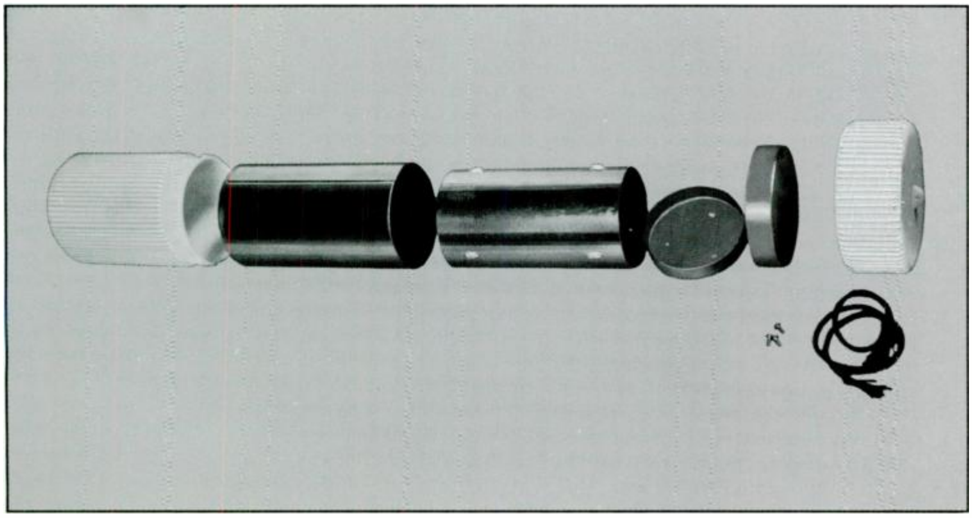
A 300-home community being built in Florida will have an electronic security system, consisting of individual home security systems for the dwellings and sensing equipment around sections of the community to detect and locate intrusion. Known as "The Soundings," the community is being built by Hobe Sound North, Inc., at the town of Hobe Sound 28 miles north of Palm Beach.

Each home system will alert the family to intrusion, fire, smoke, and air-conditioning failure, and it also can be used to summon help in case of emergencies such as sudden illness and accident. The perimeter system will give an alarm when an intruder attempts to move across the protected area. Signals from both systems are fed to a communications center, scheduled to be manned 24 hours a day by security guards. There the information is decoded and the location and nature of the emergency determined; if necessary, the guards summon whatever additional help is warranted.

Westinghouse Security Systems, Inc., will install, staff, and service the total security project. Placing its own security personnel between the emergency and public law-enforcement, fire, and medical services is a vital part of the community security concept. The arrangement essentially eliminates false alarms, speeds the handling of emergencies, and tailors the community's security to its needs. The necessary wiring and electronic equipment are part of the original construction, which means a better overall system at less cost to the homeowner than if it were added later.

The basic home security system is a unit with a small solid-state digital computer to receive, interpret, and transmit information relayed to it by various sensors placed in the home to detect emergencies. Its computer, located in a master control panel in the home, processes the information, sets off audible and visual alarms, and directs the coded information to the central communications center. The information is automatically decoded there, displayed, and printed out in detail on paper tape that serves as a permanent record. At the push of a button, the occupant of the home also has emergency voice contact with the guard at the communications center.

The perimeter security system is a version of an industrial and military system developed to detect intrusion by means of the vibrations generated when people move over the surface of the earth. The tiny vibrations are detected by two liquid-filled tubes that initiate a signal to warn of the intrusion and to give its location.



Products for Industry

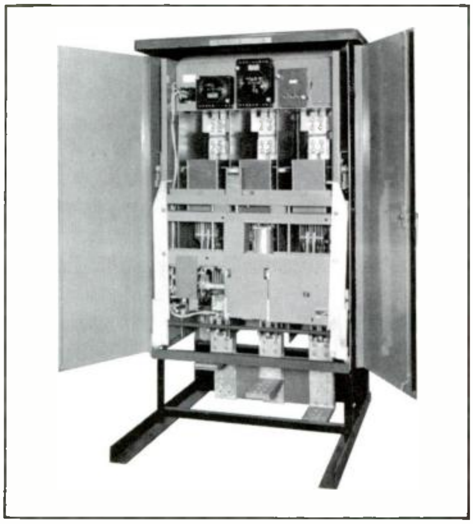
Gardwel Motor Controller is designed specifically for 1500-volt ac service to meet the needs of such applications as deep-well pumping, where voltages higher than the commonly used 600 volts are required to compensate for voltage drop along the supply cable. Ratings range up to 250 hp. Standard features include a fused disconnect switch, three magnetic overload relays, recording ammeter with 7-day clock, undercurrent relay, and provision for other auxiliary components. The unit comes in NEMA 1 or 3 enclosure. *Westinghouse General Control Division, 4454 Genesee Street, Box 225, Buffalo, New York 14240.*

Aluminized sealing alloys, Kovar and Westro 42, are useful for chemical etching or stamping of integrated-circuit lead frames. Aluminizing the alloys before stamping or etching eliminates the expensive masking and vapor-deposition steps otherwise needed to aluminum-coat finished lead frames, and it also eliminates the yield losses associated with those steps. The alloys are available in sheet and strip, fully coated or striped. Standard base metal thickness is 0.010 inch, but other gauges can also be made. Coating thickness up to 300 microinches is available; it is uniform within ±50 microinches. *Westinghouse Specialty Metals Division, Blairsville, Pennsylvania 15717.*

Ventilated dry-type transformers for outdoor service weigh less than 40 percent as much as conventional liquid-filled power transformers and require less than 15 percent as much floor space. They are made in both conventional and "tamper-proof" case construction for pad mounting, and in ratings from 112.5 through 10,000 kVA, with high voltages up to 15 kV. Outdoor application is made possible by waterproof case design and by use of Doryl varnish to protect the windings. Space heaters reduce humidity in the housing when the transformer is not energized. *Westinghouse Power Transformer Division, 460 Sharpsville Avenue, Sharon, Pennsylvania 16146.*

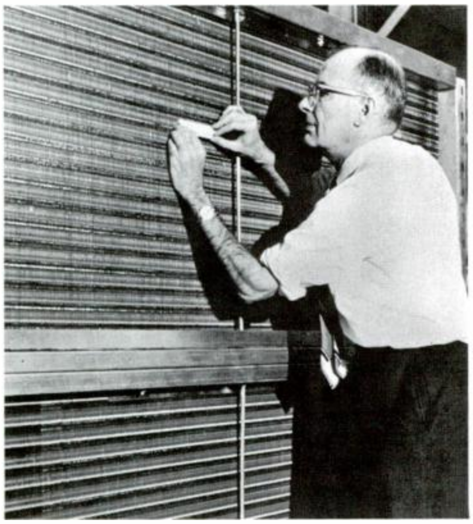
K-W Lifeguard SCR Charger employs power semiconductor components to improve protection of industrial batteries while effectively recharging them. Use of power semiconductors and printed circuit boards also results in size and weight savings; the new charger is only about two-thirds the size and weight of saturable-reactor chargers. Operating temperature is lower, and the unit is convection cooled. The charger is available in models that operate on 120/240-volt single-phase ac power and 240/480-volt three-phase power. Ratings cover 6 to 32 cells and 200 to 1400 ampere-hour capacity. High-capacity models can be modified to charge lower-capacity batteries by substitution of a single printed circuit board. Solid-state circuitry protects batteries against damage from overcharging, overheating, and current and voltage surges and fluctuations. For more protection, the charging cycle is timed. *K-W Battery Company (a subsidiary of Westinghouse Electric Corporation), 3555 Howard Street, Skokie, Illinois 60076.*

Steam heating coils are heavy-duty copper-tube units that provide long and reliable service for industrial applications. The Type FB (blast) and FD (distributing) coils handle up to 200-psig steam pressure and 400-degree-F steam temperature. Among the advantages of the new coils over previous designs are: wider fin spacing for low air resistance, minimal dirt buildup, and easy cleaning; larger and heavier tubes for longer life and better condensate drainage; heavier aluminum fins for greater strength, minimal fin damage, and steam or water cleaning; and two-in-one construction (two rows in one casing). Use of one header (supply and return) for the two-row coils eliminates one set of supply and return piping, traps, and valves, thereby saving space and reducing installation cost. Three coil types (for low, medium, and high temperature rise) are available. *Westinghouse Sturtevant Division, Damon Street, Hyde Park, Massachusetts 02136.*



Network Protector

K-W Lifeguard SCR Charger



Steam Heating Coils

Network protector, type CMR, is a 4500-ampere unit for use on above-ground and subsurface systems in areas of high load density. Closing and interrupting rating is 60,000 amperes rms for both 125/216- and 277/480-volt systems. Wide clearance and spacing plus removable barriers provide easy access to all protector parts and safety to operator and maintenance people. Three-inch phase-to-phase and phase-to-ground clearance is included throughout. A caliper-type multiple-contact disconnect device is captive to the roll-out unit and allows disconnection from the transformer side without removal of loose parts. A motor-operated spring-close mechanism reduces wear and maintenance on protector parts by eliminating the need for a braking device; it is trip-free in all stages of operation and always returns to its proper starting point for reclosing. *Westinghouse Switchgear Division, 700 Braddock Avenue, East Pittsburgh, Pennsylvania 15112.*

About the Authors

J. Haley graduated from the U.S. Naval Academy in 1949 with a BSEE degree. His naval career ran from 1949 until mid-1963. Early in that period, he received advanced degrees in Naval Engineering and Nuclear Engineering at M.I.T. From mid-1956 until mid-1962, he was on detached duty from the Navy to work directly for the Atomic Energy Commission on the Naval Reactors Program.

After a four-year stint with another industrial concern, working in various phases of the nuclear business, Haley joined the Westinghouse Nuclear Fuel Division as a project manager in 1967. He has been project manager for the Saxton Plutonium Program and project manager for the EEI-Westinghouse plutonium recycle demonstration program.

Haley is presently Manager of the Plutonium Fuel Development Project, with overall responsibility for developing plutonium recycle capability for Westinghouse, both design and manufacturing.

Harold T. Blair graduated from the University of Utah in 1968 with a BS degree in ceramic engineering. He had served two years with Battelle Northwest as a development engineer in the Fast Flux Test Facility (FFTF) fuel fabrication pilot facility when it became a part of WADCO Corporation last year. (WADCO is a Westinghouse subsidiary.) He is now in WADCO's FFTF Subassembly Development Section, Fuels and Materials Division.

Blair's responsibilities include development and demonstration of FFTF fuel fabrication processes, development and demonstration of mechanized and semiremote process equipment, and fabrication of the first prototype Fast Test Reactor (FTR) fuel subassembly. Thus, he has played a leading role in the developments reported in his article.

Z. A. Tendorf is an engineer in the Special Products Engineering Section, Medium AC Motor and Gearing Division. He has contributed to the development of computer programs for analyzing bearing load and shaft stress, and he is responsible for selection and application of bearings and lubricants for all motors made at the Division. He also has complete engineering design responsibility for motors in which bearing problems are most difficult, such as those for vibratory service and the "hot-shaft" motors made for driving fans inside annealing furnaces.

Tendorf came to Westinghouse in 1960. After 2½ years of drafting experience in the Systems Control Division, he moved over to the Medium AC Motor and Gearing Division. There he served as an engineering aide in work that included mechanical design projects connected with development of the Life-Line T motor, and he also studied for his BSME at the State University of New York at Buffalo under a Westinghouse program. He received his degree in 1966 and is now working on an MSME.

Dr. Alfred B. Laponsky attended Lehigh University, where he obtained a BS in Engineering Physics in 1943, followed by an MS in 1947 and a PhD in 1951. From 1951 until 1963, Dr. Laponsky was a Research Associate at the General Electric Research Laboratories, where he worked in the general area of physical electronics. He did research on high-vacuum techniques, secondary electron emission from metals and insulators, and auger electron emission from metals and insulators. He investigated various problems in television picture tubes, both monochrome and color.

Dr. Laponsky moved to the University of Minnesota in 1963 to become an associate professor in the Electrical Engineering Department. His activities there included both teaching and direction of graduate research in physical electronics.

In 1966, Dr. Laponsky joined the Westinghouse Electronic Tube Division as an advisory physicist. He has contributed to the research and development effort on SEC targets and other areas related to image devices. He was made Section Manager of the Electron Physics Section in 1967. Dr. Laponsky is presently Technical Director of the Solid State and Special Devices Section.

Vincent J. Santilli attended Rensselaer Polytechnic Institute and Catholic University of America, receiving his B.Ch.E degree in 1952. He received an M.Sc. degree from State University of New York at Buffalo in 1970.

Santilli joined Westinghouse in 1952 as a supervisory engineer for the first semiconductor pilot plant at the Electronic Tube Division.

After two years of military service with the U.S. Army in Germany (1954-1956), Santilli returned to Westinghouse and was assigned to vidicon tube manufacture, where he worked in all phases of manufacturing—evaporation, mounting, sealing, exhaust, and testing. Santilli was made a development engineer in 1959, and he worked on storage tubes, slow-scan vidicons, permachons, and other electrical-in/electrical-out devices. He has also worked on the development of high-temperature photoelectric materials and on low-light-level image devices, including the design and fabrication of SEC vidicon devices.

Santilli was made a project engineer for SEC tube development and camera tubes in 1964 and was assigned image intensifier design and development in 1967. He is presently project engineer for EBS camera tubes. This tube made its initial space flight on Apollo 14.

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All-computer contouring control operates a machine tool. (See page 93.)