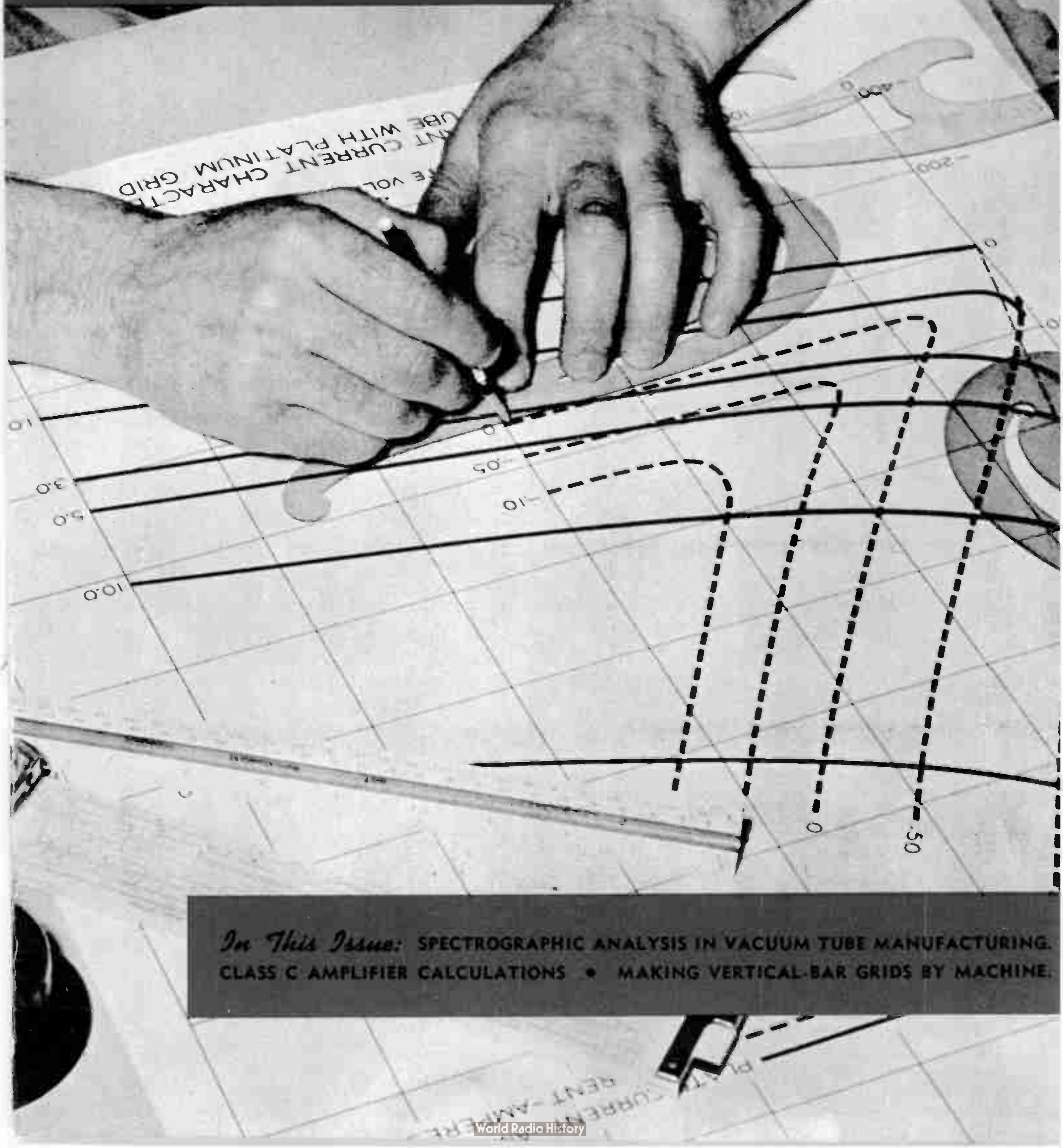
Eimac News

MARCH • APRIL • 1945



In This Issue: SPECTROGRAPHIC ANALYSIS IN VACUUM TUBE MANUFACTURING. CLASS C AMPLIFIER CALCULATIONS • MAKING VERTICAL-BAR GRIDS BY MACHINE.

World Radio History

Eimac News

INDUSTRIAL EDITION

VOLUME 3 NUMBER 23

MARCH-APRIL, 1945

IN THIS ISSUE

THE COVER PHOTO: *Eimac draftsman preparing constant-current characteristic curves for vacuum tube data sheet. Use of these curves is explained in this issue (see page 8).*

THE BACK COVER: *The Eimac 750TL, a general purpose, high frequency, high power triode, used in military and commercial communications and broadcasting services, including FM and television.*

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The Editor's Notebook

The delay in publication of the March industrial edition of the Eimac News resulted from a rather complicated change in schedule among the three magazines produced by Eitel-McCullough.

In order to conserve paper and also to integrate inter-plant relations, the Salt Lake City plant edition, hitherto issued semi-monthly, and the San Bruno plant edition, issued weekly, have been combined, to appear weekly.

The industrial edition, for both plants, is to appear every other month, on a date not yet determined, replacing on that date, however, the plant edition for that week.

Photo Presentation

This and subsequent industrial editions will be devoted largely to pictorial presentations, with reading material confined to captions except for technical discussions which cannot be expressed in photographs.

Since technical and engineering information of interest to the trade, to other engineers and manufacturers, and to the military services is now concentrated in the industrial edition, this edition will replace the plant edition on the general mailing list for the Eimac News. The Eimac News plant edition will be confined in its distribution to plant personnel, to personnel now in the services and to men overseas, along with a few exchanges.

Thousand to Navy

Distribution of the industrial edition has grown apace, meanwhile. Through the U. S. Navy Welfare Office, a thousand copies of each issue are going out to ships and shore stations for the information of the many technical branches of the service using electronic equipment.

For those interested particularly in vacuum tube data, reprints are now available upon request of the article on Vacuum Tube Ratings which appeared in the January (1945) industrial edition, and the article on the 4-125A Tetrode Power Tube which appeared in the February (1945) edition.

Errata

Three technical errors which appeared in the (4-125A Tetrode) article have been corrected in the reprints. They are as follows: In the tentative data listed on Page 6, the D-C plate current for typical operation at 215 Mc. should have appeared at 220 milliamperes instead of 200 milliamperes. Page 8, second column, last paragraph, should have read "375 watts" instead of "750 watts." Page 17, second column, first paragraph, should have read "which employs a 6F6 oscillator-doubler" instead of "which employs a 6L6 oscillator-doubler."

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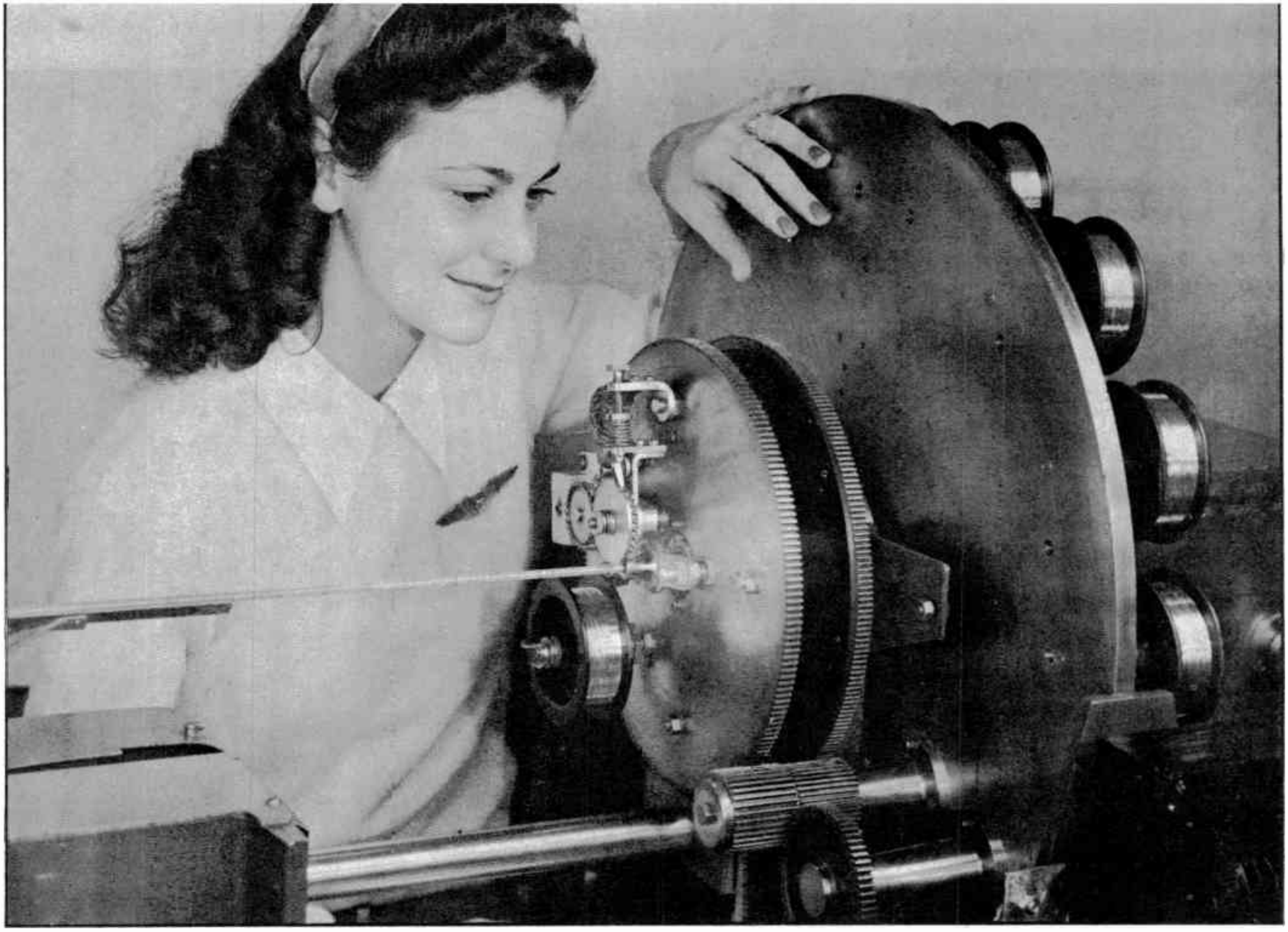

Making Vertical Bar Grids By Machine

The mass production of vertical-bar, cage-type power tube grids, long considered impossible to make by machine, is now a routine process at the San Bruno plant of Eitel-McCullough, where the grid fabricating machine illustrated above and in the following pages is in daily use, along with other models of the same machine.

Before the development of this machine, all grids for the various types of transmitting tubes produced by the two Eimac plants were made by hand. Under the pressure of military demands for as many as 4000 a day of certain grid types, some means of turning out grids with greater speed and greater uniformity had to be devised at once.

Of all the unusual, the intricate and the downright fantastic machines to be found in an electronics laboratory-in-production, few devices in the San Bruno Eimac plant arouse more interest in the layman and the engineer alike than the grid fabricating machines. Their high-speed simultaneous winding and welding motions attract and hold the attention of every visitor who sees them.

The experimental laboratory offered several ideas, one of which was incorporated by Eimac's engineers and machinists into the device pictured here—a machine that fabricates precision cage-wound grids, winding and welding the vertical grid bars and the spiral wrapping simultaneously, uniformly and rapidly.

An accurate gear-driven roller-feeding mechanism controls the advance of the mandrel on which the grids are made to ensure absolute similarity of each succeeding grid on the continuous chain. This exact similarity was particularly necessary for the type of grid for which the machine was originally designed—the 304TL, which has four grids (and four plates and four filaments) internally connected in parallel. Each grid in this tube must be in perfect electrical balance, requiring great exactness as to dimension, spacing, pitch of spiral and wire diameter. The machine meets these requirements admirably, and now ranks among the industry's most important wartime achievements. It has also been adapted to several other types of grids required in mass production quantities, with great success. Some recent production figures on the operation of these machines measure this success, in grids per minute, by tube type, as follows: 304TH, 5.63 per minute; 304TL, 5.00; 3C24, 5.15; 15E, 7.35; 35T, 5.15; 527, 1.28.

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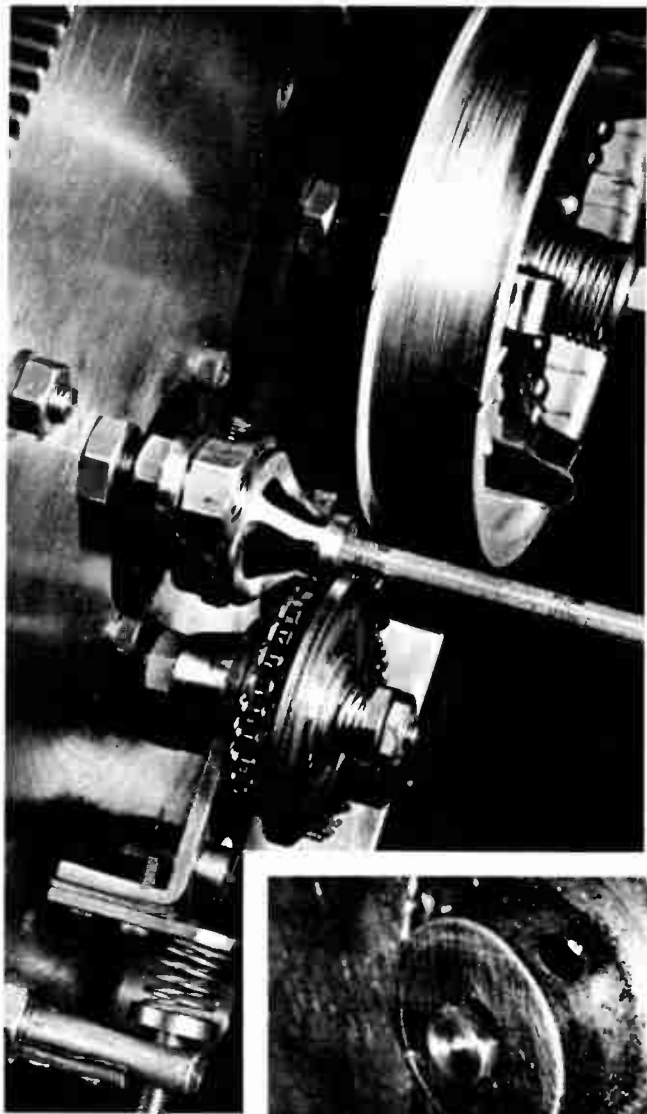
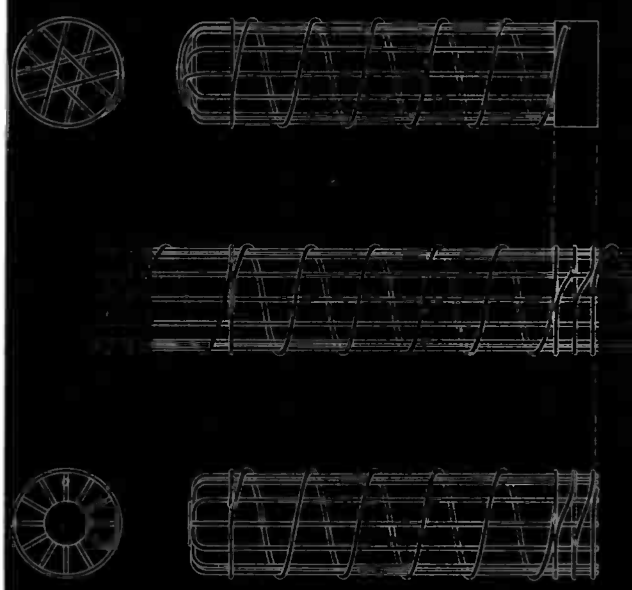
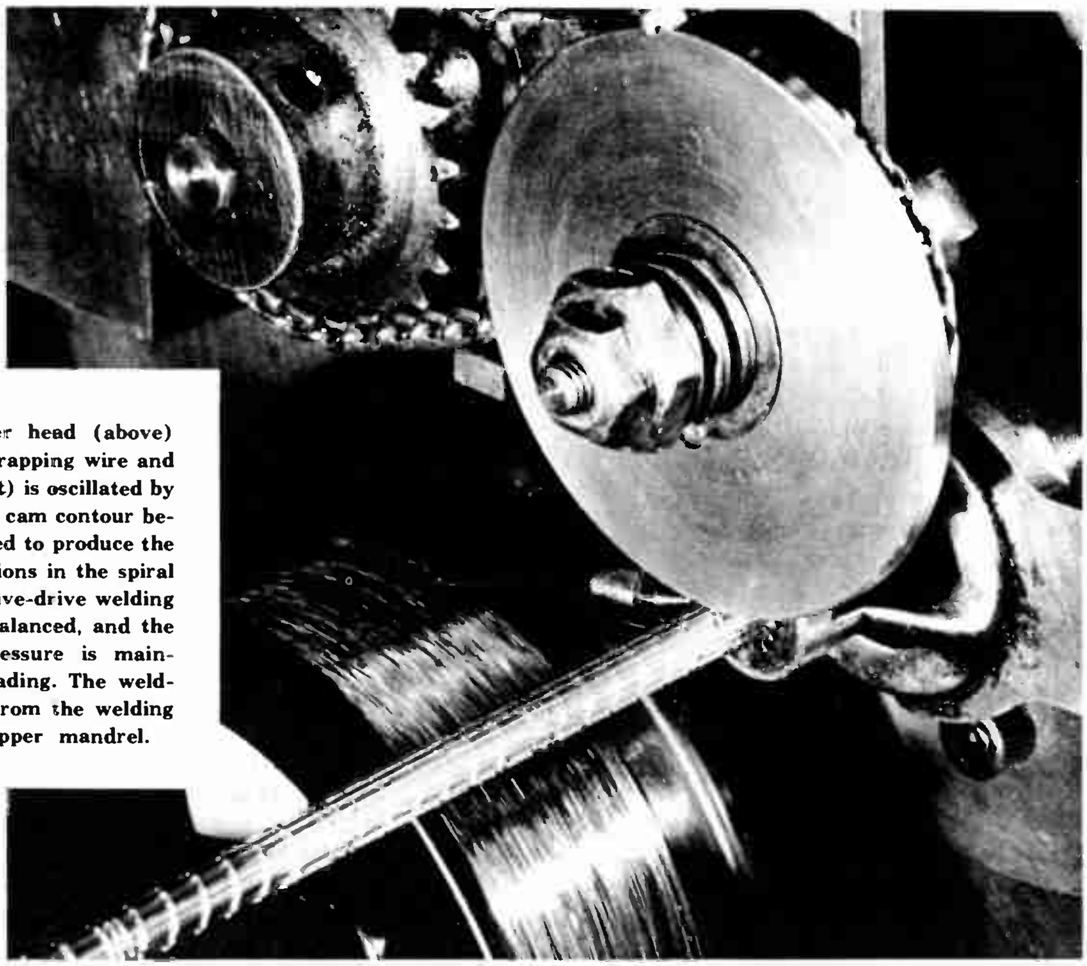




TOP—A HAND-MADE, CLOSED-TOP GRID; CENTER—A PORTION OF A CONTINUOUS STRING OF GRIDS ISSUING FROM THE GRID MACHINE BEFORE CUTTING AND FORMING OF THE TOP; BOTTOM—THE MACHINE MADE CLOSED-TOP GRID, COMPLETED



The rotating winder head (above) which carries the wrapping wire and welding wheel (right) is oscillated by means of a cam, the cam contour being carefully designed to produce the desired pitch variations in the spiral wrapping. The positive-drive welding wheel is carefully balanced, and the desired welding pressure is maintained by spring loading. The welding current passes from the welding wheel to the copper mandrel.

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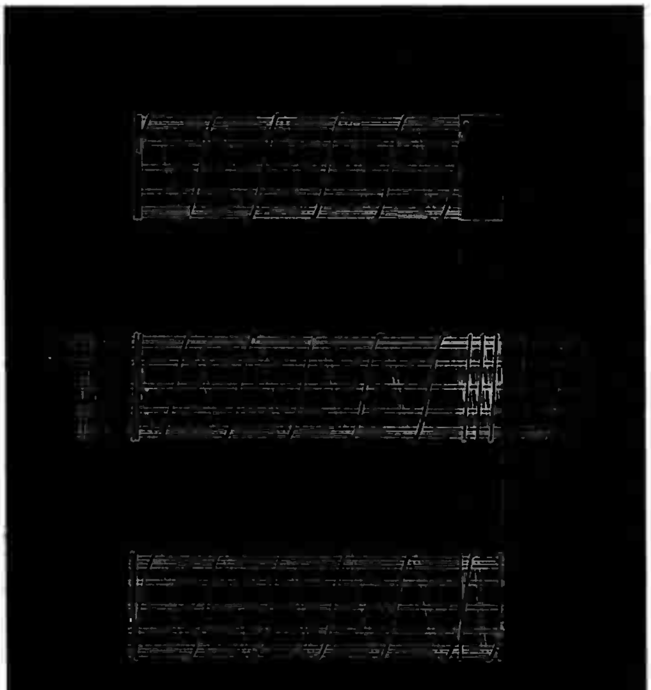
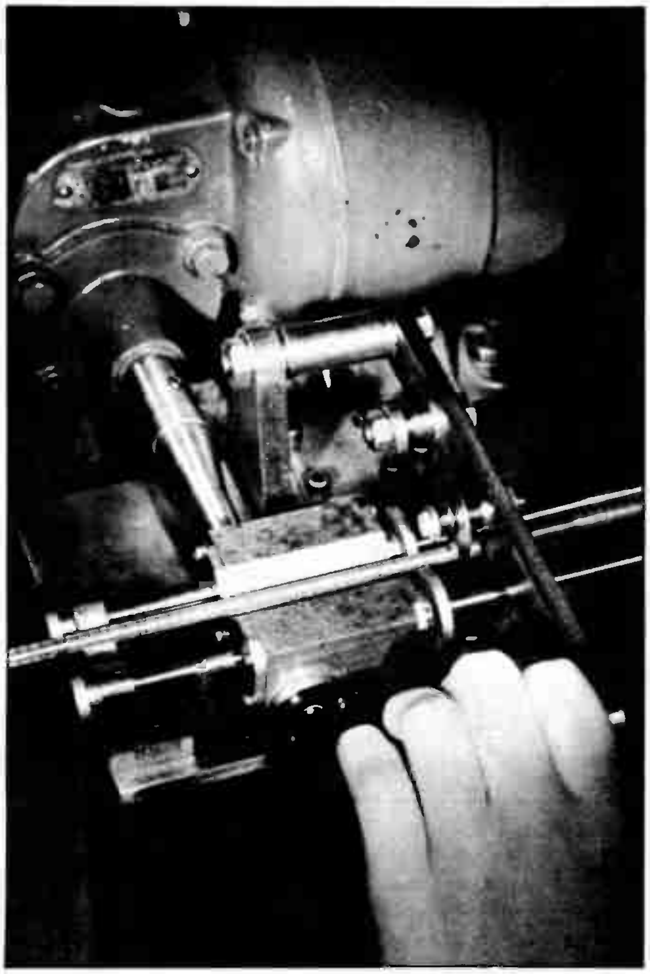


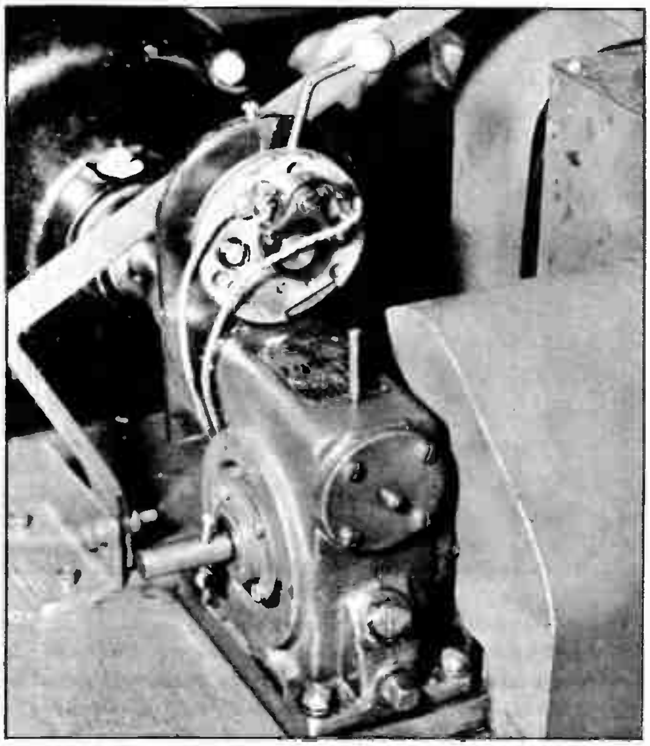
TOP—A HAND-MADE, OPEN-TOP GRID; CENTER—A PORTION OF A CONTINUOUS STRING OF GRIDS OF THE SAME TYPE ISSUING FROM THE MACHINE; BOTTOM—A COMPLETED MACHINE-MADE GRID SHOWING ONE OF MANY POSSIBLE VARIATIONS

Hand-winding this large-type grid (the 527, above) in which there are more than 800 welds, represents a difficult production problem. This type is now machine produced.

Strings of machine-made grids are separated quickly and accurately on the specially-built cutting machine (left).

The machine welding current power supply produces one complete cycle of current for each weld. The circuit is triggered by means of timer points (below) geared to the machine, which is driven by a synchronous motor.





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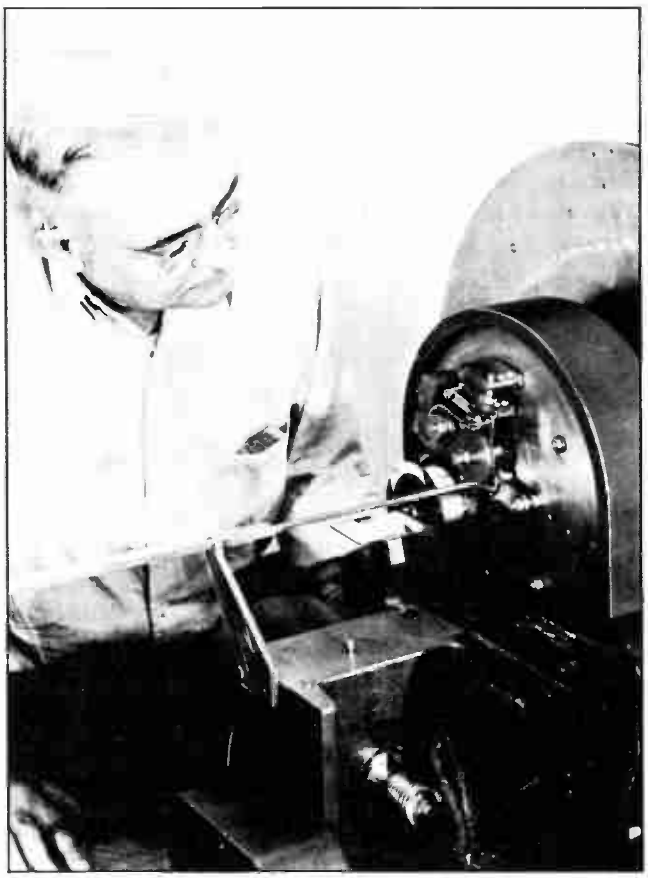
Steps in setting up the grid machine for operation. (1) Securing wire for threading one of the 12 to 40 bars; (2) feeding wire to nozzle in the welding head; (3) aligning it on the mandrel; (4) threading the wire for the spiral wrapping.

Note operator is releasing pressure of welding wheel with his left hand on the counter-balance, while passing wire through the small nozzle, which feeds the spiral wrapping wire.



The grid machine in operation, producing as many as 2400 uniform grids in an 8-hour shift, releasing manpower for other operations and relieving a large burden of supplying individual spot-welders, mandrels and electrodes.

Before the advent of the grid machine, grids were fabricated entirely by hand methods, requiring skilled personnel. Women operators were found to be best suited for this exacting work. Note the spot-welder converted from a drill press.

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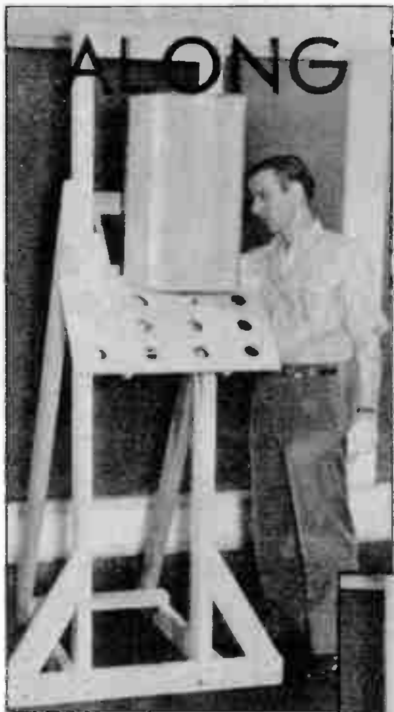
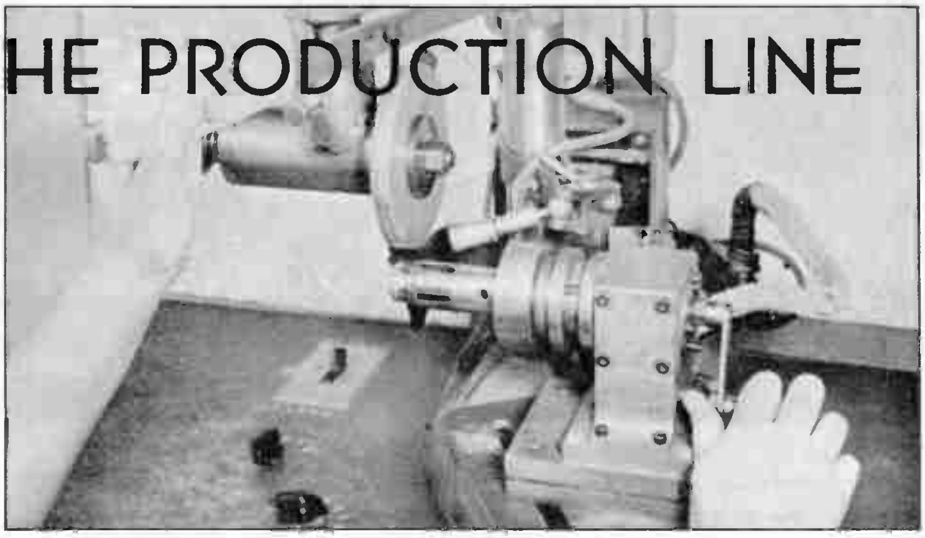
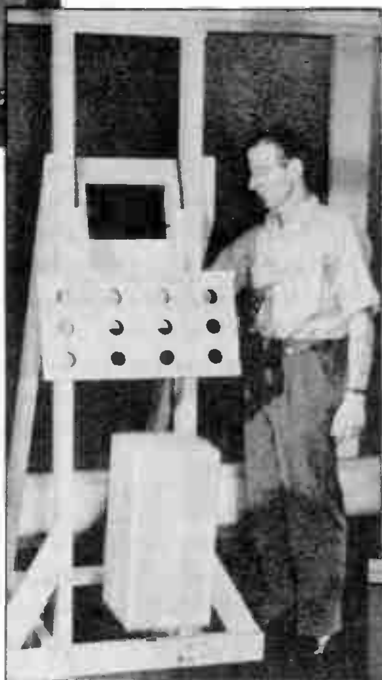
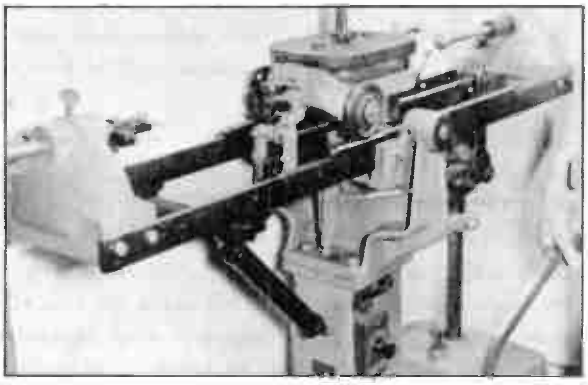
ALONG THE PRODUCTION LINE





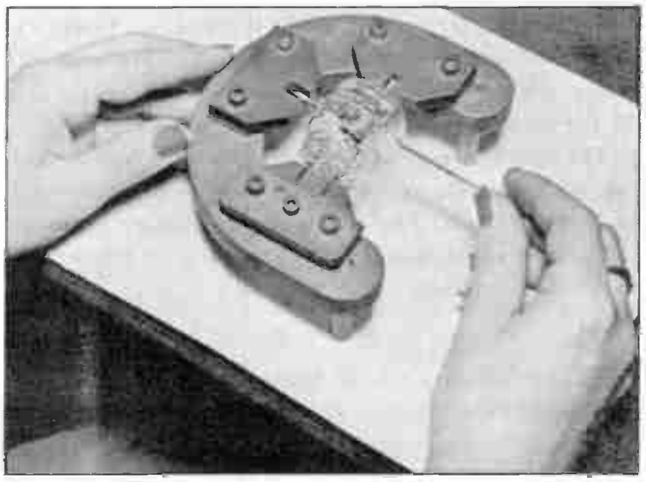
End-cans are seam-welded to the cylinder sections of vacuum capacitors by this roller-welding device.



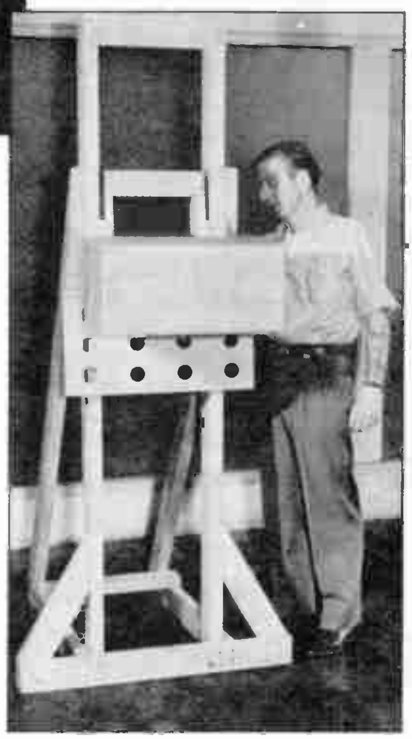


The tensile strength of wire used in making vacuum tube grids is accurately measured with this tensilgraph.

To insure that transmitting tubes arriving at the battlefront will be intact and ready for use, drop tests have been devised as a part of the series of tests given to Eimac tubes. With the apparatus illustrated above, right and below, a packaged tube is tested at various drop-levels, usually three feet or five feet, then it is opened and inspected for damage of any kind. The package is dropped on each end (right) and on each side (below).



The length and alignment of plate, grid and filament leads on the 15-E, miniature high frequency transmitting tube are checked in the Eimac inspection department by means of this go-no-go gauge.



As explained in detail in the January (1945) industrial edition of the Eimac News, transmitting tube packaging has undergone a considerable evolution since the beginning of the war, enabling tubes to withstand much rougher handling than was dreamed possible a few years ago. Drops of as much as 20 feet have been sustained in tests by the use of steel spring suspension packaging, though the usual test of a package is limited to conditions illustrated here. This apparatus permits a free fall from accurately measured heights, ranged in 2-inch steps from 3 feet to 6 feet.

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Class C Amplifier Calculations With The Aid of Constant-Current Characteristics

In calculating and predicting the operation of a vacuum tube as a class-C radio frequency amplifier, the considerations which determine the operating conditions are plate efficiency, power output required, maximum allowable grid and plate dissipation, maximum allowable plate voltage and maximum allowable plate current. The values chosen for these factors will depend both on the demands of a particular application and the tube selected to do the job.

The plate and grid currents of a class-C amplifier are periodic pulses, the durations of which are always less than 180 degrees. For this reason the average plate and grid currents, power output, driving power, etc., cannot be directly calculated but must be determined by a Fourier analysis from points selected along the line of operation as plotted on the constant-current characteristics. This may be done either analytically or graphically. While the Fourier analysis has the advantage of accuracy, it also has the disadvantage of being tedious and involved.

An approximate analysis which has proven to be sufficiently accurate for most purposes is presented in the following material. This system has the advantage of giving the desired information at the first trial. The system, which is an adaption of a method developed by Wagener[1], is direct because the important factors, power output, plate efficiency and plate voltage may be arbitrarily selected at the beginning.

In the material which follows, the following set of symbols will be used. These symbols are illustrated graphically in Figure 1.

Symbols

P_i = Plate power input
P_o = Plate power output
P_p = Plate dissipation
n = Plate efficiency expressed as a decimal
E_{bb} = D-c plate supply voltage
E_{pm} = Peak fundamental plate voltage
e_{bmin} = Minimum instantaneous plate votage
I_b = Average plate current
I_{pm} = Peak fundamental plate current
i_{bmax} = Maximum instantaneous plate current
θ_p = One-half angle of plate current flow
E_{cc} = D-c grid bias voltage (a negative quantity)
E_{gm} = Peak fundamental grid excitation voltage
e_{cmp} = Maximum positive instantaneous grid voltage
I_c = Average grid current
i_{cmax} = Maximum instantaneous grid current
P_d = Grid driving power (including both grid and bias losses)
P_g = Grid dissipation
μ = Amplification factor

Method

The first step in the use of the system to be described is to determine the power which must be delivered by the class-C amplifier. In making this determination it is well to remember that ordinarily from 5 to 10 per cent of the power delivered by the amplifier tube or tubes will be lost in well-designed tank and coupling circuits at frequencies below 20 Mc. Above 20 Mc. the tank and coupling circuit losses are ordinarily somewhat above 10 per cent.

The plate power input necessary to produce the required output is determined by the plate efficiency:

$$P_i = \frac{P_o}{n}$$

For most applications it is desirable to operate at the highest possible efficiency. High-efficiency operation usually requires less expensive tubes and power supplies, and the amount of artificial cooling needed is frequently less than for low-efficiency operation. On the other hand, high-efficiency operation often requires more driving power and higher operating plate voltages. Eimac triodes will operate satisfactorily at 80 per cent efficiency at the highest recommended plate voltages and at 75 per cent efficiency at medium plate voltages.

The first determining factor in selecting a tube or tubes for any particular application is the maximum allowable plate dissipation. The total plate dissipation rating for the number of tubes used must be equal to or greater than that calculated from

$$P_p = P_i - P_o$$

After selecting a tube or tubes to meet the power output and plate dissipation requirements it becomes necessary to determine from the tube characteristics whether the tube selected is capable of the required operation and, if so, to determine the driving power, grid bias and grid current.

1 W. G. Wagener "Simplified Methods for Computing Performance of Transmitting Tubes," Proc. I.R.E., Vol. 25, p. 47, (Jan. 1937).

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The complete procedure necessary to determine the class-C-amplifier operating conditions is as follows[2]:

1. Select plate voltage, power output and efficiency.
2. Determine plate input from

$$P_i = \frac{P_o}{n}$$

3. Determine plate dissipation from

$$P_p = P_i - P_o$$

P_p must not exceed maximum rated plate dissipation for tube or tubes selected.

4. Determine average plate current from

$$I_b = \frac{P_i}{E_{bb}}$$

I_b must not exceed maximum rated plate current for tube selected.

5. Determine approximate i_{bmax} from

$$i_{bmax} = 4.5 I_b \text{ for } n = 0.80$$
$$i_{bmax} = 4.0 I_b \text{ for } n = 0.75$$
$$i_{bmax} = 3.5 I_b \text{ for } n = 0.70$$

6. Locate the point on constant-current characteristics where the constant plate current line corresponding to the approximate i_{bmax} determined in step 5 crosses the line of equal plate and grid voltages ("diode line"). Read e_{bmin} at this point.[3]
7. Calculate E_{pm} from

$$E_{pm} = E_{bb} - e_{bmin}$$

8. Calculate the ratio $\frac{I_{pm}}{I_b}$ from

$$\frac{I_{pm}}{I_b} = \frac{2n\ E_{bb}}{E_{pm}}$$

9. From the ratio of $\frac{I_{pm}}{I_b}$ calculated in step 8 determine the ratio $\frac{i_{bmax}}{I_b}$ from Chart 1.
10. Calculate a new value for i_{bmax} from ratio found in step 9.

$$i_{bmax} = (\text{ratio from step 9})\ I_b$$

11. Read e_{cmp} and i_{cmax} from constant current characteristics for values of e_{bmin} and i_{bmax} determined in steps 6 and 10.
12. Calculate the cosine of one-half the angle of plate current flow from

$$\cos\theta_p = 2.32\left(\frac{I_{pm}}{I_b} - 1.57\right) \quad [4]$$

13. Calculate the grid bias voltage from

$$E_{cc} = \frac{1}{1-\cos\theta_p}\left[\cos\theta_p\left(\frac{E_{pm}}{\mu} - e_{cmp}\right) - \frac{E_{bb}}{\mu}\right]$$

14. Calculate the peak fundamental grid excitation voltage from

$$E_{gm} = e_{cmp} - E_{cc}$$

15. Calculate the ratio $\frac{E_{gm}}{E_{cc}}$ for values of E_{cc} and E_{gm} found in steps 13 and 14.
16. Read ratio $\frac{i_{cmax}}{I_c}$ from Chart 2 for ratio $\frac{E_{gm}}{E_{cc}}$ found in step 15.
17. Calculate average grid current from ratio found in step 16 and value of i_{cmax} found in step 11.

$$I_c = \frac{i_{cmax}}{\text{ratio from step 16}}$$

18. Calculate approximate grid driving power from

$$P_d = 0.9\ E_{gm} I_c \quad [5]$$

19. Determine grid dissipation from

$$P_g = P_d + E_{cc} I_c$$

P_g must not exceed the maximum rated grid dissipation for the tube selected.

Example

A typical application of this procedure is shown in the example below.

1. Desired power output.............. 1250 watts
   Desired plate voltage.............. 4000 volts
   Desired plate efficiency.......... 75 per cent (n=0.75)

2. $P_i = \frac{1250}{0.75} = 1670$ watts

3. $P_p = 1670 - 1250 = 420$ watts

Try type 450TL; Max. $P_p = 450W$; $\mu = 18$

4. $I_b = \frac{1670}{4000} = 0.417$ ampere

(Max. I_b for 450TL = 0.600 ampere)

5. Approximate $i_{bmax} = 4.0 \times 0.417 = 1.67$ ampere

6. $e_{bmin} = 315$ volts (see figure 2)

7. $E_{pm} = 4000 - 315 = 3685$ volts

8. $\frac{I_{pm}}{I_b} = \frac{2 \times 0.75 \times 4000}{3685} = 1.63$

9. $\frac{i_{bmax}}{I_b} = 3.45$ (from Chart 1)

10. $i_{bmax} = 3.45 \times 0.417 = 1.44$ amperes

11. $e_{cmp} = 280$ volts
    $i_{cmax} = 0.330$ amperes
    (see figure 3)

12. $\cos\theta_p = 2.32\ (1.63 - 1.57) = 0.139$

13. $E_{cc} = \frac{1}{1-0.139}\left[0.139\left(\frac{3685}{18} - 280\right) - \frac{4000}{18}\right]$
    $= -270$ volts

14. $E_{gm} = 280 - (-270) = 550$ volts

15. $\frac{E_{gm}}{E_{cc}} = \frac{550}{-270} = -2.04$

16. $\frac{i_{cmax}}{I_c} = 5.69$ (from Chart 2)

17. $I_c = \frac{0.330}{5.69} = 0.058$ amperes

18. $P_d = 0.9 \times 550 \times 0.058 = 28.7$ watts

19. $P_g = 28.7 + (-270 \times 0.058) = 13.0$ watts
    (Max P_g for 450TL = 65 watts)[6]

[2] In the case of push-pull or parallel amplifier tubes the analysis should be carried out on the basis of a single tube, dividing P_i, P_o and P_p by the number of tubes before starting the analysis and multiplying I_b, I_c and P_d by the same factor after completing the analysis.

[3] In a few cases the lines of constant plate current will inflect sharply upward before reaching the diode line. In these cases e_{bmin} should not be read at the diode line but at the point where the plate current line intersects a line drawn from the origin through these points of inflection.

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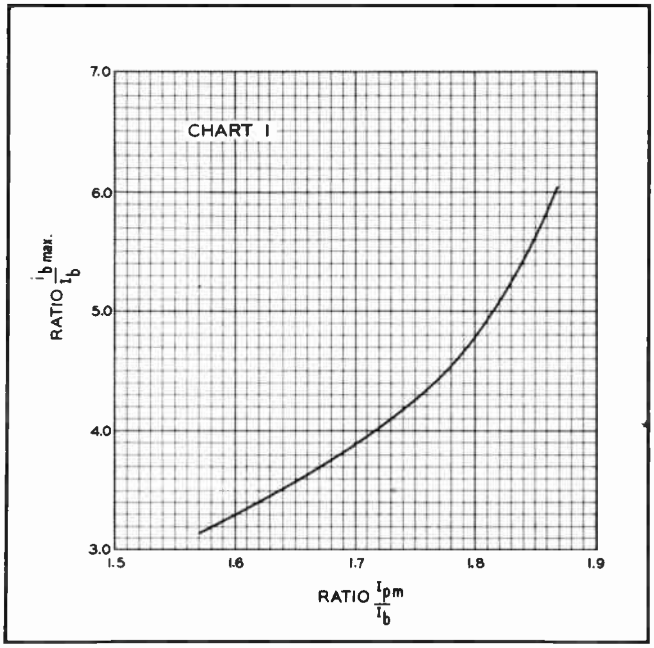

Chart 1

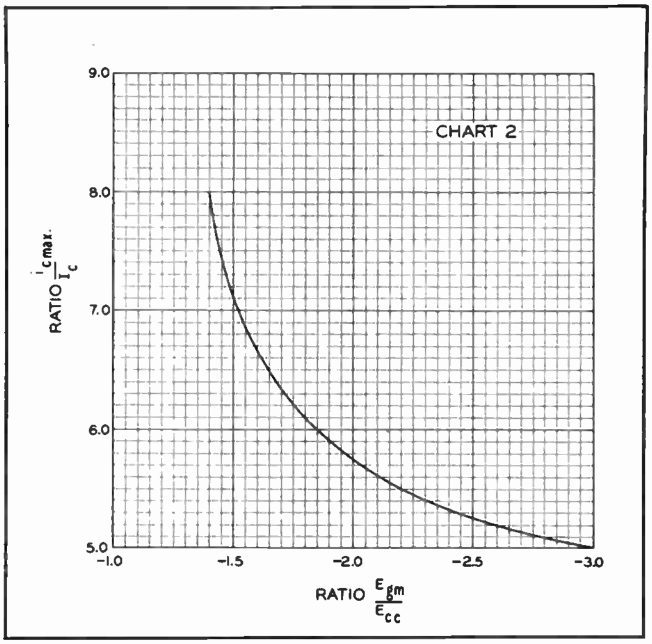

Chart 2

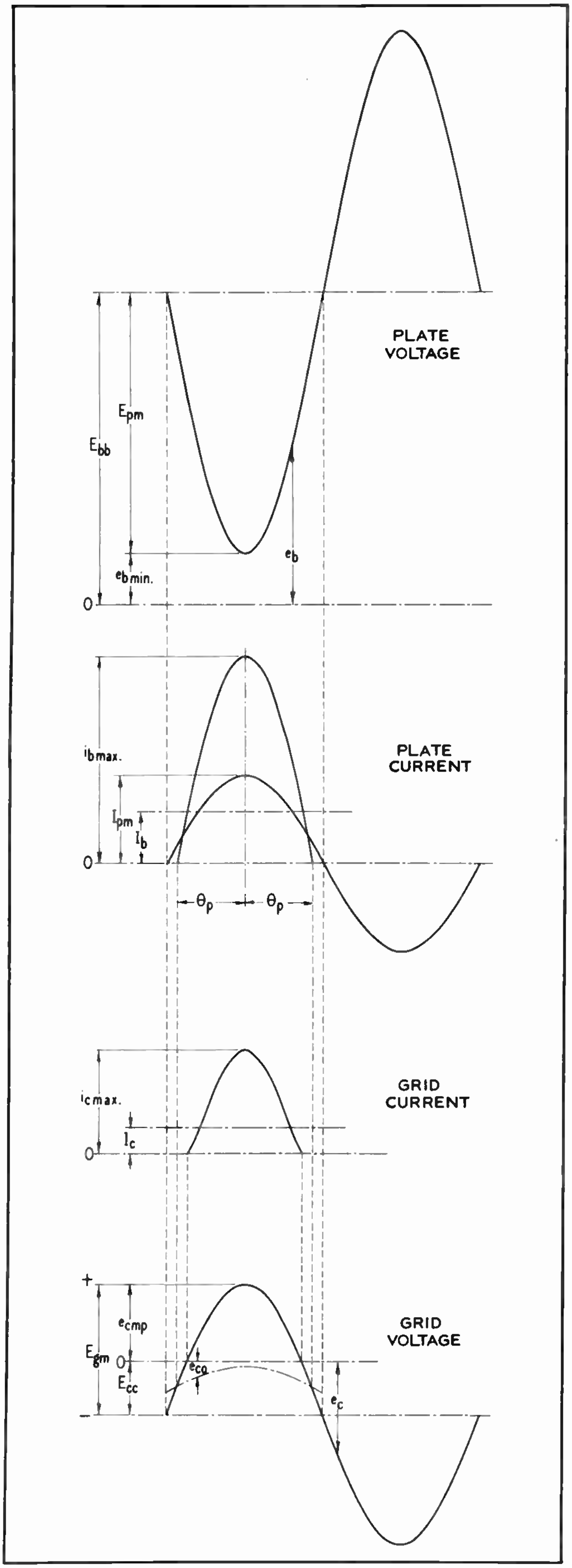

Figure 1. Symbols

Nomographs

This system of class-C amplifier analysis is now being converted to nomograph form for presentation in the near future.

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4 If this calculation gives Cos θ_p as zero or a negative quantity class-B operation is indicated and new operating conditions should be chosen on a basis of higher efficiency (less plate dissipation, more power output or less power input).

5 The calculated driving power is that actually used in supplying the grid and bias losses. Suitable allowance in driver design must be made to allow for losses in the coupling circuits between the driver plate and the amplifier grid.

6 "Vacuum Tube Ratings" Eimac News, Industrial Edition, Jan. 1945.

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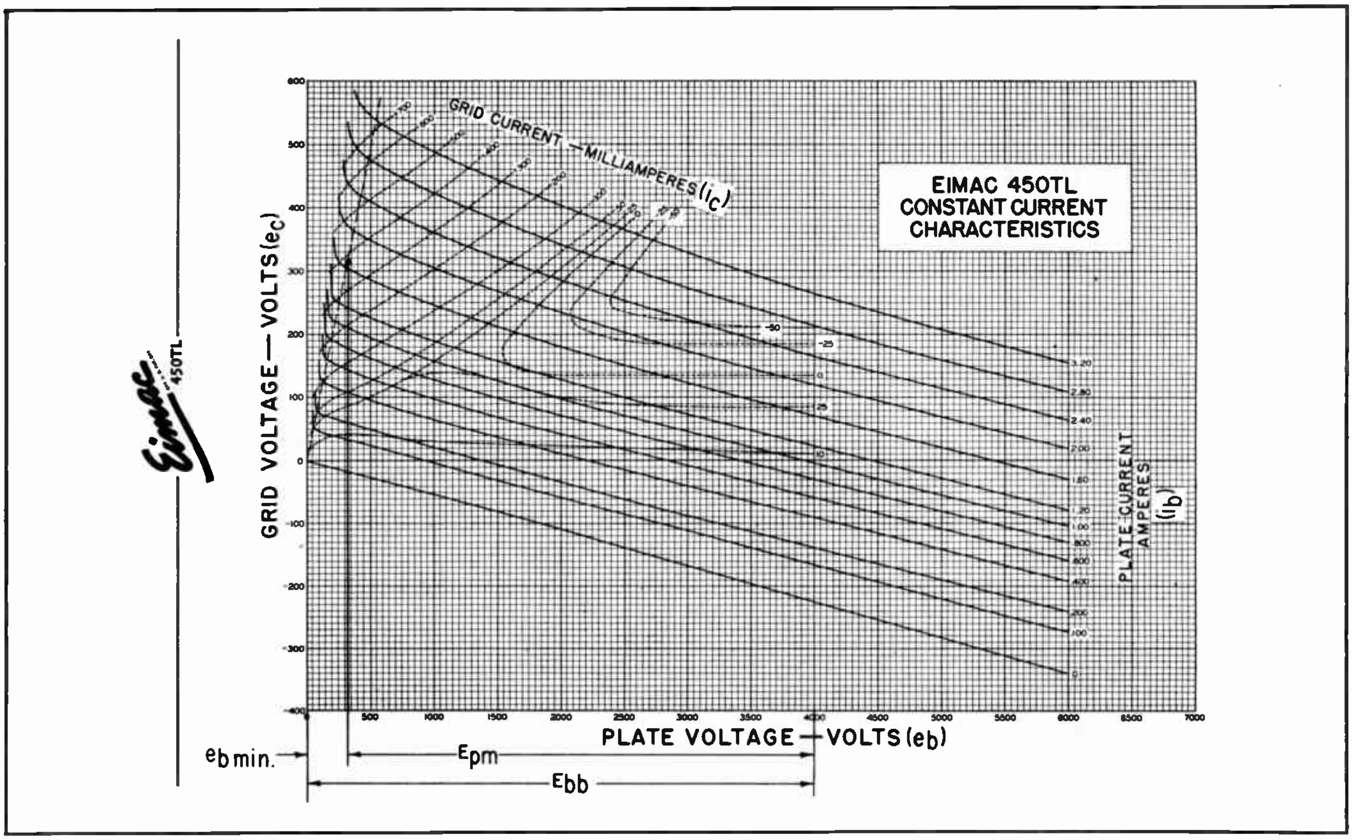

Figure 2. 450TL constant-current characteristics showing method of determining e_{bmin} and E_{pm} in steps 6 and 7 from value of i_b obtained in step 5.

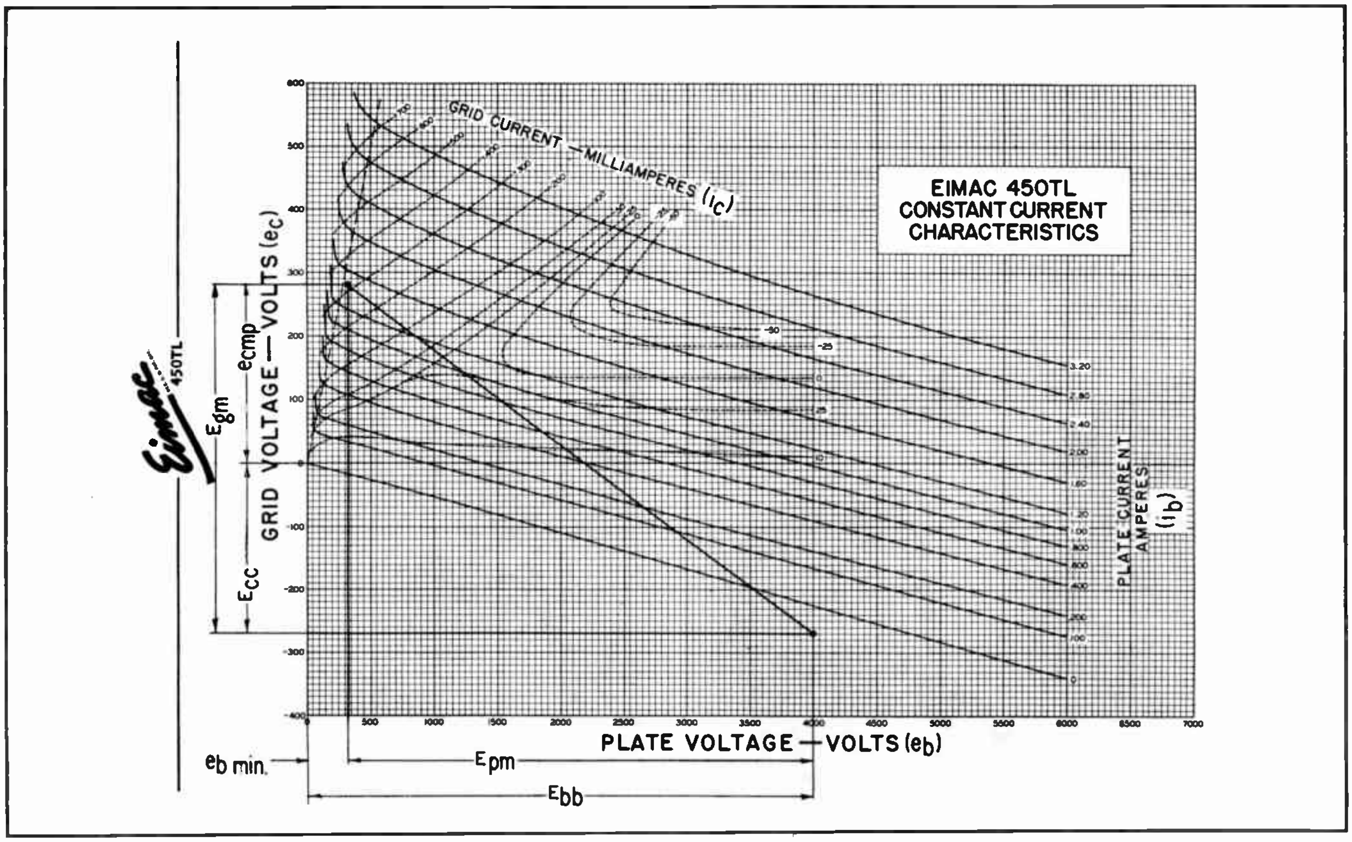

Figure 3. Method of determining e_{cmp} and i_c on 450TL constant-current characteristics from values of e_{bmin} and E_{pm} found in steps 6 and 7 and value of i_b found in step 10. The value of E_{cc} and E_{gm} from steps 13 and 14 and the operating line are also shown.

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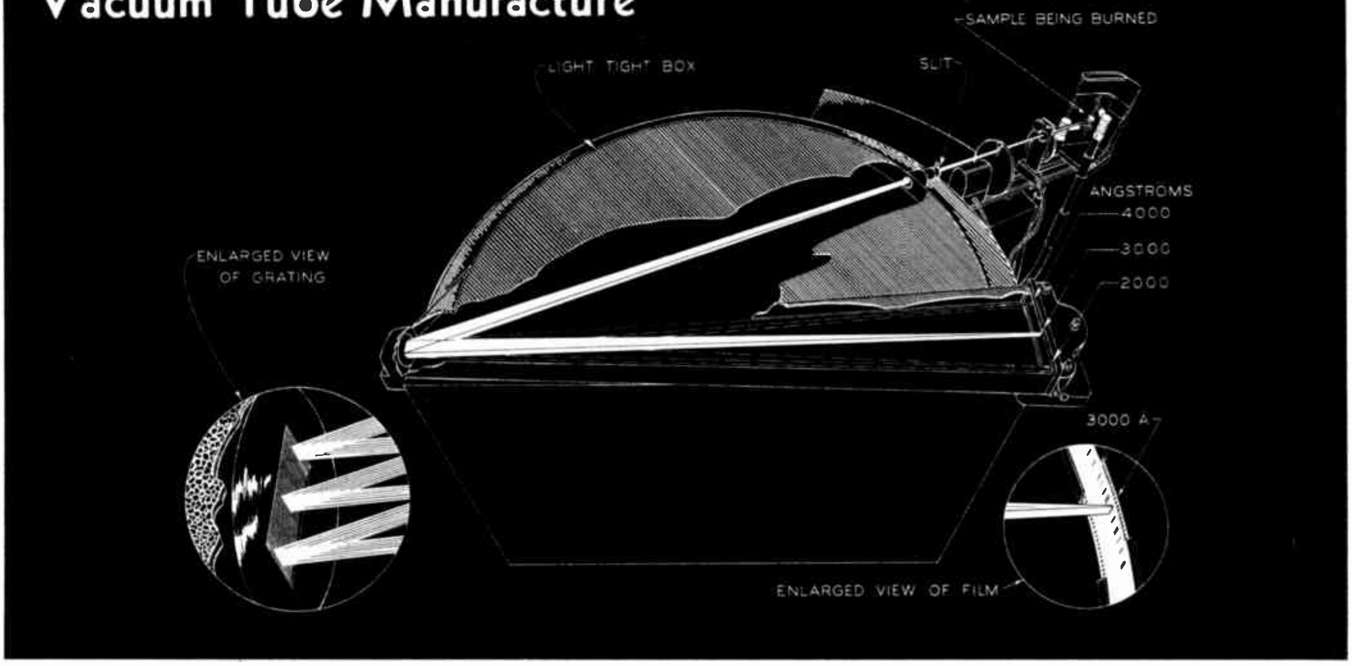
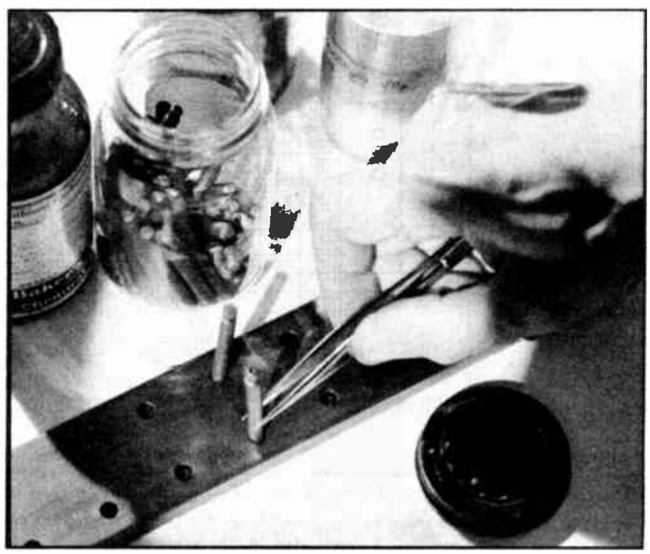
The Spectrograph In Vacuum Tube Manufacture



The analysis, by spectro-chemical means, of the materials used in the design and production of vacuum tubes, is a standard procedure in the Eitel-McCullough research laboratory at San Bruno. Not only are quality standards in materials received from various suppliers thus maintained, but the presence and the source of minute quantities of contamination both in the materials and in the assembled tubes are discovered and eradicated through the use of the spectrograph.

This instrument, illustrated above, is an ARL original concave grating type spectrograph of 24,000 rulings per inch, giving a dispersion of seven angstroms per mm. The resolution attained allows separation of lines 0.1 angstrom apart at a wave length of 2400 A.

A sample to be analyzed (right) is placed in the spectrograph and raised to temperatures as high as 4000°C by use of an arc (or spark) source of excitation (below, left) which causes the electrons of the sample material to digress from their orderly movements and go on excursions to outer orbits. Being unstable in these orbits, the electrons return to the stable orbits with numerous variations in path, emitting light of a specific frequency for each path. This light is directed through a fine slit in the optical system of the spectrograph (as illustrated above) and onto the grating which causes diffraction of the many separate frequencies present, each being focused onto the spectrograph film as an image of the slit. The picture thus obtained is one of a great many parallel lines arranged side by side, each representing a definite frequency by its position on the 12-inch strip of film used to record them.



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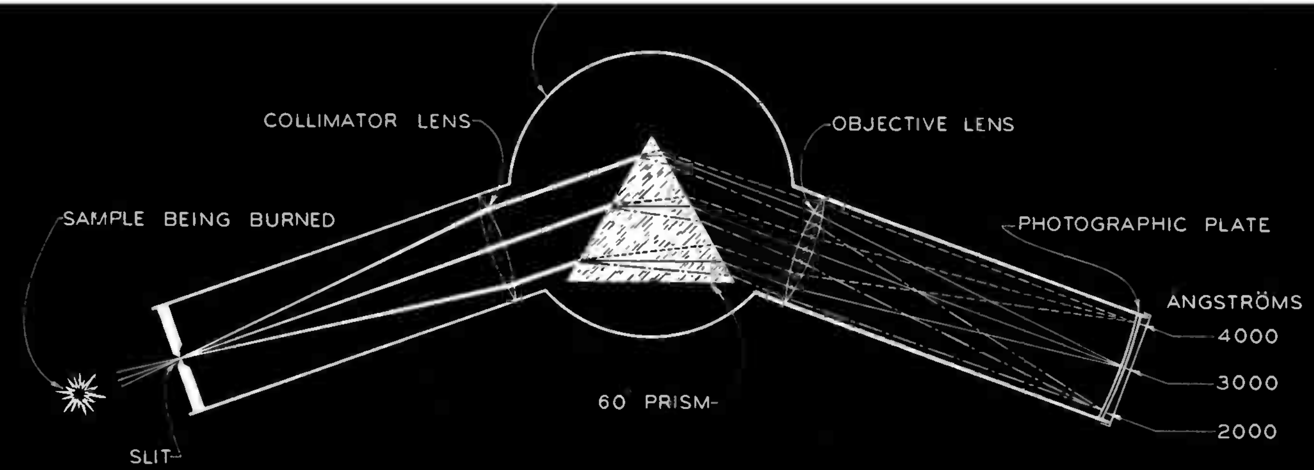

The above diagram serves to illustrate the more familiar type of spectrograph, still in use. Its prototype was developed by Newton in the 17th century, although the use of photography and the useful ultra violet region did not come till the beginning of the 19th century. The U. V. is found to be more prolific in lines and the film allows a record to be made of what would otherwise be a brief visual inspection when only a limited quantity of sample is available. A thorough study may thus be made of the material burned for example in very pure carbon electrodes (see photo), the "exposure" lasting but a few seconds.

The strip of film is processed by ordinary photographic methods (above) but under much more rigidly controlled conditions than those required for usual photographic purposes. The relative density or opacity of the spectrum lines appearing on the film must be held in direct ratio to the quantity of the element producing the line, unaffected by any variations in photographic procedure. Time of exposure, temperature of excitation, form of sample and other conditions in the operation of the spectrograph are, of course, maintained at standard values in order that they may be repeated or reproduced accurately.

Since each of the elements in the periodic table has its own arrangement of lines, as different and as individual as a set of fingerprints, it is possible to detect a great number of different elements in a single sample and to record them on the film strip.

The H & D curve for each film emulsion must be computed so that the effect of various light quantities upon the film may be determined and standardized. The finished photograph is placed in a precision densitometer (below) which magnifies any desired portion of the lined spectrum to 20 times film size, and by means of a photocell, allows accurate measurement of the opacity of any single line. A comparison of the relative opacities of the lines of two or more elements in a sample will permit calculation of the percentage of those elements present.

Concentrations of elements amounting to as little as .001% of the total sample are sometimes detectable, and even one part in a million has been measured by this means. Such measurements may also be made by chemical procedures, but they are vastly more painstaking.

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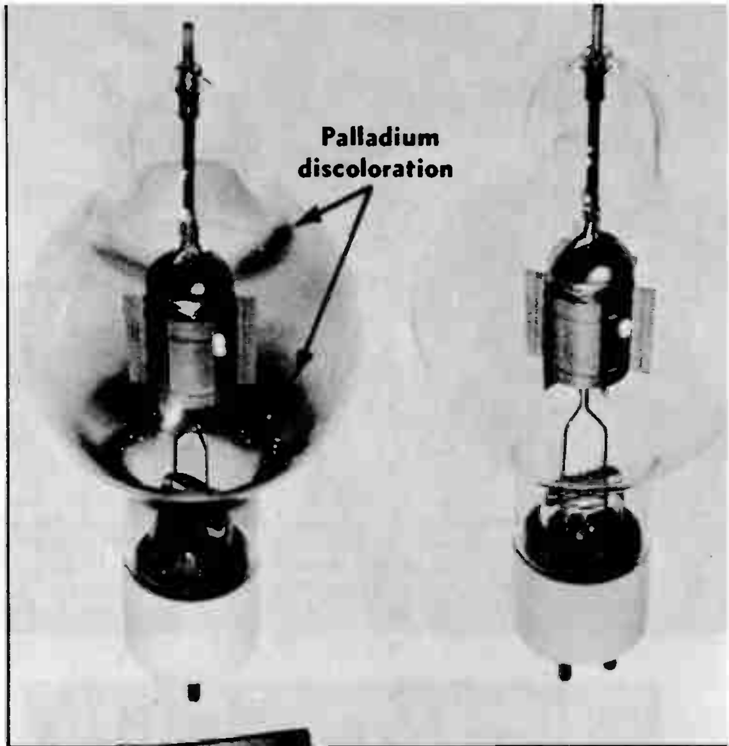
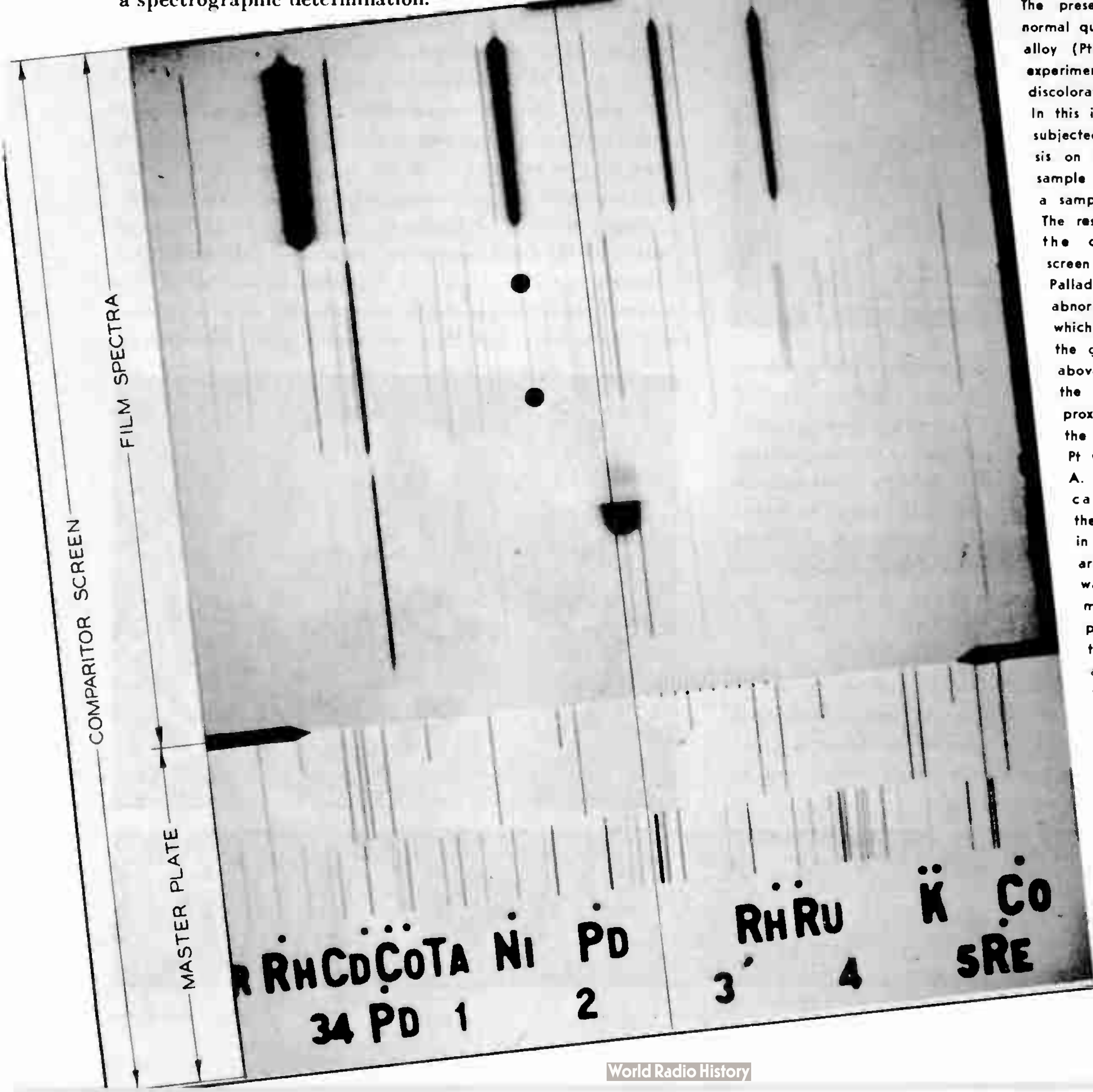
The high temperature employed in the processing and evacuating of transmitting tubes will cause the most minute quantities of certain impurities to volatilize from the elements and condense on the glass envelope (right). Such contamination, usually appearing as a discoloration of the glass, restricts the function of the envelope both as a transmitter of heat and as an insulator, and under extreme conditions may produce electron emission from the contaminated area. An example of glass contamination due to the use of palladium in an experimental filament structure is shown at right.

Such substances may bombard or react with the filament to cause its rapid deterioration, or they may adversely affect the primary and secondary emission characteristics of the grid. Discoloration of the glass envelope has been traced, for instance, to zinc oxide deposited in the envelope by contact with adhesive plaster on an operator's finger; in another instance to a brass part in a jig used in assembling the tube. The analysis of such minute traces and the tracing of their origins could scarcely be accomplished practically by any means other than a spectrographic determination.





The presence of Palladium in abnormal quantity in a platinum-tungsten alloy (Pt-W) grid wire in another experimental tube also resulted in discoloration of the glass envelope. In this instance, the grid wire was subjected to spectrographic analysis on the same film strip as a sample of normal Pt-W wire and a sample of high purity Pt wire. The resulting picture, as seen on the comparator-densitometer screen (left), revealed the high Palladium (Pd) content of the abnormal grid wire (top line) which caused the darkening of the glass similar to that shown above. The middle line shows the normal Pt wire, with approximately 0.01% of Pd, and the third line shows high-purity Pt with a trace of Pd at 3404 A. Neither of the latter two causes any discoloration of the glass. (The short lines in the middle row of lines are from iron used to check wavelengths against the master image which comprises the lower section of the picture. The master is a permanent 12-inch photographic plate built into the comparator unit. This plate and the film bearing the sample pictures are moved together to permit viewing any area of particular interest, allowing rapid determination of wavelength anywhere on the 12 inch film).

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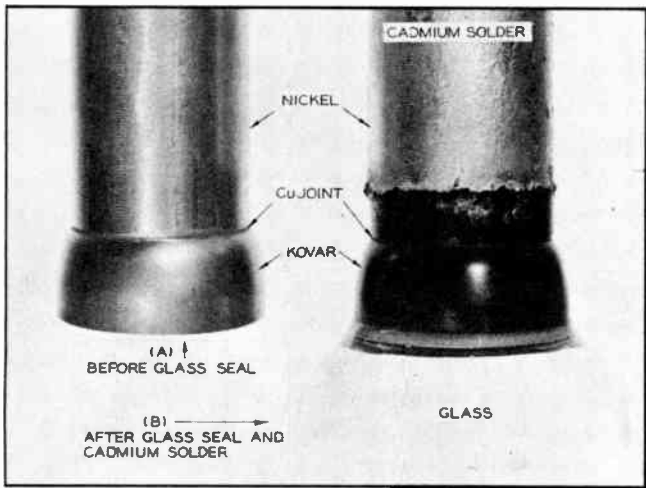
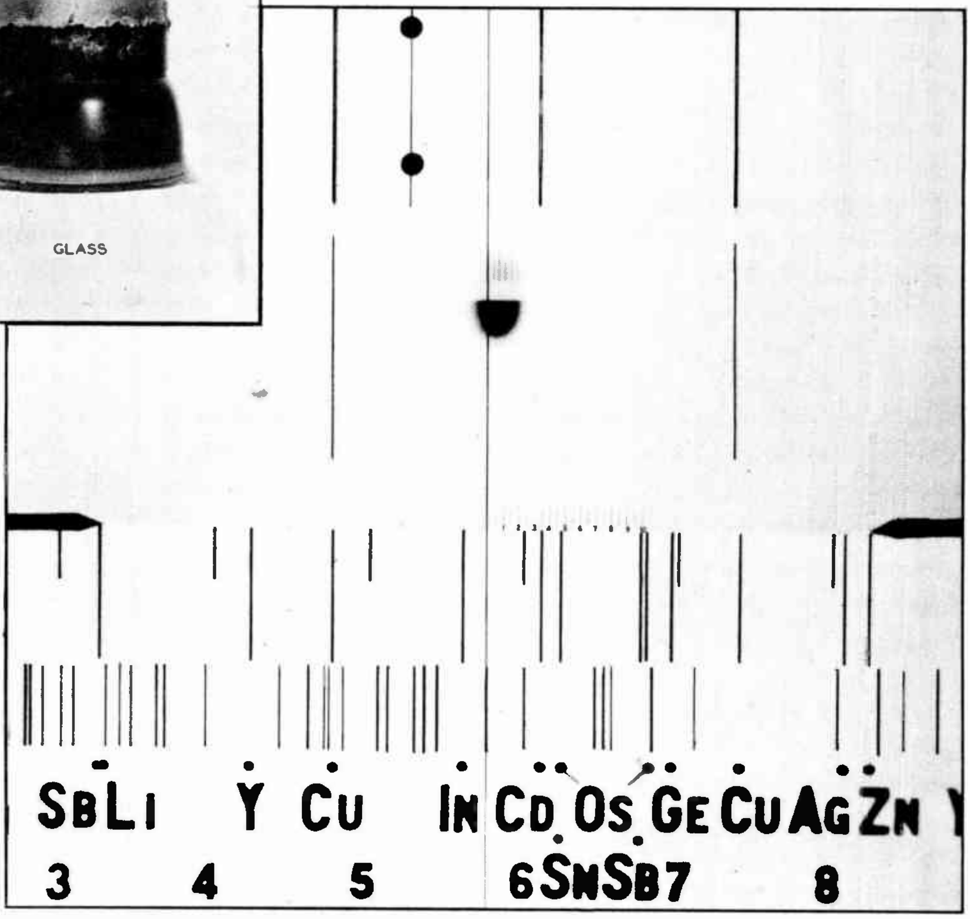


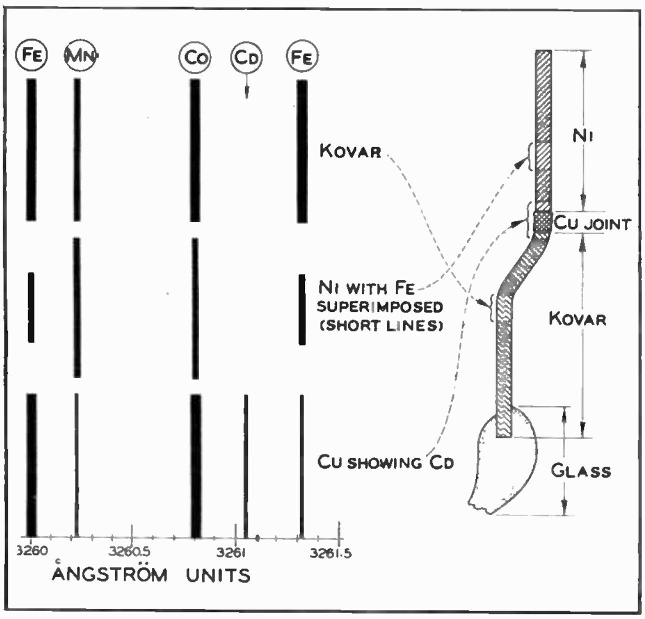
This glass-to-kovar-to nickel series of materials (above), used to produce a metal-to-glass seal in an experimental tube, resulted in an unusual situation which was explained by use of the spectrograph as described in the accompanying text.

One of hundreds of examples of uses of the spectrograph in locating sources of production difficulty arose in the fabrication of a glass-to-kovar-to-nickel series of materials in an experimental vacuum tube. The two metals were first joined by a brazing operation. When the experimental tube



This spectrogram (right) was made from a sample of the silvery deposit left on the inside of the glass envelope of the experimental tube mentioned above. Note the cadmium (Cd) line appearing in the top row of lines, just to right of center. Appearance of the cadmium line here enabled the researcher to trace its presence in the glass envelope to a copper joint through which the cadmium had diffused under high temperatures used in evacuating the tube (see text), since no cadmium appeared in the nickel or the kovar samples which were exposed on the same film strip (see diagram below).

Cross-sectional diagram of spectrogram (below) shows how the three portions of the glass-to-metal seal were analyzed simultaneously for comparative purposes in the spectrogram to trace the origin of the cadmium discoloration of the glass envelope.



was evacuated, a deposit of a silvery metal was observed on the interior of the glass envelope. The discolored glass was submitted as a spectrographic sample, and the deposit was found to be zinc, vaporized from the brazed joint by heat.

A new assembly was then made using copper as a joint between the kovar and the nickel. This proved satisfactory, so a set of cooling fins was attached to the nickel as a heat radiator, using cadmium as a solder. Later, this combination was found to have a minute air leak in the glass portion. The cooler was removed, the exterior of the system cleaned chemically of the cadmium, and the leak was repaired.

To test the unit, it was evacuated before the cooler was re-attached. A silvery deposit again appeared. This deposit was analyzed and found to be cadmium, apparently diffused into the interior of the tube by some path, due to the high temperature used in outgassing the tube. The spectrograph was again called into use, this time to discover the course of the cadmium migration. Sections of the copper joint and of the adjoining materials (see sketch at left) were prepared in three samples, which were burned successively to produce three adjacent exposures on the same film strip for comparative analysis.

The copper joint was found to contain cadmium, whereas neither the nickel nor the kovar was contaminated, thus indicating conclusively that the copper had provided an unsuspected path for the cadmium as a result of reheating.

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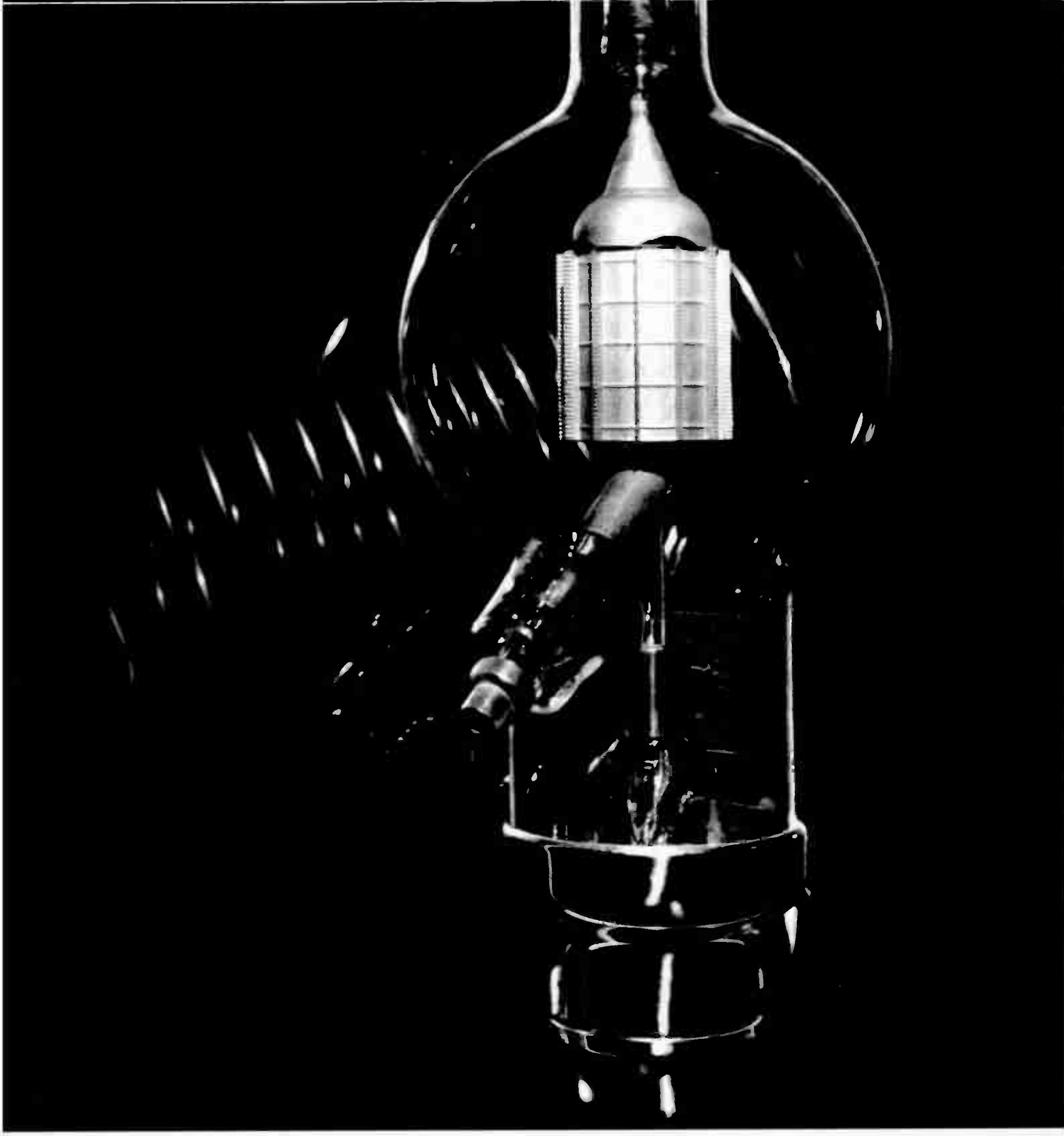

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