CANADA

THE MINES BRANCH CATHODE-RAY COMPARATOR-DENSITOMETER

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by

R.F. Sturrock* and A.H. Gillieson**

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SYNOPSIS

An instrument for the comparison of spectra has been designed to combine the advantages of a simple optical display with those of a corresponding cathode-ray display. Optical comparison is made by means of a projection system which focusses an enlarged image of the spectra on a ground-glass screen facing the operator. A section of one spectrum or of both spectra is scanned photo-electrically and presented in the form of a trace of relative transmittance versus wavelength on the face of a seven-inch cathode-ray tube adjacent to the ground-glass screen. The scanning mechanism, which is of the vibrating-mirror type, is so arranged that the optically projected image and the intensity trace are simultaneously visible. In this respect this instrument presents a considerable advantage over many previous scanning units. In the dual-trace model it is capable of being used for the improved detection of very faint lines in complex spectra. In the single-trace model with a measuring trace (so-called "peak-rider"), it can be used for the accurate and rapid measurement of line intensities for quantitative spectrographic analysis. With both models, accurate determination of wavelengths can be made and the intensity distribution or line-shape easily observed and recorded.

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Direction des mines

Bulletin technique TB 34

LE DENSITOMÈTRE-COMPARATEUR À RAYONS CATHODIQUES DE LA DIRECTION DES MINES

par

R. F. Sturrock* et A. H. Gillieson**

RÉSUMÉ

Pour fins de comparaison des spectres, la Direction a mis au point un appareil qui a le double avantage du simple étalage obtenu par des moyens optiques et d'un étalage correspondant obtenu à l'aide des rayons cathodiques. La comparaison optique se fait au moyen d'un dispositif de projection qui met au point une image agrandie du spectre sur un écran de verre dépoli en face de l'opérateur. Une section donnée de l'un des spectres ou encore des deux est explorée par voie photo-électrique et présentée sous forme de trace de la transmittance relative au regard de la longueur d'onde sur la surface d'un tube à rayons cathodiques de sept pouces placé à côté de l'écran de verre dépoli. Le dispositif d'exploration, qui est du genre à miroir oscillant, est monté de façon que l'image projetée par voie optique et la trace de l'intensité soient visibles simultanément. A cet égard, l'appareil en question présente un avantage considérable sur les nombreux appareils explorateurs employés jusqu'ici. L'appareil à double trace peut servir à déceler plus facilement les lignes très atténuées d'un spectre complexe. L'appareil à trace unique capable de mesurer (appelé "peak-rider" en anglais), permet de mesurer de façon précise et rapide les intensités de lignes lors de l'analyse quantitative des spectres. Avec l'un ou l'autre appareil, on peut déterminer les longueurs d'onde de façon précise et observer et enregistrer la répartition des intensités ou la forme des lignes.

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1. INTRODUCTION

The cathode-ray comparator-densitometer described in this bulletin was developed from 1953 to 1956 by R.F. Sturrock while he was a member of the staff of the Mines Branch Mineragraphic and Spectrographic Section. The final model designed and built by him has been in continuous use since 1955 for measurement of line intensities in routine quantitative and semi-quantitative spectrographic analysis.

By 1959, when the second author took charge of the Spectrographic Laboratories, the instrument had both thoroughly proved its value and become much worn, mainly mechanically, by the heavy and continuous demands on it. Fortunately the opportunity arose to have a second instrument built commercially, and at the same time to incorporate some improvements that the years of use had shown to be desirable.

This report covers the basic design of the two models, and then describes the features differing in them.

An optical comparator for the visual comparison of spectra is standard equipment in any spectrographic laboratory. Optical comparison of an unknown spectrum against a known series of spectra on a standard plate permits the rapid identification of the elements present in the sample. In addition, whenever quantitative analysis is to be done, it is necessary to have a micro-densitometer for the measurement of spectral line intensities.

Densitometers may be of the non-recording or the recording type. In the former, readings at selected points on the plate are made by observing the deflections of a galvanometer; in the latter a continuous traverse is made and the readings are recorded by means of a pen recorder unit. Several combined comparator-densitometer units are commercially available, and these instruments are mainly of the non-recording type.

Another type of microphotometer has come into limited use in recent years. This was first described by Furth (1)* and consists of an optical scanning mechanism in conjunction with associated electronic equipment to provide an instantaneous display on a cathode-ray tube of the optical density variations across a region of the photographic plate. This instrument permits a very rapid survey of the region under examination, as well as providing great horizontal magnification for extremely precise measurement of wavelengths. Several instruments of this type have since been described by others (2, 3, 4, 5, 6).

The scanning microphotometer described by Furth suffers from two limitations. First, it is not possible for the operator to observe the photographic plate visually, for identification and alignment purposes, without stopping the scanning process. Second, only one plate at a time can be scanned. If it were possible to scan and display two density traces simultaneously, a great deal

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* The references are listed numerically at the end of the bulletin.

of information could be obtained by direct comparison. The problem of identifying very faint lines would be minimized, since it is much easier for the eye to distinguish differences in height than faint differences in optical density. Also, a direct comparison of two density traces allows verification of some doubtful lines by relative intensity or by peculiarities in the shape of the line.

In view of the advantages of continuous optical density and of dual-trace cathode-ray display, the first instrument to be built was designed with both of these features (7). The first instrument will be referred to as "Model I", and a view of the instrument is shown in Figure 1.

After about one year's use, it was felt that the dual-trace instrument, while possessing great advantages for comparison of spectra, identification of lines and measurement of wavelengths, could be improved in regard to the measurement of line intensity. The measurement of the height of lines on the intensity trace, by means of a grid placed in front of the cathode-ray tube screen, cannot be done with any great degree of precision, largely because the whole cathode-ray trace moves about to a slight extent on the screen. This system of having transparent calibrated scales attached to the face of the cathode-ray tube was tried out but proved disappointing, both because of parallax errors in reading and because of the necessity for extreme electrical stability of the amplifier and deflection circuits to hold the trace steady. Thus, the dual-trace

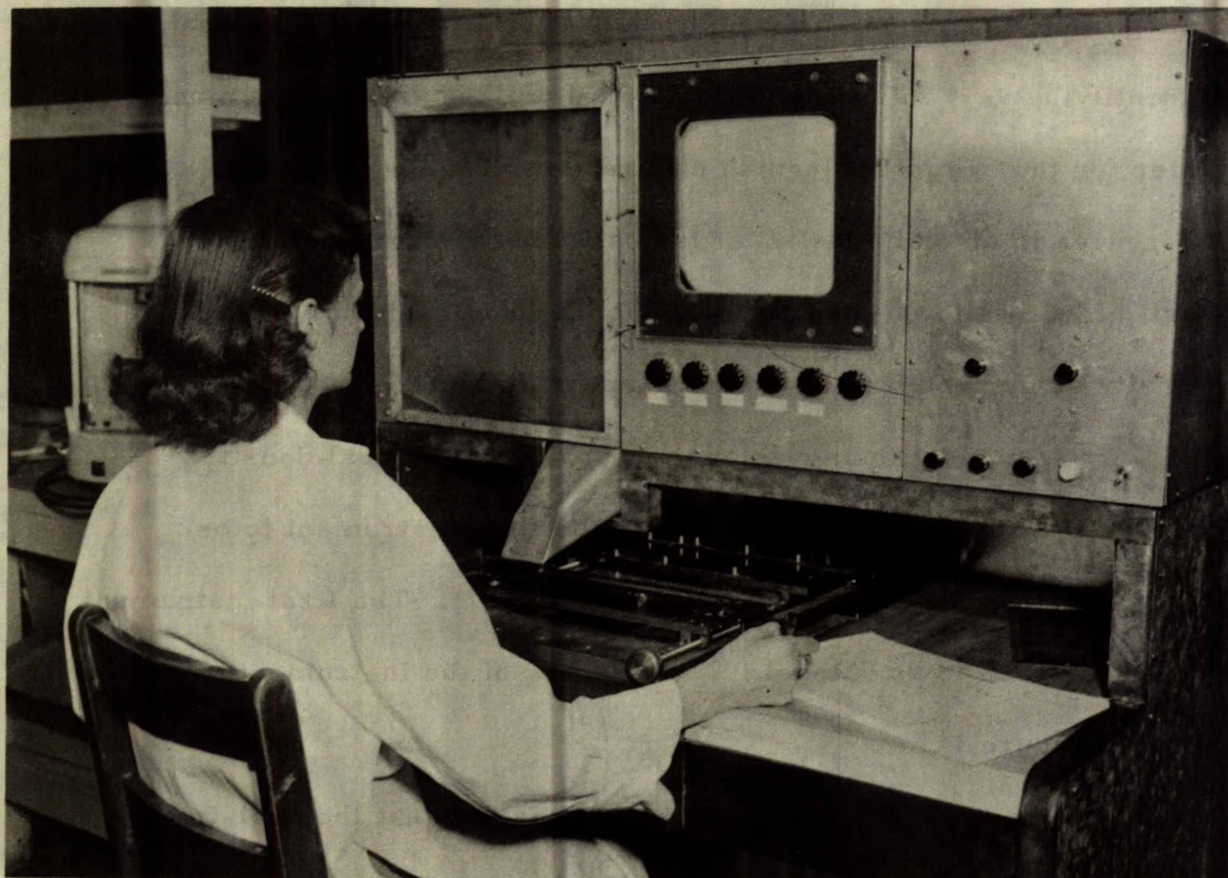

Figure 1. View of Model I.

instrument was of value for qualitative work but did not entirely meet the requirements of quantitative spectrography, in which greater precision is required.

A measurement system was therefore added to the first instrument, which eliminated both of the difficulties mentioned above. This modified instrument will be referred to as "Model IA", and is shown in Figure 2.

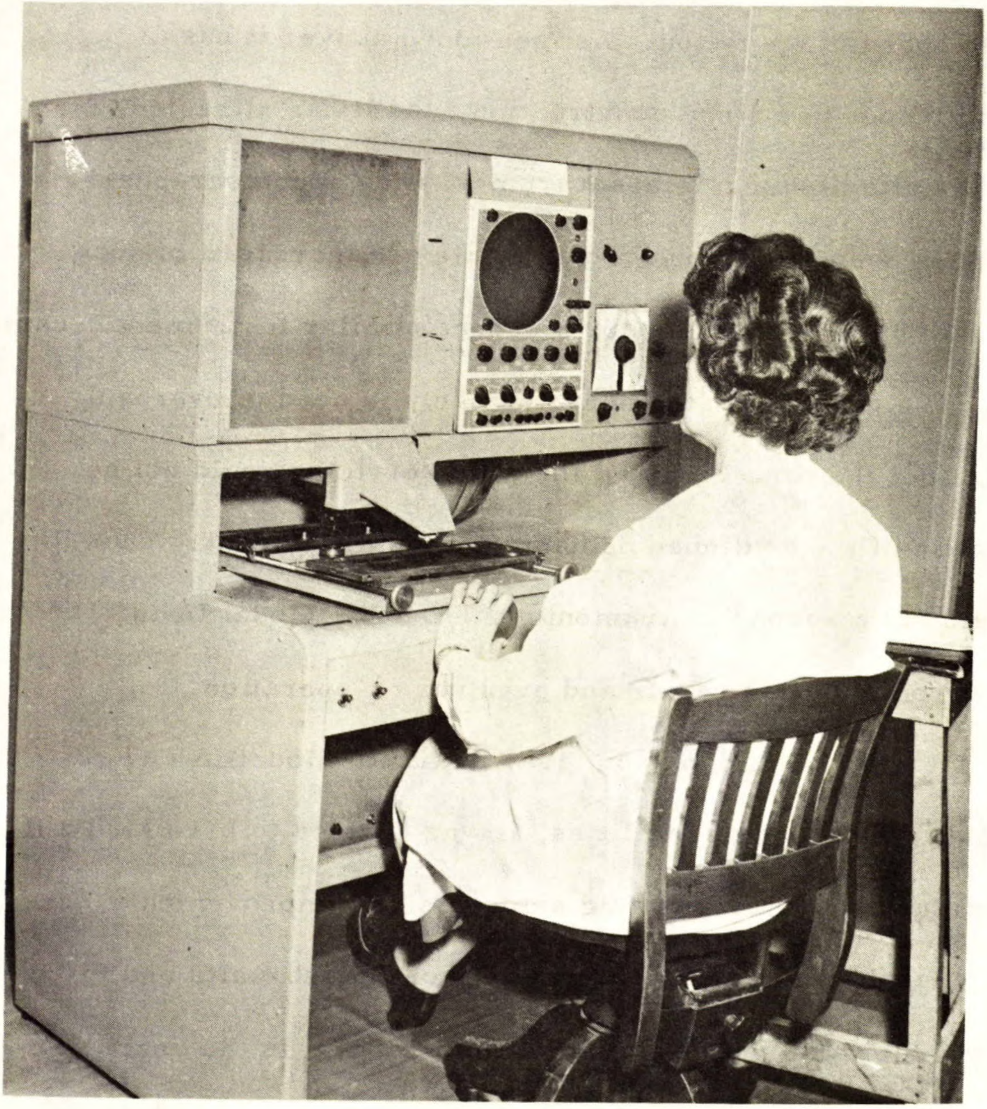

Figure 2. View of Model IA.

Model IA proved a very successful advance in the design of comparator-densitometers, especially as regards operator fatigue and speed of operation. As mentioned above, it has been in continuous use since construction, and it has attracted considerable attention and interest from visiting spectrographers.

The volume of work requiring its use increased to such an extent that by 1959 the need for a second similar instrument became apparent. The existing instrument was badly in need of overhaul and repair, but the time required for such servicing could not be found because of the continued demands on the instrument. Thus the provision of a second instrument would enable Model IA to be retired from duty for repair and eventual re-operation.

For the twofold reason, i.e., repair of Model IA and expansion of plate-reading facilities, it was decided to have Model II built commercially, incorporating some desired improvements, mainly in console design and arrangement of the sub-units and in the design and operation of the plate-holder stage. In the years of operation of Model IA, relatively little use had been made of the provision for the comparison of line-intensity traces, and in Model II, for reasons of economy and to avoid possible infringement of the Price-Mayer patent (5), the authors agreed to omit this facility. In this way, not only did a certain amount of simplification of the circuitry result, but there were also improvements in the optical arrangement, the chief of which was that the axis of the projection could now be central on the ground-glass screen, and the illumination of the screen in consequence made more even and symmetrical. The improvement in external appearance and arrangement of Model II is clear from Figures 3 and 4.

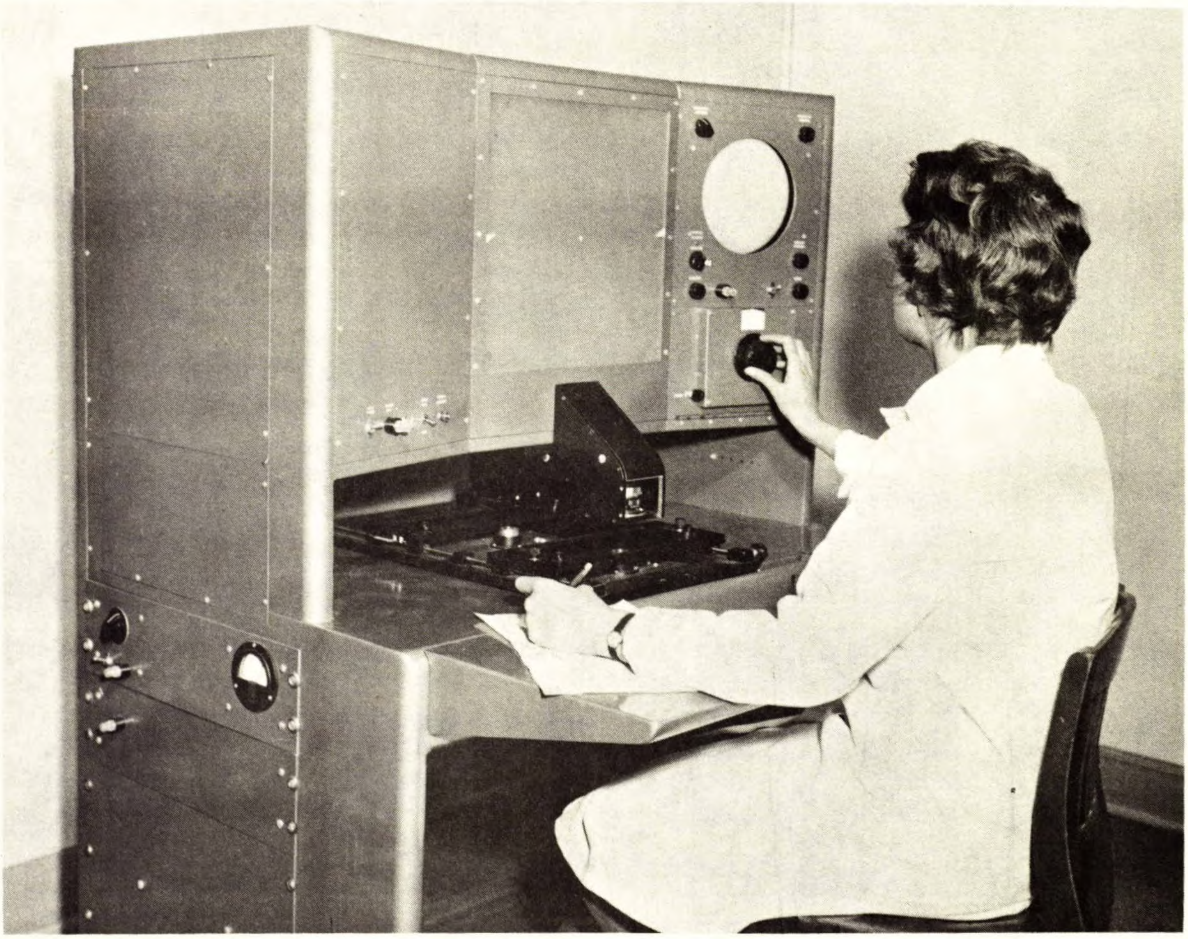

Figure 3. View of Model II - left front.

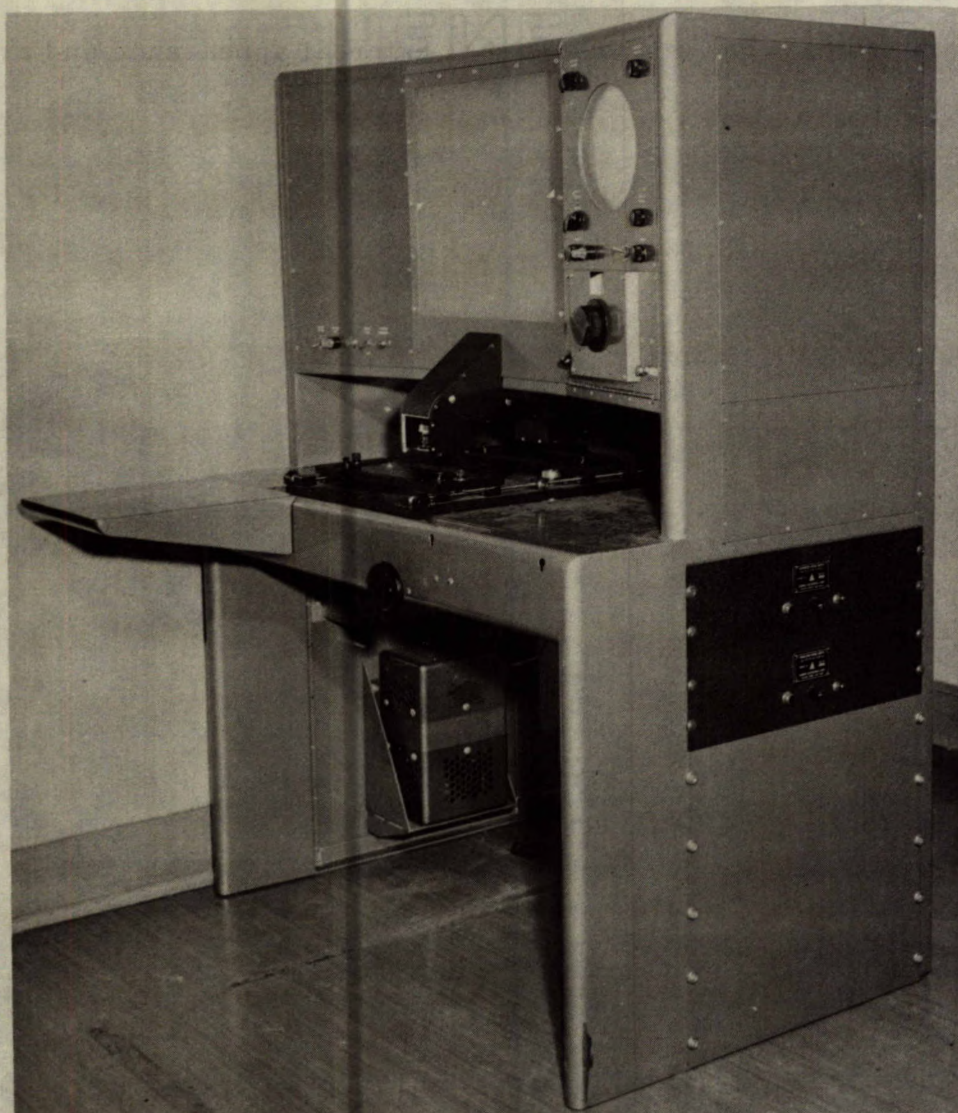

Figure 4. View of Model II - right front.

2. DESIGN

2.1 Basic Principle

The basic principle of the scanning comparator is illustrated in Figure 5. The photographic plate C is illuminated by the light source A through a condensing lens B. An image of the photographic plate is projected on screen F by means of lens D. Part of the light between D and F is reflected by a half-silvered mirror E to another mirror G which is vibrated at a frequency of 60 cycles per second by electromagnetic means. The light from the vibrating mirror is brought to a focus on a narrow slit H, which passes a very small portion of the beam to the light-sensitive cathode surface of a photomultiplier tube I. The orientation of the system is such that the spectral line images are parallel to the slit. The motion of the vibrating mirror G causes these line images to be swept back and forth across the slit and to produce variations in the electrical output of the photomultiplier which correspond to the variations in optical density across the portion of the plate being scanned. The output of the photomultiplier is then amplified and applied to the vertical input of an oscilloscope J. The horizontal deflection of the oscilloscope is driven by a 60-cycle sine wave in phase with the motion of the mirror. A trace results on the oscilloscope screen, corresponding vertically to the relative transmittance of the photographic plate and horizontally to the

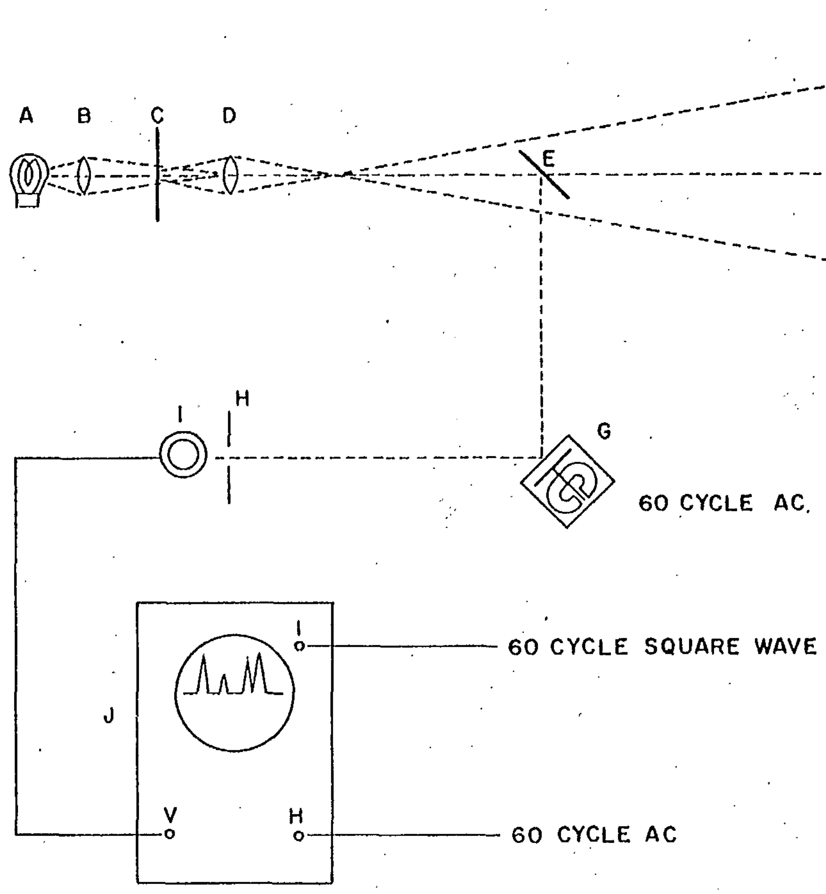

FIGURE 5. SIMPLIFIED DIAGRAM OF SCANNING SYSTEM.

position on the plate. Although the plate is scanned first in one direction and then in the other, the appearance of the return trace on the screen is prevented by application in the intensity circuit of a 60-cycle square wave which suppresses this unwanted trace.

2.2 General Design

As can be seen from Figures 1-3, all three models are of the console type, in front of which the operator sits, with the projection screen in front of him and the oscilloscope screen to his right, both at convenient eye-level. The console has lower and upper units separated by about 6 in. On the top of the lower unit is mounted the stage holding the two plates, and beneath it are fixed, centrally, the projection lamp box with its two condensing lens systems, and to the back or side, the stabilized power supplies for the projection lamps, the photomultiplier and the control circuits.

In Models I and IA, the upper unit contains the objective lenses, the remainder of the projection system and the half-silvered mirror, in one sub-unit; the vibrating mirror slits and photomultipliers in a second sub-unit; the oscilloscope in a third sub-unit; and the control circuitry in a fourth sub-unit. Model II has only three upper sub-units, but they differ from the previous model in having one photomultiplier and slit assembly, and the whole upper unit contains the same equipment arranged more conveniently for operation, access and servicing.

In all three instruments the oscilloscope is of the conventional type, obtained as a kit, the screen being of medium-persistence green.

All three instruments differ only in detail, and therefore the design of Model I will first be described, followed by descriptions of the modifications introduced in Model IA and in Model II. Optical design will be considered first, electrical second, and mechanical third.

3. DUAL-SCANNING COMPARATOR, MODEL I

3.1 Optical Design

The optical system used in the dual-scanning comparator is shown in somewhat simplified form in Figures 6a and 6b. Figure 6a shows the optical system of the comparator unit. The principal function of this unit is to form equally magnified images of the two photographic plates on a single ground-glass screen, for optical comparison. An image of the front plate is formed on the lower half of the screen by objective lens L_2 through the optical path joining mirrors M_1, M_2 and the screen. The image of the back plate is formed on the upper half of the screen by means of projection from lens L_4 to M_3, M_4 and screen. Part of the light from both M_2 and M_4 is intercepted by a half-silvered mirror M_5 and thereby reflected, horizontally and perpendicularly to the axis of the projection beams,

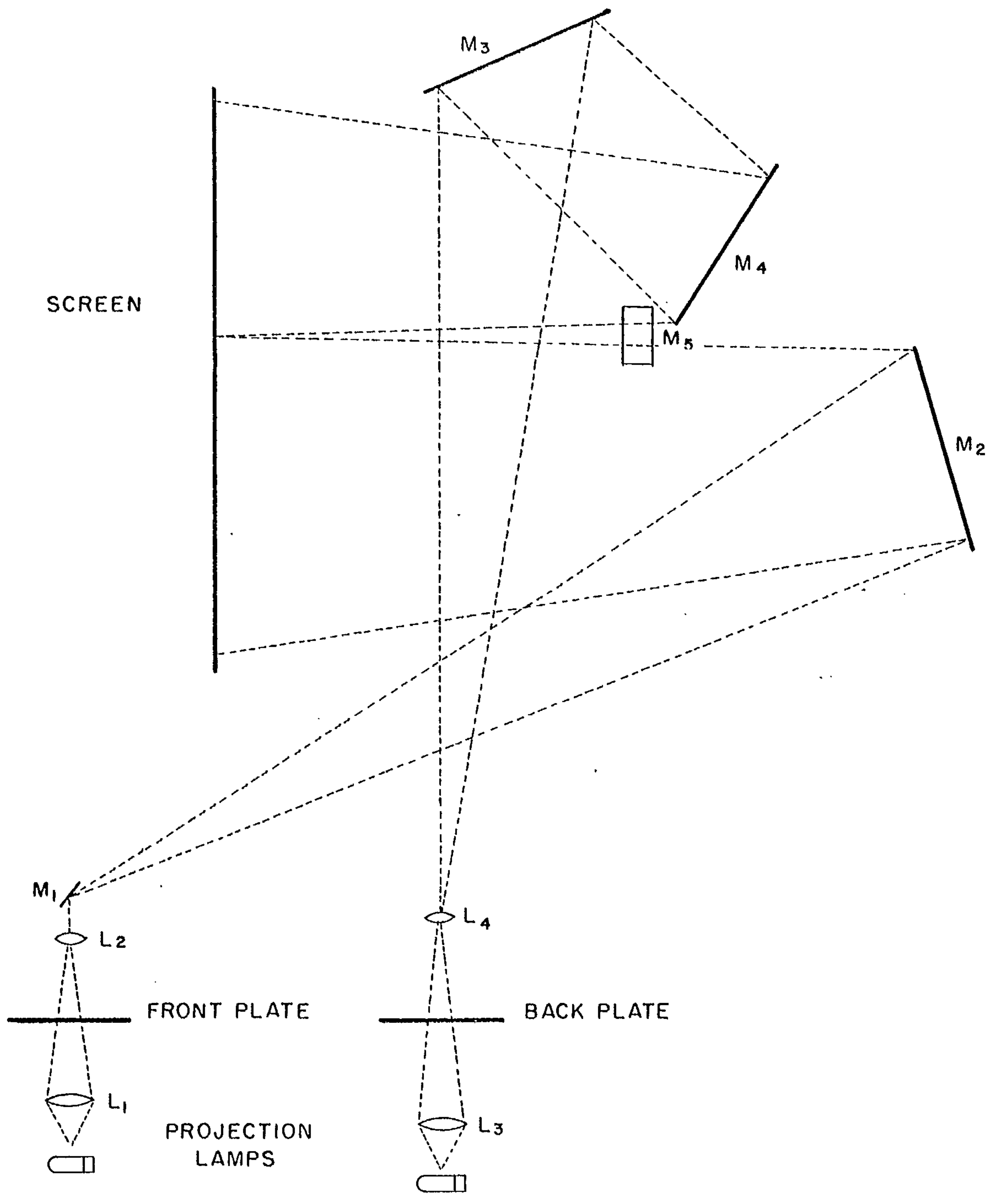

FIGURE 6a. MAIN OPTICAL SYSTEM OF COMPARATOR.

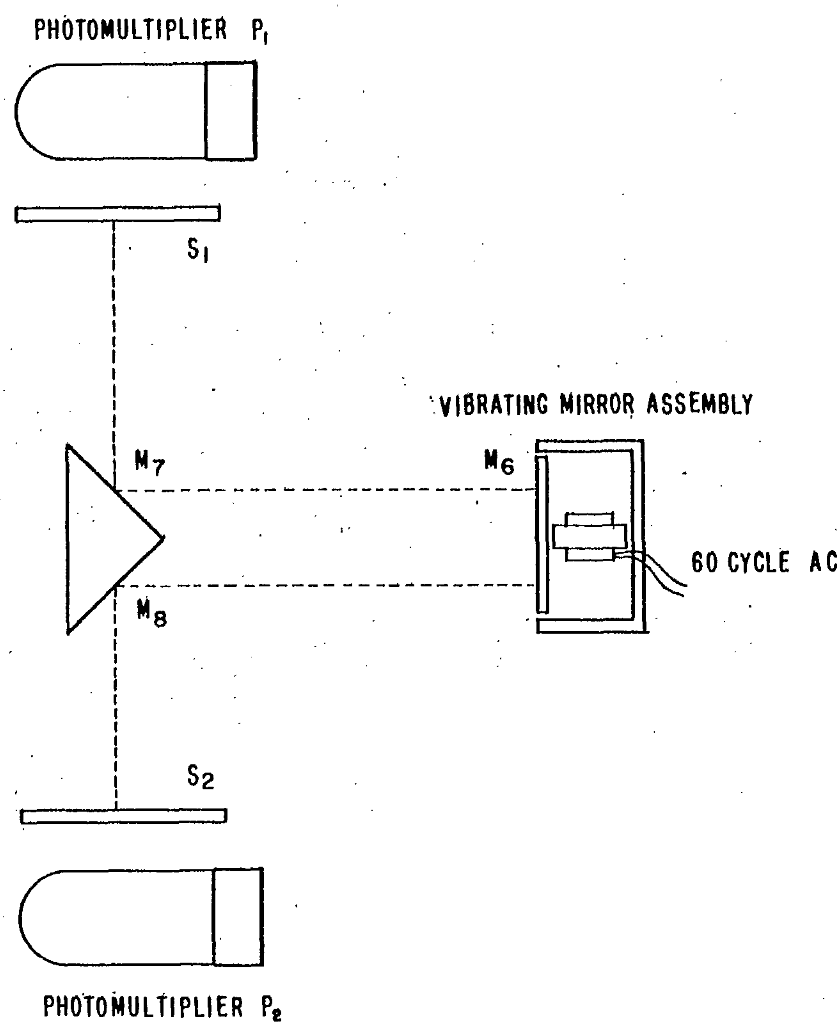

FIGURE 6b. OPTICAL ARRANGEMENT OF SCANNING UNIT.

to the scanning unit. The particular area being scanned is easily located on the optical screen by means of the shadow cast by the edges of M_5, and by the reduced intensity of the light passing through the half-silvered surface of M_5.

Figure 6b shows the scanning unit. The light from the half-silvered mirror in the main optical system is reflected from the surface of the vibrating mirror M_6 to M_7 and M_8. The portion of the light originating from the back plate is reflected upwards by mirror M_7 to focus on slit S_1, while that part of the light originating from the front plate strikes mirror M_8 and is directed downwards to focus on slit S_2. Light passing through these slits is picked up by photomultiplier tubes P_1 and P_2.

3.2 Electrical System

The electrical output of the photomultipliers is converted into a dual-trace,cathode-ray display by means of the electronic system shown in block diagram form in Figure 7. The two outputs are fed into a high-speed electronic switch, whose circuit is illustrated in Figure 8 and which alternately samples a portion of each signal. The output of the electronic switch is then applied as the vertical input of a conventional cathode-ray oscilloscope. The horizontal input to the oscilloscope is a 60-cycle sine wave produced and phase-controlled by the left-hand portion of the circuit in Figure 9. If this signal is in the same phase as the motion of the

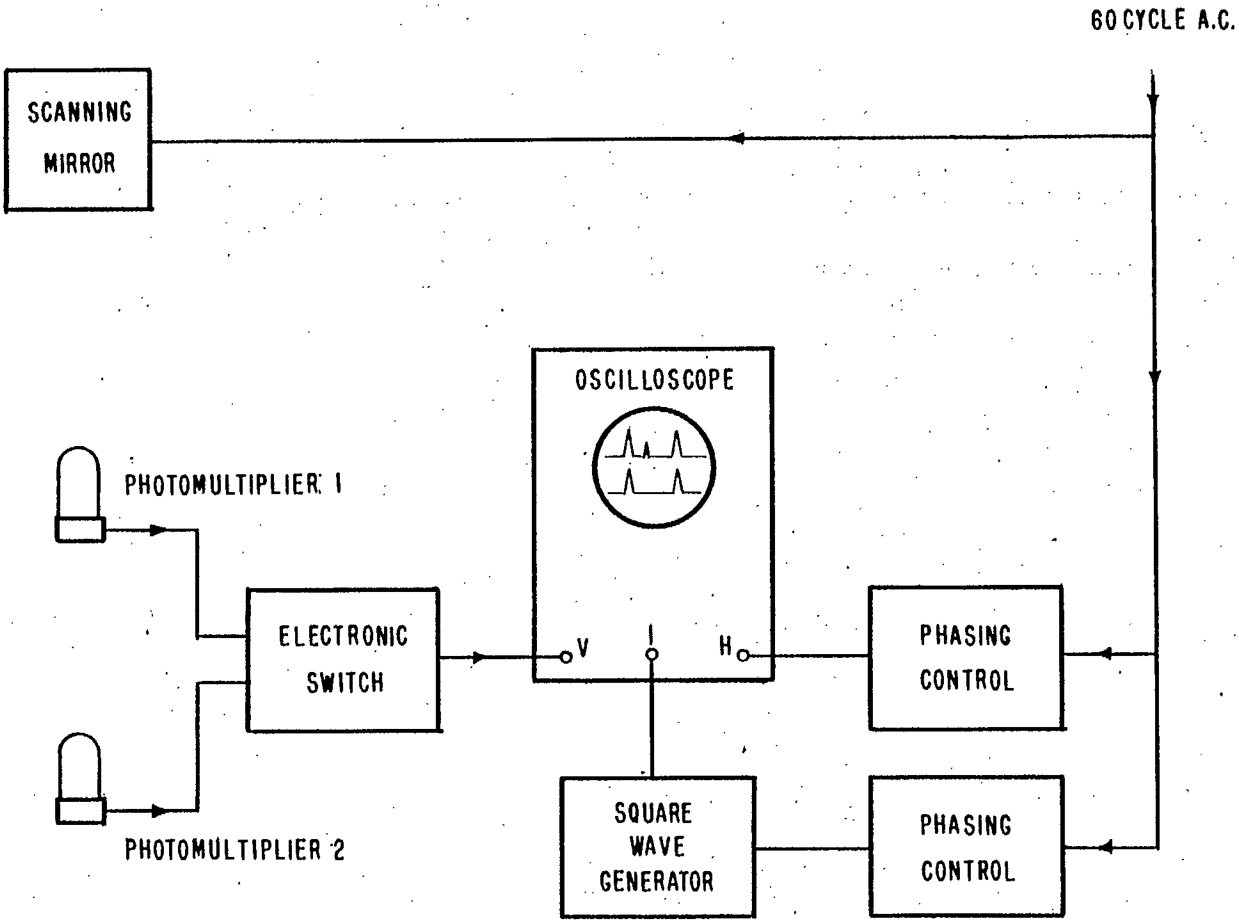

FIGURE 7. BLOCK DIAGRAM OF CATHODE-RAY DISPLAY UNIT.

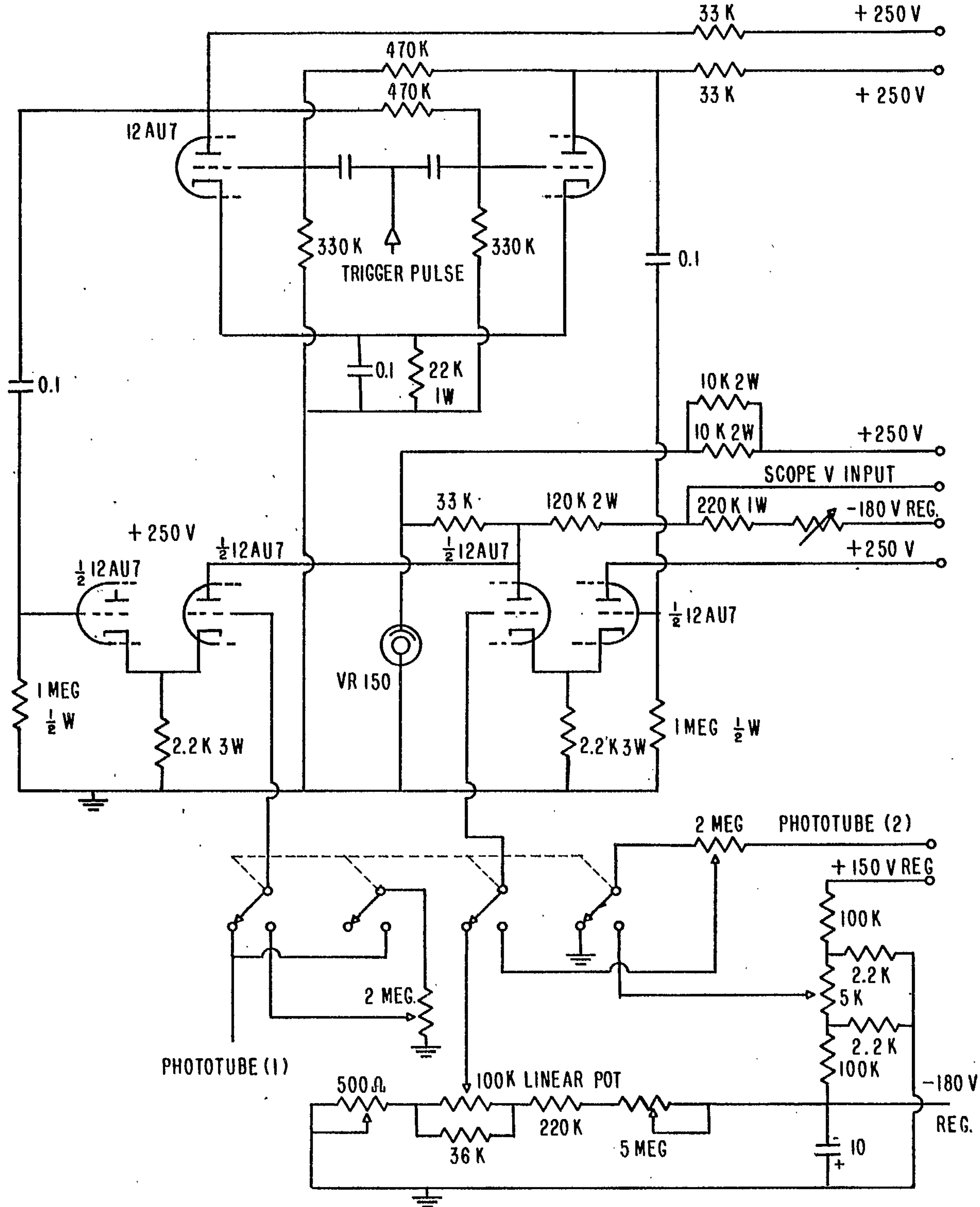

FIGURE 8. ELECTRONIC SWITCH AND VERTICAL TRACE CONTROL CIRCUIT.

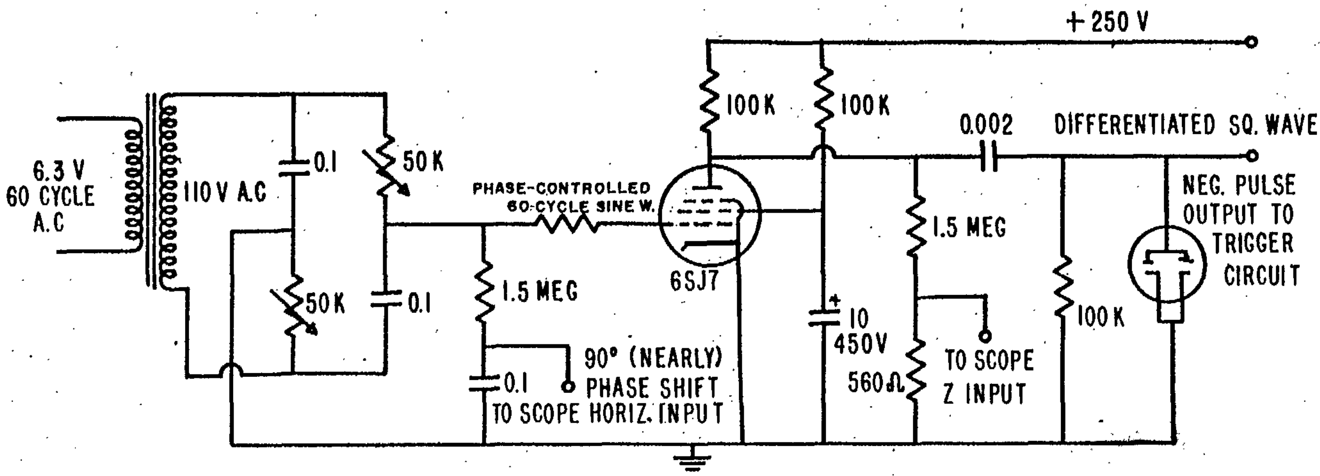

FIGURE 9. PHASING CONTROL AND TRIGGER CIRCUITS.

scanning mirror, the cathode-ray trace will have a horizontal deflection corresponding linearly with the position on the photographic plate.

In the right-hand portion of the circuit of Figure 9, the 60-cycle sine wave is amplified, converted to a square wave, and differentiated. A portion of the undifferentiated 60-cycle square wave is applied to the intensity grid of the cathode-ray tube to cut off the electron beam during one half-cycle and prevent the appearance of a double scan due to the two directions of scan.

The differentiated 60-cycle square wave signal is applied to the trigger circuit of Figure 10 to produce a 30-cycle square wave. This 30-cycle output operates the electronic switch.

A four-pole, two-position switch is provided to allow display either of signals from both the reference and unknown spectra, or of the unknown spectrum and a dc voltage reference for "peak-height" measurement of relative transmittance as described later in this report. For the dual-display technique, provision is made for controlling the relative gains of A and B channels, and also for relative positioning on the face of the cathode-ray tube. For peak-height measurements, the gains of A and B channels are identical and the positioning feature is eliminated to prevent confusion.

The relative phases and nature of the different signals of significance, and the functions of the electronic scanning circuits, are shown diagrammatically in Figures 10 and 11.

The stabilized power supplies are of conventional design, giving 300 volt dc for the control circuitry, 120 volt dc for the projection lamps, and 1200 volt dc for the photomultipliers.

The projection lamps are cooled by a fan or blower coupled to the box by wide-bore, thin-walled, corrugated rubber tubing, and are operated from the 110 volt ac supply.

3.3 Mechanical Design

The framework of the lower part of the console is of welded angle-iron, and is clad at the sides with sheet aluminum to form a thin compartment through which the electrical power leads from the supplies in this lower part are fed to the units in the upper part of the console. The power supplies rest on a shelf, about 6 in. off the floor, at the back of the console.

The mechanical stage fits into the top of the lower part above the lamp projection box. The whole stage can be moved right or left by a rack and pinion, the latter operated by a handwheel projecting through the narrow panel and conveniently placed for the seated operator's hand. The large main stage travels on ball bearings running in two machined grooves set parallel to the front, in the top of the console.

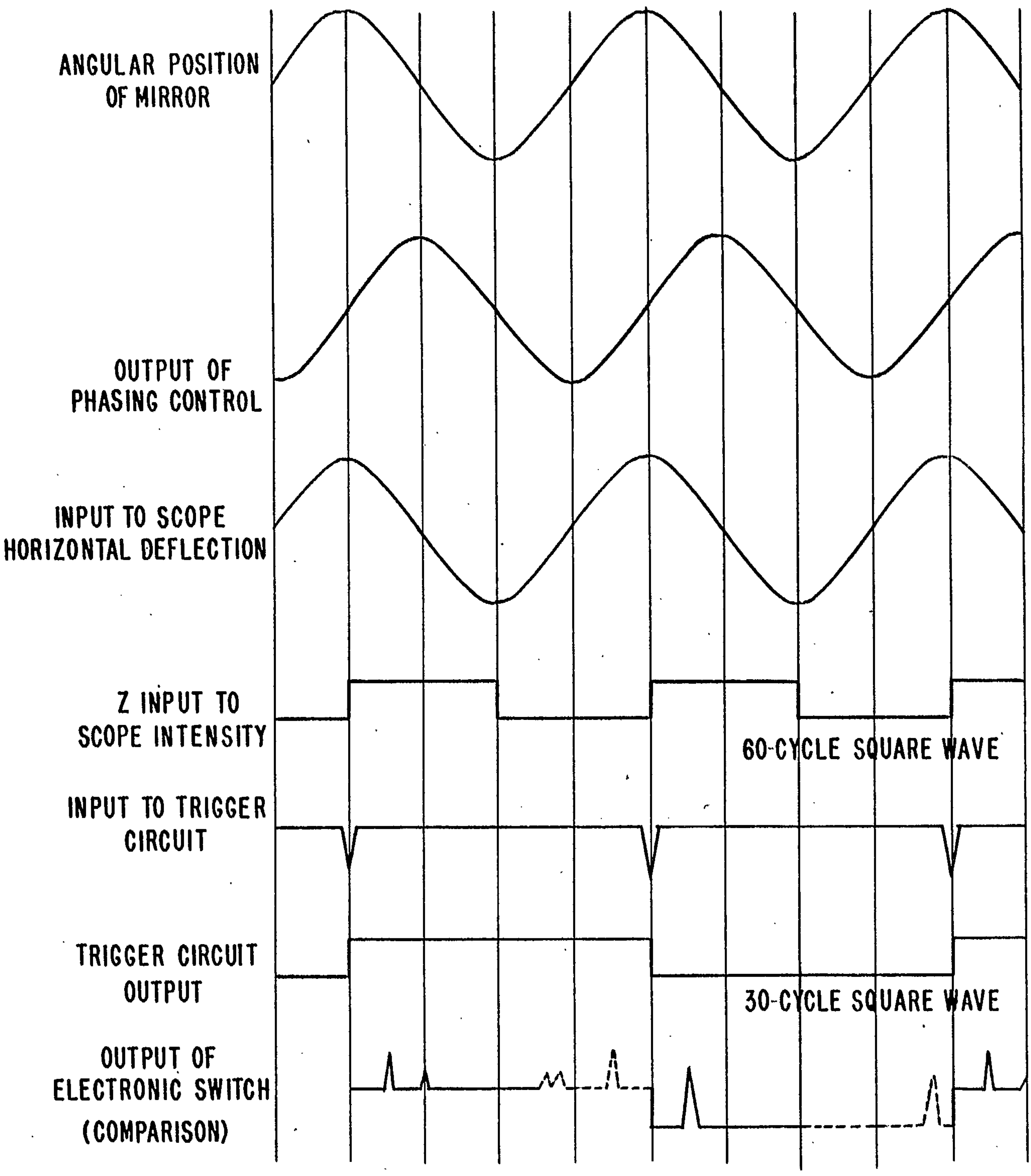

FIGURE 10. PHASING OF SIGNALS.

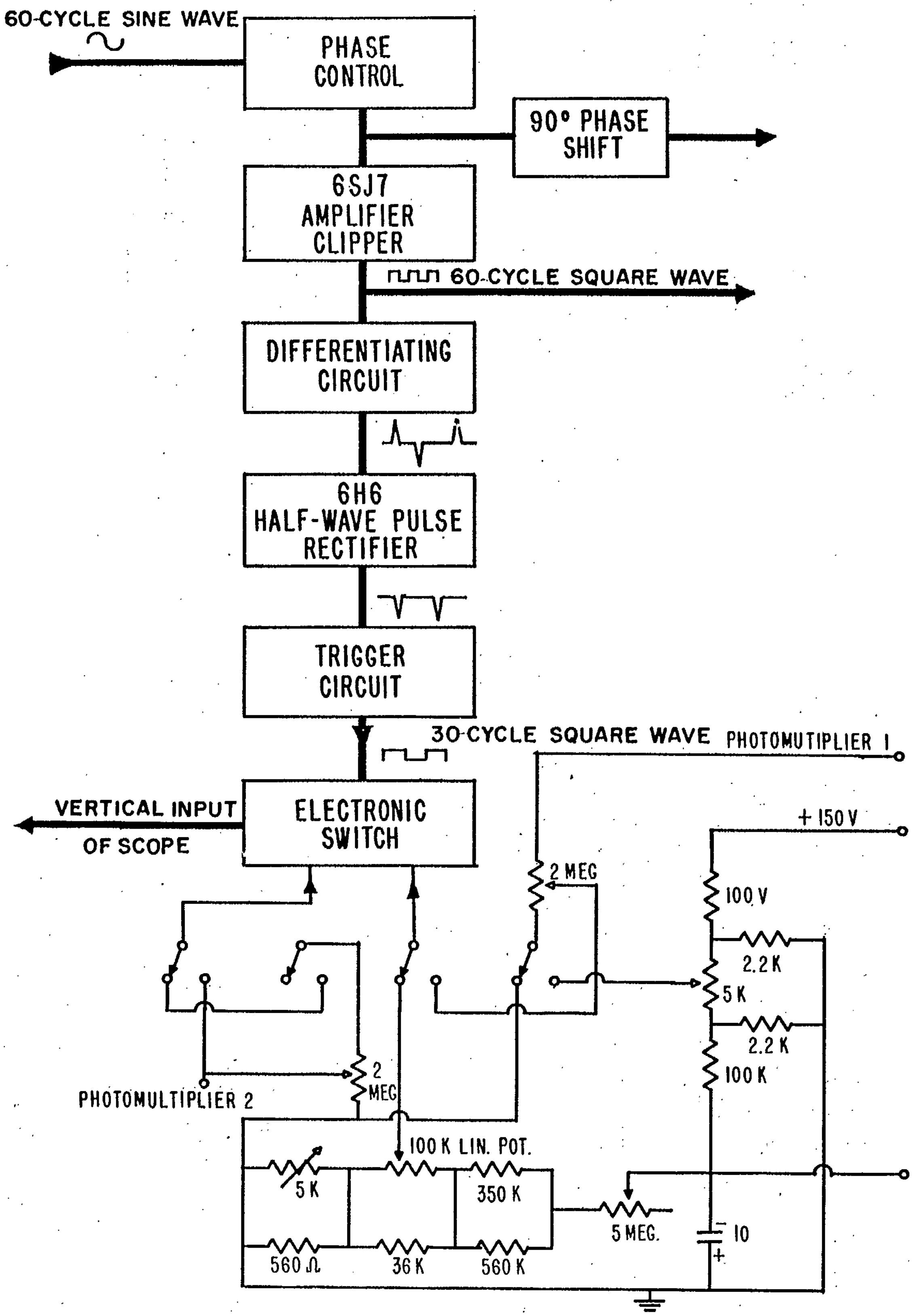

FIGURE II. ELECTRONIC FUNCTION DIAGRAM.

On the top of the main stage, two plate-holder sub-stages travel on the same type of ball bearing system, with grooves at right angles to those of the main stage. These plate-holders are moved backwards and forwards by lead screws operated by small handwheels at the front of the main stage, the left-hand wheel controlling the movement of the back plate and the right-hand wheel controlling that of the front plate.

The lead screws engage half-nuts on the upper stages and the half-nuts are kept in contact with the screws by springs. By means of a push button above each half-nut, the latter can be disengaged from its lead screw to permit rapid and large movement of the plate-holders by hand.

The front plate-holder has a device for allowing alignment of the plate, by small rotation through a vertical axis placed approximately at the right-hand edge of the plate. The plate rests on ways at front and back, and is held by spring clips at both ends, that on the right end being movable by a small lead screw and thumb wheel to permit small lateral adjustments of the plate. If required, the plate can be held in close contact with the ways by means of pins fitting into the holes along the front and back of the holder and having a small spring blade bearing on the plate near its edge.

The back plate-holder is of simpler construction, and does not possess the angular or lateral adjustments of the front holder. Unlike the latter, the plate recess runs from one side of the holder to the other, permitting considerable lateral offset of the back plate in comparison with the front one. Plates from the same spectrograph, whose wavelength ranges differ by half the spectrograph's wavelength range for a plate, can thus still be compared--at least while their wavelength ranges overlap. The upper units, containing the main part of the optical system, the scanning unit, the oscilloscope and the control circuits, rest on an angle-iron frame extending about 6 in. up from the top of the lower part and set back from the front by about the same distance.

4. DUAL-SCANNING COMPARATOR-DENSITOMETER, MODEL IA

The mechanical and optical systems of this instrument do not differ from its predecessor: the important modification made is the introduction of the "peak-rider" for measuring the heights of the line peaks on the intensity trace from the front plate.

4.1 Peak-height Measuring Device

The method of measurement consists essentially of the direct comparison of the output signal from the measurement photomultiplier with a potentiometer-controlled reference voltage, by means of simultaneous display on a cathode-ray tube. This is achieved by feeding the electronic switch with the reference voltage in place of the output from the photomultiplier associated with the back photographic plate. The resulting appearance of the two

 Range Potentiometer — 1 Meg

traces is shown in Figure 12. When the reference voltage is adjusted so that the flat trace just sits or "rides" on the peak of the line being scanned, the two signals are just equal in amplitude. By calibrating the potentiometer scale linearly from zero to one hundred per cent, and using two controls to set the correct range limits, the potentiometer arm will read directly the percentage transmittance of the line peak. One of these controls is used to set the reference trace to coincide with the dark level of the scanning trace when the potentiometer is set to read 100 per cent transmittance. The relative transmittance of any peak or background level can then be read directly from the potentiometer scale by setting the reference trace at the desired point on the scanning trace. A block diagram of the modified system is shown in somewhat simplified form in Figure 13. The electronic switch is designed so that when measurements are being made, the actions of the individual gain controls and of the positioning control of the electronic switch are rendered inoperative and thus the positions of the controls do not affect the measurement.

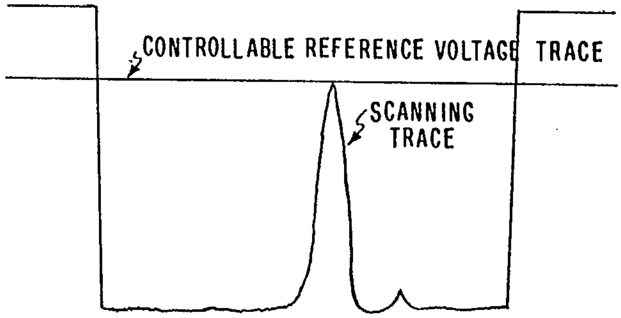

Figure 12. Simultaneous display of scanning and reference voltage traces.

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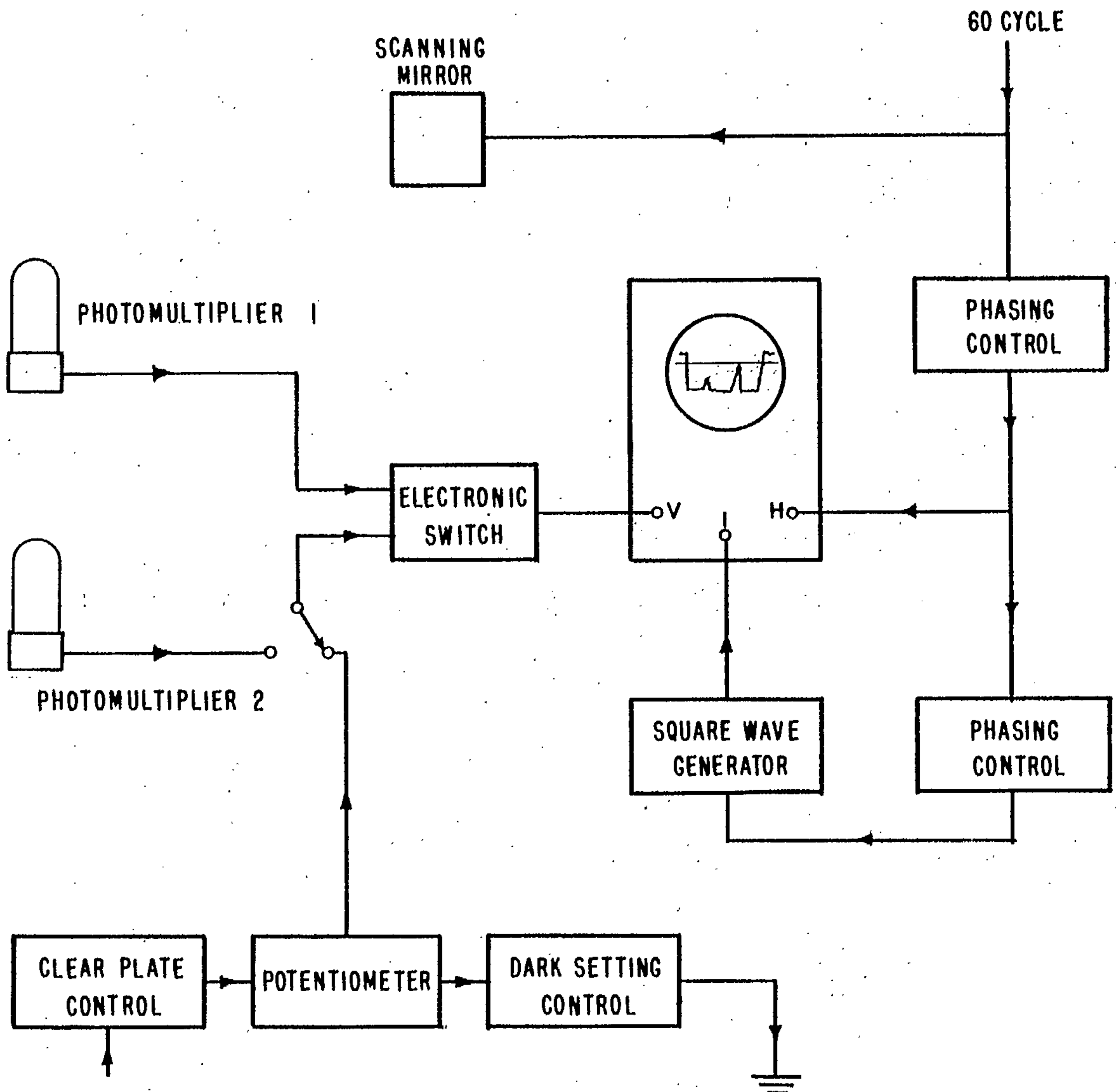

FIGURE 13. BLOCK DIAGRAM OF MEASURING CATHODE-RAY DISPLAY UNIT.

5. SINGLE-SCAN COMPARATOR-DENSITOMETER, MODEL II

For this, the first model built commercially by Measurement Engineering Ltd., Arnprior, Ont., the mechanical and optical designs were altered and the electrical design simplified.

5.1 Optical Design

The abandonment of the provision of the second spectrum scanning permits considerable simplification and some improvement of the optical system. In particular, mirrors M_7 and M_8 (see Figure 6b) are no longer required, nor is it necessary (see Figure 6a) that the beam-splitter mirror M_5 lie between mirrors M_2 and M_4 and the screen. Since it is only necessary to intercept the light from the lower mirror M_2, the beam-splitter M_5 can be placed farther back, thus lengthening the available optical path between this half-silvered mirror and the focal point on the slit of the photomultiplier. The additional path length thus introduced is taken up by bringing the "beam-splitter" into the middle of the field of view on the screen, thus improving the symmetry of the design and rendering the illumination of the screen more even.

At the suggestion of T.R. Flint of the Physics and Radiotracer Subdivision, the half-silvered "beam-splitter" M_5 is now placed as far back as it can go, namely in the plane of mirror M_2, centrally and within its upper edge (see Figure 14). M_5 no longer intercepts light between M_2 and the screen, but is a part of the

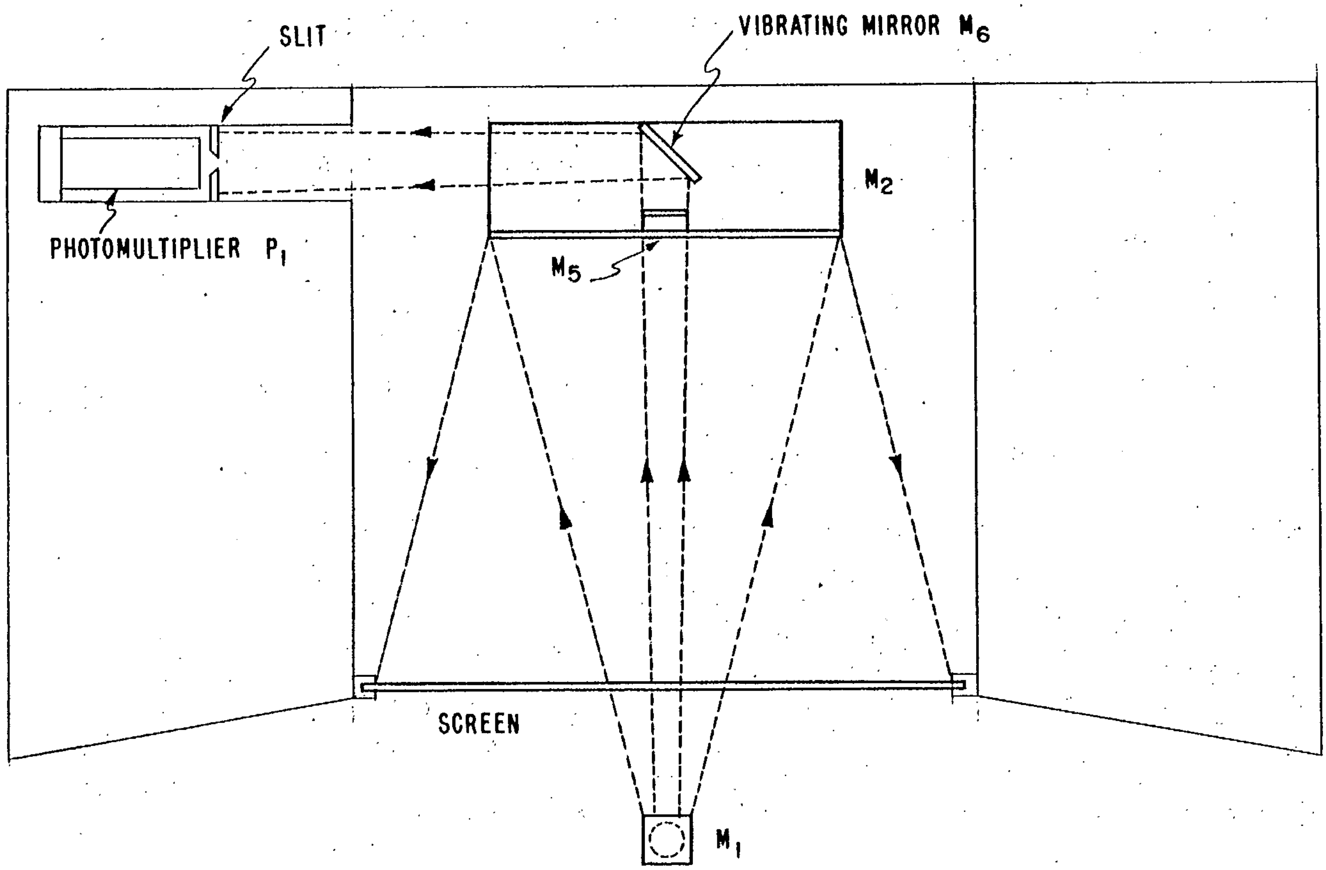

FIGURE 14. OPTICAL PROJECTION AND SCANNING SYSTEM OF MODEL II.

reflecting surface of M_2. A portion of the light passes through it, to fall on the vibrating mirror M_6 mounted behind M_2, and is reflected parallel to the back of M_2 to the photomultiplier slit. The optical lever distance between the vibrating mirror M_6 and the photomultiplier is thus increased to a maximum, and in consequence the amplitude of vibration of M_6 necessary for scanning that portion of spectrum transmitted by M_5 is brought to a minimum. At the same time the accessibility of M_5 and M_6 and the photomultiplier and slit assembly is much increased.

Opportunity has been taken to make other minor improvements in the optical system, as follows:-

(i) The projection lamps have been fitted with a "dim-bright" switch, so that filament life is conserved during standby.

(ii) The aperture of the objective lenses L_2 and L_4 has been increased to f2.5, thus considerably raising the maximum of the screen illumination level.

(iii) The dial system of the "peak-rider" measurement potentiometer has been altered, from a cursor moving over a fixed scale, to a fixed cursor and a moving scale indirectly illuminated. The ease of reading scale values has been increased and operator fatigue lessened.

5.2 Electrical Design

The decision to abandon the provision for scanning the upper or reference spectrum removes the need for a second photomultiplier and the amplifier and control circuits associated with it, and the second input to the electronic switch now consists solely of the reference voltage.

5.3 Mechanical Design

The plate-holder stage of the previous models, described in 3.3, although ingenious in design, suffered from the practical disadvantages of too great ease of movement of the main stage and undue slip in the plate-positioning controls of the substage.

In Model II both the main stage rack-and-pinion and the substage lead-screws and half-nuts are replaced by steel cable controls laid out much as in the modern radio-receiver wavelength indicator. Motion is still easy, but there is no tendency to "coast". Both the main stage and the substages now run on circulating ball-bearings running on rod guides, so that the stages cannot jump and their movement is very rigidly defined.

6. PERFORMANCE

6.1 General Operation

Information as to performance is almost solely based on Model IA. Model II has not been in use sufficiently long for adequate appraisal.

A unique feature of these instruments is that they make possible an objective means of focussing the projection lens. Ordinarily a densitometer is focussed by adjusting the projection lens to produce a magnified image of the photographic plate, which in the judgement of the operator is as sharp as possible. The densitometer readings so obtained are partly dependent on the acuity of vision of the operator, and errors may result when combining the densitometric results of different operators.

In the present instruments the focus may be set by adjusting the objective lens until for any suitable peak, maximum height (i.e., minimum transmittance) is recorded in the spectrum intensity trace. This is made possible by the continuous nature of the scanning process. Focussing by determining minimum transmittance may also be carried out on an ordinary densitometer, but must then be done as a number of separate transmittance readings, from which, along with plate position for the readings, the position for minimum transmittance is obtained graphically in a manner so time-consuming that the method is not normally employed.

Customarily, quantitative readings on spectral lines are made in terms of the per cent transmittance of the line peaks. These readings are then converted into equivalent intensity units by means of a special calibration curve for the type of plate emulsion used. The concentration of the particular element is then determined by referring these intensity determinations to a working curve of intensity versus concentration.

In the Models IA and II, of the cathode-ray comparator-densitometer, the results are obtained in the form of the reading from a circular scale mounted on the measuring potentiometer. Due to the ease with which the scale can be changed, it has been found practical to make up a number of scales calibrated directly in equivalent intensity for the photographic emulsions in common use.

A further step has been taken in that scales were prepared reading directly in concentration of a number of elements, when using a particular photographic emulsion and carrying out a particular type of analysis. This was done for most of the elements in low-alloy steel analysis, recording on Eastman Kodak Spectrographic Plate S.A. 2; this proved highly satisfactory both in speed and accuracy.

Before the introduction of Model IA, visual estimation of line intensities was carried out by the Stallwood Air-jet Semi-quantitative Technique, by which two-thirds of the samples submitted to the laboratory were examined. All of this work was done for a number of years on the cathode-ray densitometer, and proved much more satisfactory and less fatiguing to the operator than the visual technique, particularly where heavy background to the spectral lines was present.

6.2 Accuracy of Measurement

Model IA was primarily designed to provide high-speed measurement for semi-quantitative analysis with the object of replacing visual estimates of intensity with a more accurate and objective system. As such, it was not intended to compete in accuracy with the very precise commercial instruments such as the Leeds and Northrup recording micro-densitometer. The measuring system ("peak-rider") does, however, provide sufficient accuracy to put the scanning instrument on a directly competitive basis so far as accuracy is concerned.

Table 1 shows a comparison of the densitometry of a single line by the Leeds and Northrup and the cathode-ray instruments.

TABLE 1

Measurement of Percentage Transmittance by the Leeds and Northrup Densitometer and by the Mines Branch Cathode-ray Densitometer (Model IA)

Cathode-ray Densitometer		L. and N. Densitometer	
Observer 1	Observer 2	Observer 1	Observer 2
19.1	20.3	31.8	30.1
20.0	20.2	31.8	30.3
20.0	20.2	32.1	30.1
20.0	20.1	31.8	30.1
20.1	20.2	32.2	29.9
19.9	20.0	31.8	30.2
20.0	20.0	31.8	30.0
20.0	19.9	31.7	30.2
20.0	20.1	31.8	30.0
19.8	20.0	32.2	30.1
19.97 ± 0.07	20.10 ± 0.11	31.92 ± 0.16	30.10 ± 0.08
*C.V. 0.35%	0.5%	0.5%	0.27%

The precision, as indicated by the average deviation of the readings, is approximately the same for the two instruments. The differences between the readings obtained by the two observers are less for the cathode-ray instrument than for the Leeds and Northrup, even though both observers had had much more experience with the latter instrument.

Table 2 shows a comparison of the relative intensity of a line pair, Ni 2992.6/Fe 2990.4, as determined by measurements on the same two instruments. The precision of the ratio determination is almost the same for each instrument.

*C.V. = Coefficient of Variance.

TABLE 2

Measurement of Relative Intensity of Ni 2992.6/Fe 2990.4 for Steel Standard SS-1

Cathode-ray Densitometer		L. and N. Densitometer	
Observer 1	Observer 2	Observer 1	Observer 2
1.35	1.39	1.29	1.28
1.35	1.39	1.26	1.28
1.36	1.39	1.26	1.28
1.37	1.38	1.27	1.29
1.37	1.37	1.25	1.29
1.37	1.37	1.28	1.30
1.34	1.37	1.26	1.28
1.38	1.38	1.29	1.31
1.40	1.37	1.26	1.26
1.38	1.37	1.27	1.28
1.37 ± 0.013	1.38 ± 0.008	1.27 ± 0.011	1.28 ± 0.010
C.V. 0.95%	0.58%	0.87%	0.78%

It will be noted that neither the absolute measurements on relative transmittance nor the intensity ratio is the same for each instrument. This is due to fundamental differences in the optical design of the two instruments and does not affect the accuracy of the spectrographic results, since working curves apply only to the particular instrument on which the measurements were originally made. In the cathode-ray densitometer, the line image is moved across the slit, behind which the photomultiplier measures the amount of light passing through the slit at any instant. The Leeds and Northrup densitometer on the other hand has no slit, as such, in front of its light detector, which is a photocell. The place of the slit is taken by a demagnified image of the fine straight filament of a lamp, focussed on the plate spectrum. The plate with its lines is moved past this illuminated image, and the light transmitted through the plate at any instant is measured by the photocell.

It is considered that the differing results from the two systems arise chiefly from diffraction effects and the scattering of the light beam by the photographic emulsion. With the cathode-ray densitometer, although the light beam, in passing through the slit, is spread out by diffraction, nearly all the light represented by the diffraction pattern is received by the light-sensitive cathode of the photomultiplier. In the L. and N. instrument, diffraction affects the filament image focussed on the spectrum, and in consequence the photocell does not see a simple virtual slit, but instead a more or less complex pattern spread out on either side of the main image. The resultant scan thus includes transmittance contributions from areas other than that which it is desired to measure. It will be noted from Table 1, in support of this explanation, that the percentage transmittance as measured by the Leeds and Northrup densitometer is indeed almost fifty per cent higher than that measured by the cathode-ray densitometer.

Comparison of the effects of light scattering by the photographic emulsion with the two instruments is more difficult to assess, but it can be said that, with the cathode-ray densitometer, scattering occurs at the entrance end of the projection system and would be expected to make only a small reduction in the contrast of the spectrum image scanned by the slit. In the Leeds and Northrup densitometer, emulsion scattering of the light will tend to blur and smear out the line filament image forming the virtual slit as seen by the photocell and will therefore increase the error in transmittance already caused by the diffraction effects on the image.

6.3 Speed of Measurement

The speed achieved in determining line intensities will vary with the problem under consideration and the familiarity of the operator with the measuring instrument. A rough comparison of the cathode-ray instrument and the Leeds and Northrup densitometer was made by determining the comparative times taken to measure the line intensities of three pairs of lines in the spectrum of a steel sample.

TABLE 3

Comparative Speed of Measurement, in Minutes, by the Cathode-ray and Leeds and Northrup Densitometers

Cathode-Ray Densitometer		L. and N. Densitometer	
Observer 1	Observer 2	Observer 1	Observer 2
3	$5\frac{1}{2}$	18	43

7. REFERENCES

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