Aug. 30, 1949. A. SIMMON 2,480,424

DEVICE FOR DETERMINING OPTIMUM CONDITIONS FOR PHOTOGRAPHIC PRINTING PROCESSES USING TWO PHOTOCELLS RECEIVING LIGHT FROM TWO MOVING BEAMS

Filed Sept. 24, 1948 5 Sheets-Sheet 1

Fig:2

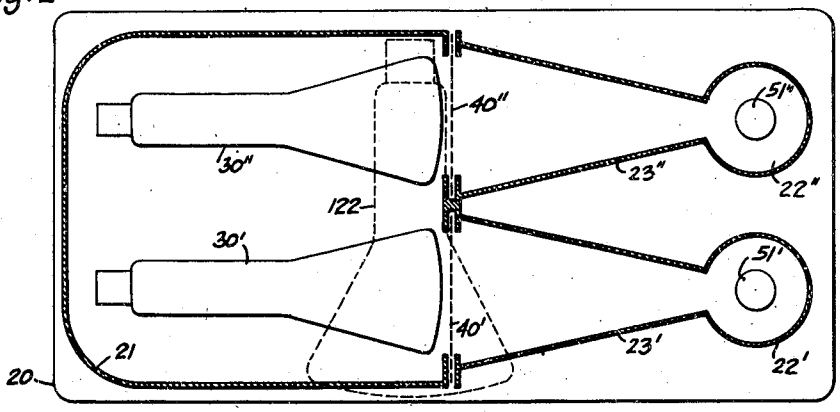

Fig:1

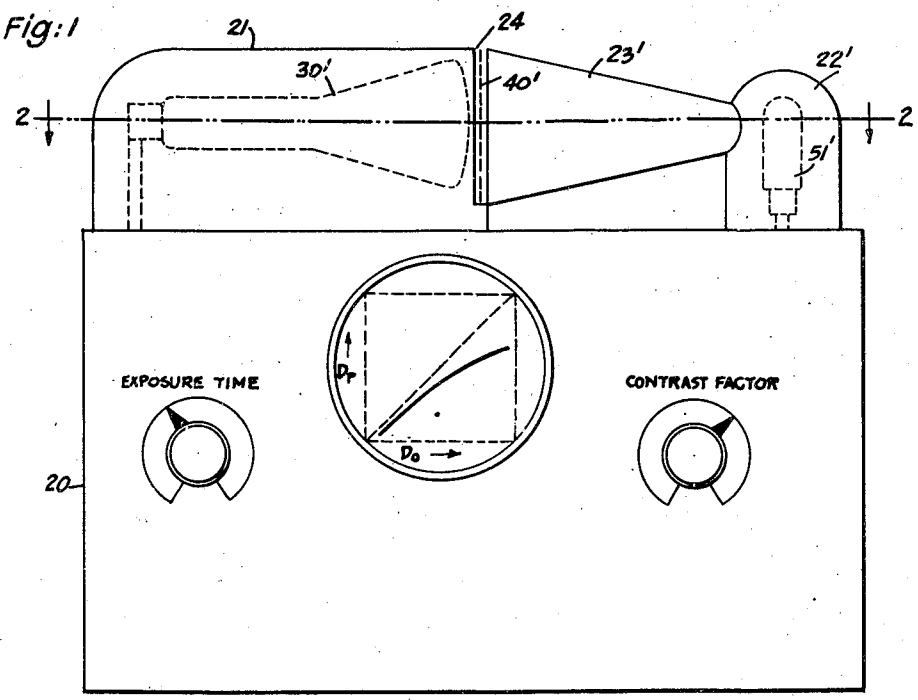

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Fig: 3

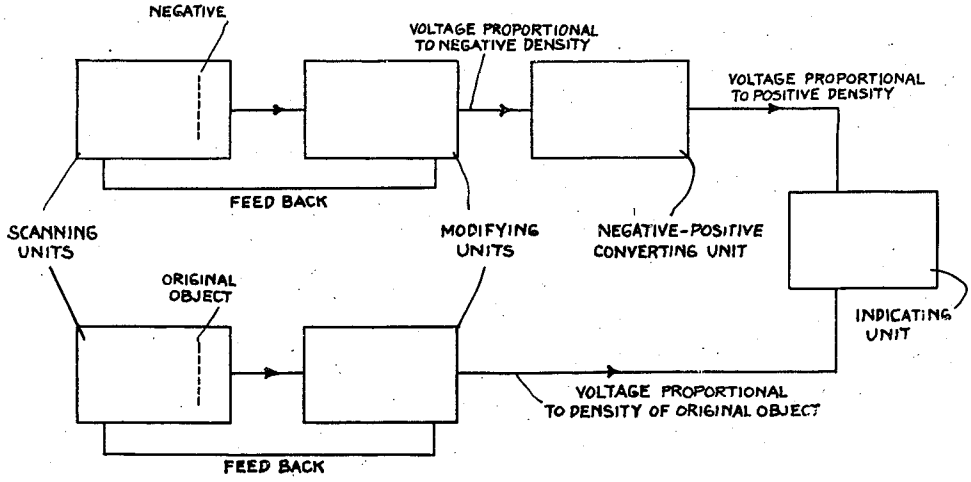


Fig: 7

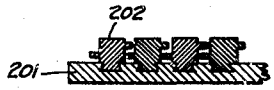


Fig: 8

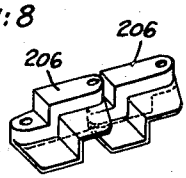
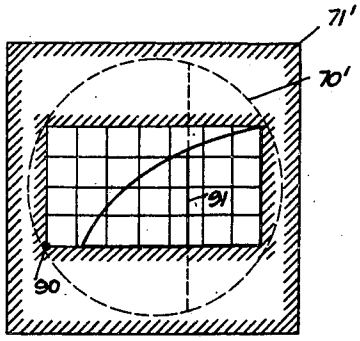


Fig: 9



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Aug. 30, 1949. A. SIMMON 2,480,424

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Filed Sept. 24, 1948 5 Sheets-Sheet 3

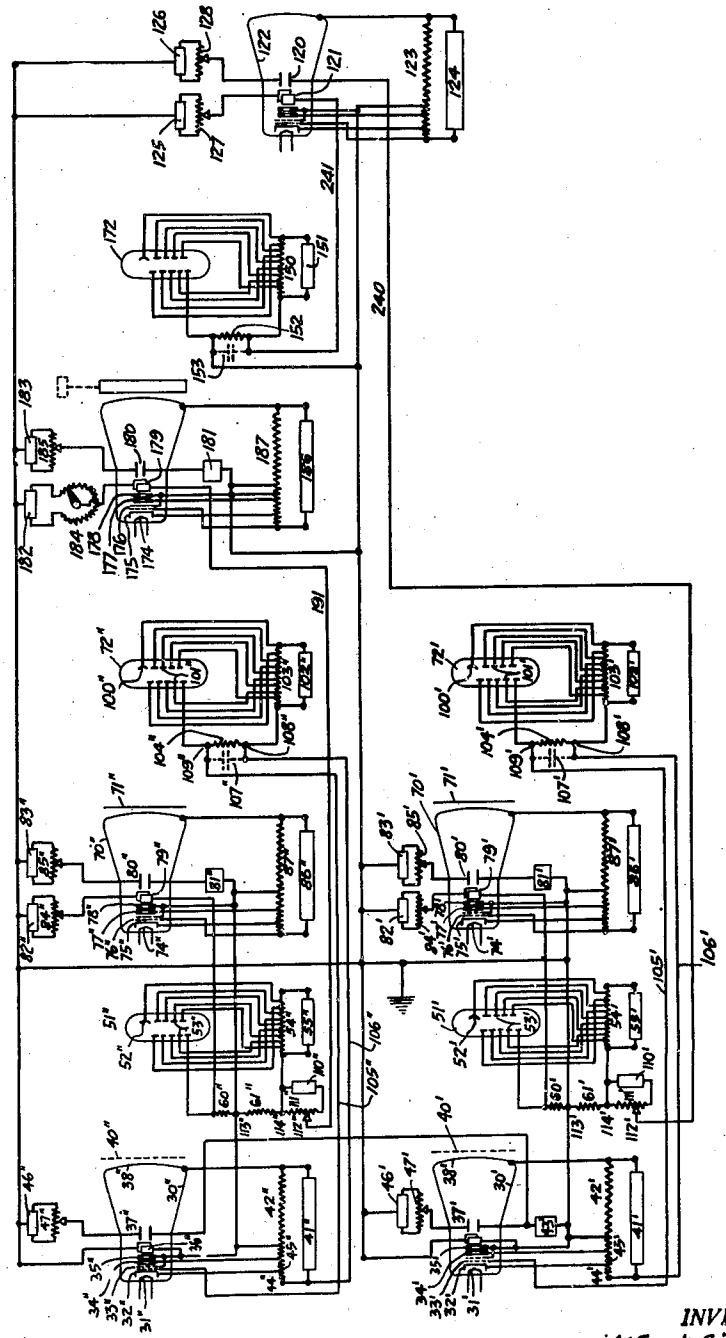

Fig: 4

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DEVICE FOR DETERMINING OPTIMUM CONDITIONS FOR PHOTOGRAPHIC PRINTING PROCESSES USING TWO PHOTOCELLS RECEIVING LIGHT FROM TWO MOVING BEAMS

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Fig: 5

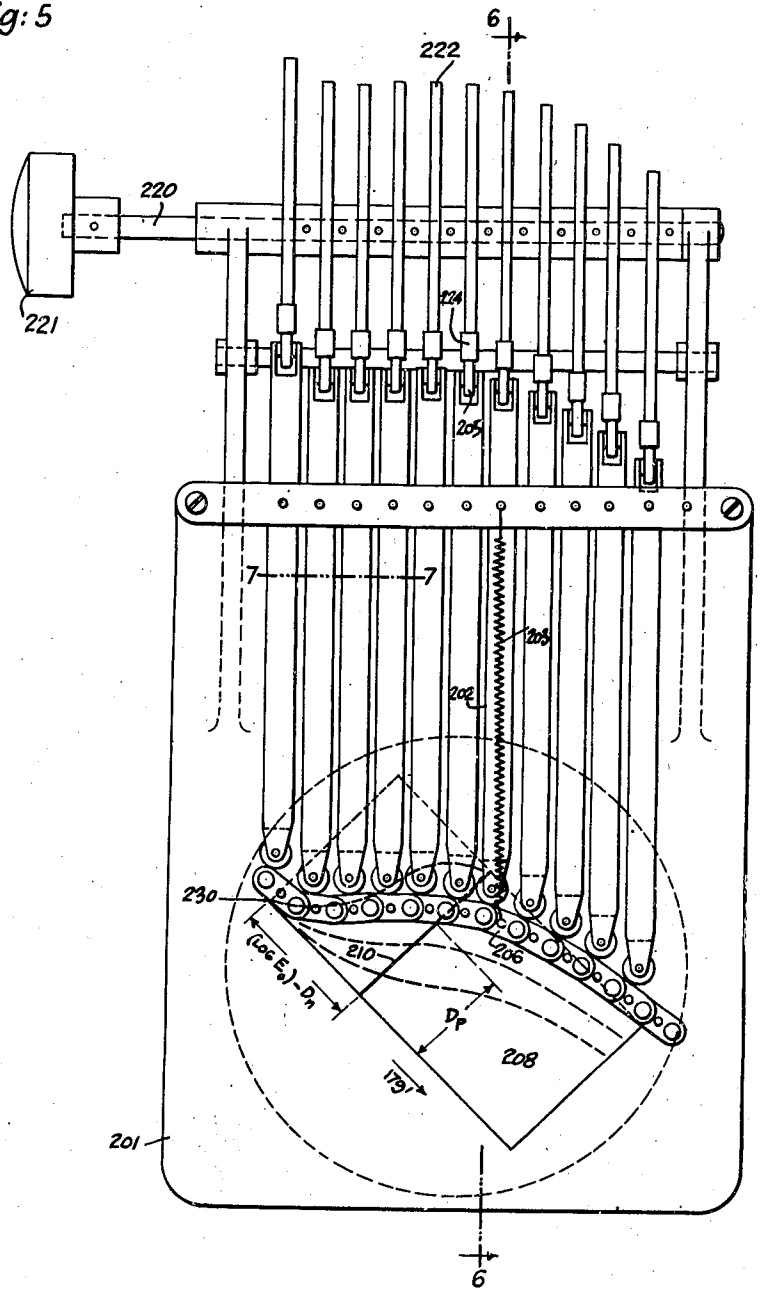

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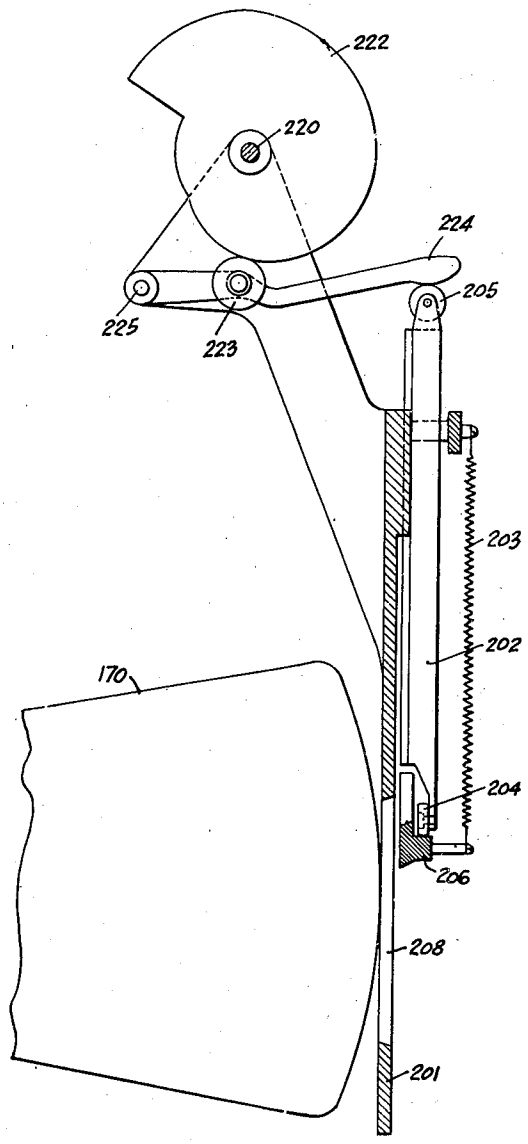
Fig: 6



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UNITED STATES PATENT OFFICE

2,480,424

DEVICE FOR DETERMINING OPTIMUM CONDITIONS FOR PHOTOGRAPHIC PRINTING PROCESSES USING TWO PHOTOCELLS RECEIVING LIGHT FROM TWO MOVING BEAMS

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Application September 24, 1948, Serial No. 51,084

8 Claims. (Cl. 88—14)

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The object of this invention is a device by means of which the optimum conditions for photographic printing processes can be determined.

A preferred embodiment of this invention is illustrated in the accompanying drawings in which

Fig. 1 is a diagrammatic elevational view of the device;

Fig. 2 is a horizontal cross sectional view along the plane of line 2—2 in Fig. 1;

Fig. 3 is a schematic diagram of the electrical circuit;

Fig. 4 is a detailed diagram of the electrical circuit;

Fig. 5 shows an adjustable mask which forms part of a unit by means of which voltages corresponding to negative densities are converted to voltages representing positive densities;

Fig. 6 is a cross sectional view along the plane of line 6—6 in Fig. 5;

Figs. 7 and 8 show in detail the shape of certain elements which form part of the mechanism shown in Figs. 5 and 6, Fig. 7 being a cross sectional view along the plane of line 7—7 in Fig. 5; and

Fig. 9 is a mask forming part of the modifying circuit by which certain photo cell currents and/or voltages are rendered proportional to photographic densities.

Principle

An original object and a photographic negative made therefrom are scanned simultaneously by synchronized pencils of light in such a way that corresponding points of original and negative always receive illumination at the same time. Part of the light reflected or transmitted, depending upon whether one deals with opaque or transparent specimens, is made to impinge upon two photo-electric cells. By means of suitable modifying circuits the photo cell currents and voltages are rendered proportional to density values. The voltage which corresponds to the negative density value is impressed upon a unit which converts voltages proportional to negative densities into voltages proportional to corresponding positive densities for a selected grade of photographic paper, for a selected exposure time and for a selected contrast factor. The term "contrast factor" as used in this patent application shall denote any one of the factors adapted to influence the contrast of the positive print; i. e., either the choice of one grade of paper of a family of similar papers with different contrast

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grades as commercially available; or the time and/or temperature of the development process; or, in the case of variable contrast papers, the color of the light to which that paper is subjected during the exposure. The voltage corresponding to the density of the original object and the output voltage of the converting unit which corresponds to a positive density of a print are then impressed, respectively, upon the horizontal and vertical deflecting means of a cathode ray tube. The quality of a reproduction of a print to be made can then be judged from the curve which appears upon the screen of the last-named cathode ray tube. This curve represents directly the density of each point of a positive print as a function of the density of the corresponding point of the original. The aforementioned unit which converts voltages corresponding to negative densities into voltages corresponding to positive densities is equipped with controls by means of which the operator can adjust it for different exposure times and for different contrast factors. In this manner the predicted characteristics of the positive print as represented by the curve on the screen of the last-named cathode ray tube are modified until optimum printing conditions are reached. The machine then indicates the conditions under which the best possible print can be made.

Representation of electrical circuits

In the interest of simplicity, voltage sources have in the following been represented by batteries, but it will be understood that in reality these batteries can be readily replaced in the conventional manner by transformers, rectifiers, and condensers. Linear sweep circuits or saw tooth wave voltage generators are also shown only in block form since their detailed construction is well known and forms no part of this invention. Supply circuits for the various filaments for the cathode ray tubes have been omitted. These filaments are, in reality, either fed from small batteries or from filament transformers. All circuits used in this device are extremely sensitive to small voltage fluctuations and, therefore, automatic voltage regulators or stabilizers must be used in order to render all voltages independent of small changes of the line voltage. In the interest of clarity, these stabilizers have not been shown in the diagram of Fig. 3. Cathode ray tubes have consistently been shown equipped with electrostatic deflection plates, but it will, of course, be understood that in their place electro-magnetic coils may be used whenever desired.

In the interest of simplicity, separate poten-

tiometers and batteries have been shown for each of the cathode ray tubes and photoelectric multiplier tubes; but if so desired, the system can be simplified, and several tubes can be fed by a common potentiometer.

Structure

In its preferred embodiment the device comprises a cabinet-like housing **20**, Fig. 3, on top of which is mounted a smaller housing **21** containing the two illuminating devices, two containers **22'** and **22''** for the two photoelectric cells, and two light collecting elements **23'** and **23''** which connect the illuminating devices with the photocell housings. A slot **24** is provided which permits the insertion of both the original and the negative. It is preferable to add mechanical adjusting means by which the negative and the original can be shifted relative to each other until the two scanning beams of the illuminating device will strike corresponding points at all times. These adjusting means should preferably comprise means to shift either the original or the negative in two directions which are at right angles to each other and should also permit a certain amount of rotation. Mechanical adjusting means of this nature are well known and can be found, for example, on microscope stages and machine tools. Since the exact design of these adjusting means has no bearing upon the object of this invention, these mechanical means have not been shown.

The cabinet **20** serves not only as a base for the illuminating means and the photoelectric cells, but also as a housing within which the component parts of the various circuits can be mounted. The most important component part is a cathode ray tube **25** which is so mounted that its screen is visible through a corresponding aperture in the front wall of the cabinet **20**. It is on this screen that later the curve appears which represents the function of the negative versus the original density. Two handwheels are mounted on the front face of the cabinet which cooperate with dials calibrated in exposure time values and in contrast factor values. These handwheels are operatively connected to the negative—positive converting unit as will be described in detail in a later paragraph.

Cabinet **20** contains all electrical parts of this machine, but since their exact position is of no consequence they have not been shown. Their working function can be understood by consulting the diagrams, Figs. 3 and 4.

Original object and photographic negative

The photographic negative is almost always a transparency, but the original object may be either transparent or opaque. A transparent object is usually preferable since a much wider contrast range may be covered thereby, but under certain conditions an opaque specimen may be satisfactory in spite of its limited contrast range. If an opaque specimen is selected, the optical system by means of which it is illuminated will, of course, be different from the system employed when a transparent specimen is used. The original object may conveniently be a wedge or a wedge print, but this is not really necessary and any other object will be satisfactory, provided it contains the necessary range of densities.

Illuminating and scanning means

The object and its negative are respectively illuminated by synchronously moving pencils of light. The light may be provided by any convenient source such as incandescent or carbon arc lamps and, likewise, scanning means of any convenient design are applicable such as, for example, rotating discs with suitable apertures on their periphery, or rotating or otherwise moving mirrors or lenses. In practice I prefer, however, to use cathode ray tubes because in this manner all mechanically moving parts are avoided and because the light output of a cathode ray tube can be most conveniently regulated by changing the voltage impressed upon a control grid. Therefore, illuminating and scanning means comprising two cathode ray tubes have been shown in the drawings, and will be described in the following paragraph.

Since the illuminating and scanning means used for the original and negative, respectively, are substantially identical, corresponding parts will be denoted by the same figures to which, in the case of the original, ', and in the case of the negative, '' has been affixed. The same practice has been followed in the two following paragraphs describing the two photocells and their supply circuits and the two modifying circuits connected therewith, respectively.

Referring to Figs. 1 and 2, the two cathode ray tubes used as illuminating means are **30'** and **30''**. Their component elements are shown in more detail in the diagram in Fig. 3 and comprise filaments **31'** and **31''**, indirectly heated cathodes **32'**, **32''**, control grids **33'**, and **33''**, two focusing elements **34'**, **34''**, **35'**, **35''** and two pairs of deflection plates **36'**, **36''** and **37'**, **37''**. In front of the tubes are mounted in the usual manner light emitting fluorescent screens **38'** and **38''**. The original **40'** and the negative **40''** are mounted in front of their respective tubes, it being assumed for the time being that both original and negative are transparencies. The modification necessary to accommodate opaque specimens will be described later.

The supply circuit for these two tubes is conventional, comprising batteries **41'** and **41''**, connected, respectively, to potentiometers **42'** and **42''**. These potentiometers have various taps connected to the elements of the cathode ray tubes in the usual manner as shown in Fig. 3.

For the purposes of this invention, only one set of deflection plates is really needed, and the second set has merely been shown because it is contemplated to use commercially available tubes which are always equipped with two sets. Therefore, the two pairs **36'** and **36''** are connected to the ground or are in any other way rendered ineffective. The remaining plates **37'** and **37''** are connected to a common sweep circuit **43**. Due to this connection, the luminous spots upon the screens **38'** and **38''** are driven synchronously by this common sweep circuit **43**. The deflection plates **37'** and **37''** are connected to additional biasing means which comprise batteries **46'**, **46''** and potentiometers **47'**, **47''**. The purpose of this arrangement is to make it possible for the operator to adjust the starting point of the sweep circuit.

The control grids **33'** and **33''** assume a certain negative potential relative to their respective cathode **32'** and **32''**. This negative bias consists of two parts, a fixed part which corresponds to the extreme left end of the potentiometer, i. e., to the voltage between points **44'** or **45'** and **44''** and **45''** and a variable part which is derived from the photoelectric cell through a modifying circuit which will be discussed in detail later.

Photoelectric cells and supply circuits

The two photoelectric cells 50' and 50'' may be of any desired type known in the art, but in practice I prefer the so-called photoelectric multiplier since additional amplifiers are usually unnecessary with this type of tube. Referring to Fig. 3, these cells comprise glass vessels 51' and 51'' within which the photo sensitive cathodes 52' and 52'' and nine additional electrodes 53' and 53'' are mounted. These elements are connected to respective points of the potentiometers 54', 54'' upon which a voltage is impressed by batteries 55', 55'' or equivalent sources of voltage. The cathodes 52', 52'' are connected to the most negative points at the extreme right of the potentiometers, and the last electrodes are connected to the extreme left point of their respective potentiometer so that they receive the most positive potential. The wire connecting the left end of each potentiometer to the last electrode is interrupted and two resistors 60', 60'', 61', 61'' are inserted in this circuit. During operation, voltages, depending upon the resistance values of these resistors and upon the current circulating in the last loop of the photoelectric multiplier circuit, are built up across these resistors.

The distance of the two photocells from their respective transparencies and from the respective screens of the cathode ray tubes must be sufficiently large so that all points of said transparency have substantially the same distance from said cell.

The light reaching the photoelectric cells from the screen of the cathode ray tubes can be magnified by placing suitably shaped light collecting elements between screen and photocell. These light collecting elements may, for example, be truncated cones or pyramids with an inner reflecting surface, or they may be solid bodies made from glass or transparent plastic in which case the light would be directed toward the photocell by total reflection along the boundaries.

Modifying circuit—General principle

The currents passing photocells 51', 51'' are proportional to the light intensities passing the specimens 40' and 40'', i. e., the original and the negative, respectively. Since it is desired to compare densities rather than light intensities, means must be provided to produce currents or corresponding voltages which are proportional to the densities to be measured. This is the purpose of the modifying circuits. Therefore, the modifying circuits may comprise suitable networks which have a non-linear response in such a way that the photocell currents fed into them are proportional to the intensity of the impinging light and that the currents or voltages delivered by these modifying circuits are proportional to the corresponding densities. Many networks with non-linear response are known, comprising non-linear resistors, vacuum tubes or similar elements, but regardless of the detailed designs, such an arrangement would suffer from the very serious disadvantage that the photocell currents themselves would have to be proportional to the light intensities and, if one measures densities up to 3, the light intensities and therewith the photocell currents will vary in the proportion of 1:1000. It is very inconvenient if not impossible to design circuits which will satisfactorily cover such an exceedingly wide range. I prefer, therefore, to solve the problem in the following manner: The intensity of the light impinging any given point

of the two specimens 40' and 40'' is modulated in accordance to the transmitted light intensity. This is done by the photocell current itself, and a voltage which is a function of said photocell current is impressed upon the grid of the cathode ray tube, changing its light output. In this manner, the fluctuations of the light impinging upon the photoelectric cells 51' and 51'' are reduced, and it is even possible to modulate the light intensities in such a manner that the resulting photocell currents are now directly proportional to density values. The modifying circuit which accomplishes this function is described in the next paragraph.

Modifying circuit—Mathematical basis

The photocell output currents or, more specifically, the voltages impressed upon resistances 60', 60'' are fed into two modifying circuits. The output voltages of these circuits are then impressed upon the grids of the respective cathode ray tubes and used there to modulate the brightness of the luminous spot formed on the screen. It is, therefore, clear that the modifying circuits must deliver output voltages which are definite mathematical functions of their input currents or voltages. This mathematical function will be derived in the following paragraph:

The current passing the cathode ray tube can be expressed within certain limits by the formula

$$I=I_{max}-ae \qquad (1)$$

I is the current passing the cathode ray tube at any given instance, and I_{max} is the maximum permissible cathode ray tube current. This value may be determined either as the maximum current that the screen of the tube will withstand without deterioration, or it may be the maximum value for which the linear relationship between cathode ray tube current and grid bias still holds true, or it may be determined by any other convenient consideration. Both I and I_{max} are conveniently expressed in microamps. (μa.). e is the additional negative voltage impressed upon the control grids 33' and 33'' which is added to the voltage impressed upon these grids by the left end of potentiometers 42' and 42''. In other words, the left ends of potentiometers 42', 42'' impose a certain constant minimum negative voltage upon the grids at all times and the voltage e which is the output voltage of the modifying circuits will be added thereto. e is expressed in volts. a is a constant which depends upon the characteristics of the individual cathode ray tube and which has a dimension

$$\frac{\mu a}{\text{volts}}$$

The light intensity on screens 38', 38'', i. e., before the light has passed the negative or the original object, is again within reasonable limits directly proportional to the cathode ray tube current or

$$L_1=bI \qquad (2)$$

L_1 is expressed in foot candles, or any corresponding metric dimension, and b is a constant again depending upon the characteristic of the cathode ray tube, measured in

$$\frac{\text{foot candles}}{\mu a}$$

The light intensity after the light has passed the transparency, is expressed by

$$L_2=L_1.10^{-D} \qquad (3)$$

where D is the density of the negative or original at the point which, at any given distance, is illuminated by the luminous spot of the cathode ray tube.

The light intensity in the plane of the photo sensitive cathode of the photoelectric cells 51', 51'' is proportional to L_2 but, of course, considerably smaller, depending upon the distance between the two tubes.

$$L_3 = dL_2 \tag{4}$$

d is a dimensionless constant.

The photocell current is again within wide limits proportional to the light impinging upon the photoelectric cell or

$$i = f.L_3 \tag{5}$$

where f is a constant denoting the light sensitivity of the photoelectric cell in

$$\frac{\mu a}{\text{foot candles}}$$

I shall now impose the condition that the modifying circuit shall deliver e as a function of i, i. e., output voltage as a function of input current, in such a way that differences of photocell currents shall become directly proportional to density differences of the specimen to be measured, or

$$i_1 - i_2 = h(D_2 - D_1) \tag{6}$$

h is a proportionality factor which has the dimension of a current and which is expressed in μa.

D_1 and D_2 are the photographic densities of two points of the specimen, and i_1 and i_2 are the corresponding photocell currents, i. e., the currents which are measured when the luminous spot of the cathode ray tube is placed, respectively, behind the two points with the two densities D_1 and D_2.

Equations 1, 2, 3, 4 and 5 can be combined and solved for D with the following result:

$$D = \log \frac{bdf}{i}[(I_{max} - ae)] \tag{7}$$

For $D=D_1$ there is, of course, $i=i_1$ and $e=e_1$ and likewise for $D=D_2$ there is $i=i_2$ and $e=e_2$. By substituting these values, I arrive at the following expression for D_2-D_1:

$$D_2 - D_1 = \log\left(\frac{I_{max} - ae_2}{i_2}\right) - \log\left(\frac{I_{max} - ae_1}{i_1}\right) \tag{8}$$

D_2-D_1 can also be computed from Equation 6:

$$D_2 - D_1 = \frac{i_1 - i_2}{h} \tag{9}$$

In the two Equations 8 and 9, e_2 becomes zero, and i_2 becomes i_{min} for $D_2=\Delta_{max}$, where Δ_{max} is the highest density within the measuring range of the device. Δ_{max} usually need not exceed the value 3.

$$\Delta_{max} - D_1 = \log\left(\frac{I_{max}}{i_{min}}\right) - \log\left(\frac{I_{max} - ae_1}{i_1}\right) \tag{8a}$$

$$\Delta_{max} - D_1 = \frac{i_1 - i_{min}}{h} \tag{9a}$$

These two equations can be combined and solved for e_1 with the following result:

$$e_1 = \frac{I_{max}}{a}\left(\frac{1 - i_1.10^{-\frac{i_1}{h}}}{i_{min}.10^{-\frac{i_{min}}{h}}}\right) \tag{10}$$

This is the mathematical function according to which the modifying circuits have to work, i. e., when the spot of a cathode ray tube passes a point with the density D_1, a photocell current i_1 will be generated which, by the modifying circuit, will be changed into a voltage e_1 which is then impressed, in addition to a constant negative bias, upon the control grid of the cathode ray tube.

The value i_{min} which appears in Formula 10 is the minimum current which will pass the photocell when the density of a point illuminated by the cathode ray tube spot becomes Δ_{max}, which is the maximum density which the device shall be capable of measuring and which rarely, if ever, needs to exceed the value of 3, i_{min} can be computed from Formulae 1 to 5 by substituting Δ_{max} for D and by making a zero, i. e.,

$$i_{min} = bdfI_{max}.10^{-\Delta_{max}} \tag{12}$$

Modifying circuit—Preferred design

The design of the modifying circuit itself is basically of no importance and any circuit which will modify an input current into an output voltage according to Formula 10 will be satisfactory. Circuits of this type are frequently networks using at least one non-linear resistance or impedance element such as one of the so called semi-conductors or a device using a saturated iron core or one of the various types of vacuum tubes. A preferred modifying circuit, however, which is in many respects superior to these networks, has been disclosed in my co-pending application Serial No. 791,439, now Patent No. 2,474,380, and will be described as a preferred example in the following:

A modifying circuit built accordingly consists of three principal parts, cathode ray tubes 70', 70'', stationary masks 71', 71'' and photoelectric cells 72', 72''. It is emphasized that the cathode ray tubes 70', 70'' and the photoelectric cells 72', 72'' are in no way identical with elements 30', 30'' and 51', 51'' which have been described above. They are entirely independent therefrom and perform entirely different functions.

The broad principle of the modifying circuit is that in some suitable manner a luminous line is formed on the screen of the second cathode ray tubes 70', 70'' that the incoming signal, which in this case is the current passing the first photocells 51', 51'' is used to deflect this line in a direction at right angles to itself and that thereby, part of the light emitted by this line is cut off by the stationary masks placed in front of the luminous screen of tubes 70', 70''. The light permitted to pass these masks is then made to impinge upon the second photoelectric cells 72', 72'' forming part of the modifying circuit, but not upon tubes 51', 51''. The current passing these second photoelectric cells 72', 72'' or, more precisely, the corresponding voltage impressed upon a resistor of suitable magnitude, is then supplied as additional bias to the control grids 33', 33'' of the original cathode ray tubes 30', 30'' which scan the specimen in the manner described.

These circuits are shown in detail as the right half of Fig. 3. The cathode ray tubes 70', 70'' contain filaments 74', 74'', cathodes 75', 75'' heated thereby, control grids 76', 76'', two focusing members 77', 77'' and 78', 78'' including second control grids, two pairs of deflection plates 79', 79'' and 80', 80'' and a screen capable of light emittance.

A luminous line can be formed upon this screen by any desired means, for example, by giving

the focusing elements 77', 77'' and 78', 78'' a proper configuration. I prefer, however, to use a conventional cathode ray tube which forms a luminous spot upon the screen which is transformed into a line by means of sweep circuits 81', 81'' operatively connected to the deflection plates 80', 80''. This sweep circuit is a saw tooth wave generator of the customary type which has a high frequency compared to the frequency of the signal impressed upon the other pair of deflection plates. It can be seen that the other set of deflection plates 79', 79'' is operatively connected to resistance elements 60', 60'' upon which a voltage proportional to the current passing the first photocells 51', 51'' is impressed. Both sets of deflection plates 79', 79'' and 80', 80'' are biased by batteries 82', 82'' and 83', 83'' which are connected, respectively, to potentiometers 84', 84'' and 85', 85''. By means of this arrangement, the starting points of the two sweep circuits connected to deflection plates 79', 79'' and 80', 80'' can be adjusted.

The rest of the supply circuit for the second cathode ray tube is conventional. It consists of batteries 86', 86'' and potentiometers 87', 87'', the various points of which are connected to the elements within the cathode ray tubes in such a way that the control grids 76', 76'' assume a fixed negative potential with respect to the cathodes 75', 75'', but that 77', 77'' have a positive potential with respect to 75', 75'', 78', 78'' a positive potential with respect to 77', 77'', and the screen finally a positive potential with respect to 78', 78''.

In front of the screen, and preferably immediately adjacent thereto are masks 71', 71'' which are again shown in Fig. 4. Each mask has an aperture which directly represents the mathematical function expressed in Formula 10. The mask is a thin plate made of opaque material such as black paper and sheet metal, and its vertical width varies as a function of the horizontal distance from a point of reference 90 in accordance with Formula 10. For convenience, the lower borderline of this aperture is made a straight line, but this is not necessary and both the upper and lower borders may be curved as long as the vertical width of the aperture is the desired function of the horizontal distance from the point of reference 90. It can be seen that only that part of the light emitted by the luminous line 91 which is behind said aperture can pass and that the other parts which are shown in dotted lines above and below this portion are blocked off. The light impinging upon the second photoelectric cells 72', 72'' is, therefore, proportional to the length of that portion of line 91 which appears behind the aperture or is a direct function of the shape of said aperture, in other words, varies in accordance with Formula 10, provided the aperture is fabricated correctly.

The respective distance between photoelectric cells 72', 72'' and cathode ray tubes 70', 70'' must, of course, be large enough so that all points of the luminous line have substantially the same distance from the photo sensitive cathode of the photoelectric cells 72', 72''. These cells may again be of any desired design and I have again shown photoelectric multiplier tubes because then complicated amplifiers can be avoided. Each cell again has photo sensitive cathodes 100', 100'', and nine additional electrodes 101', 101''. The supply circuit comprises batteries 102', 102'', and

potentiometers 103', 103'', the various points of which are in the usual manner connected, respectively, to elements 100', 100'' and 101', 101''. The wire between the extreme left point of each potentiometer 103', 103'' and the last electrode is again interrupted to receive resistance elements 104', 104''. The voltage impressed upon these resistance elements by the current passing it represents directly the value e_1 used in Formula 10. e_1 is then by means of two wires 105', 105'' and 106', 106'' fed back into the grid control of the first cathode ray tubes 30', 30'', i. e., voltage e_1 is added to the constant negative bias which control grids 33', 33'' have with respect to cathodes 32', 32''.

If the luminous line upon the screen of cathode ray tubes 70', 70'' is formed in the preferred manner by a voltage of high frequency impressed by saw tooth wave generators 81', 81'' upon deflection plates 80', 80'', means must be provided to keep the output current or voltage of the photoelectric cells 72', 72'' from being modulated accordingly. This can be done simply by connecting condensers 107', 107'', shown in dotted lines, of suitable magnitude across points 108', 108'' and 109', 109'', or a more complete filter formed in the usual manner of a network of capacitances and inductances can be connected to points 108', 108'' and 109', 109''. A filter of this type has not been shown in detail since its design is well known and forms no part of this invention. If, however, the luminous line upon screen of tubes 70', 70'' is formed by other means, for example, by the proper configuration of the focusing elements 77', 77'' and 78', 78'', this filter means can be dispensed with.

The modifying circuit as described up to this point renders differences of photocell currents proportional to differences of photographic densities. Of ultimate interest, however, are not density differences but absolute values of densities, and these are obtained from a network which comprises resistors 61', 61'' carrying the photocell current of cells 51', 51'' and which is in series with potentiometers 111', 111'' each of which, in turn, receives a voltage from batteries or other source of voltage 110', 110''. The connection of these batteries must be so chosen that the polarity of potentiometer 111' is opposed to that of the resistors 61', 61'' or, in other words, the voltage between the sliding contacts 112', 112'' of the potentiometers and points 113', 113'' is the difference of the respective voltages impressed upon 111', 111'' and 61', 61''. The function of this network can be explained as follows:

Assuming that the resistance of 61', 61'' is R, and that the voltages corresponding to photocell currents i_1, i_2 are E_1 and E_2, Equation 6 can be transformed to read:

$$E_1 - E_2 = hR(D_1 - D_2)$$

For $D_1 = 0$, E_1 will become E_{max}, so we have

$$E_{max} - E_2 = +hRD_2$$

This means that if I impress a voltage equal to E_{max} between points 112', 112'' and 114', 114'' which is opposed to the voltage impressed upon 61', 61'', that then the voltage between points 113', 113'' and 112', 112'' is directly proportional to the density D_2 of that point which at any given distance is illuminated by the scanning beam of the cathode ray tubes 30', 30''.

If one has transparent test specimens such as pre-supposed up to this time, the adjustment of the sliding contacts 112', 112'' of potentiometers

111', 111'' is particularly easy because all one has to do is to remove the test specimens 40', 40'' altogether so that one has zero density, and then adjust sliding contacts 112', 112'' until the voltage between points 113' 113'' and 112', 112'' becomes zero.

With an opaque test specimen this adjustment is a little more difficult because even a completely unexposed white piece of paper is not of zero density because it reflects less than 100% of the incident light. However, this reflectivity can be measured by other well known means, and the device can then be adjusted accordingly making proper allowance for the fact that the maximum reflection may be, for example, of the general order of 90%.

Negative-positive converting unit

This unit converts the voltage between points 112'' and 113'' which represents a negative density into a corresponding voltage representing the density of a positive print made from this negative on a sensitized sheet of selected grade under selected exposure time and contrast conditions. By contrast conditions or contrast factors, should again be understood any factor influencing the contrast of the print; i. e., the choice of a grade of paper of a family of different papers having different contrast grades, or the time and temperature of the subsequent development, or in case of variable contrast papers, the color of the light with which the print is made.

The negative-positive converting unit is very similar to the modifying unit described above, except that it lacks the feed back feature; i. e., it again consists of a cathode ray tube, a mask and a photo electric cell, but the photo cell current in this case does not exert any influence upon the brilliancy of the luminous line formed upon the screen of the cathode ray tube.

Referring again to Fig. 4, we have a cathode ray tube 170 with a filament 174, an indirectly heated cathode 175, a control grid 176, two focusing members 177, 178, and two sets of deflection plates 179 and 180. These elements are connected in the customary manner to the various taps of a potentiometer 187 which, in turn, is energized by a battery 186. One of the deflection plates 179 is connected by a wire 191 to point 112''. The other deflection plate of the same pair is connected to potentiometer 184 which receives voltage from a battery 182, the center point of which is grounded. In other words, the deflection of the electron beam is made proportional to the voltage by the points 112'' and 113'' which represents the negative density at any given instance.

The cathode ray tube 170 must again be provided with means causing the stream of electrons to form a luminous line upon the screen. These means can again be properly shaped focusing members or, again, a linear sweep voltage of a high frequency can be impressed by means of a linear sweep circuit 181 upon the second pair of deflection plates 180. This second pair of deflection plates is biased by a potentiometer 185 energized by a battery 183.

It will be clear from the description up to this point that by this arrangement a luminous line is formed upon the screen of cathode ray tube 170 which is deflected at right angles to itself in accordance with the negative density measured at any given instance. Only a portion of the light emitted by this line can reach the photoelectric cell 172, and the magnitude of this portion depends upon the width of the aperture of the mask 200 at the place to which at any given time the luminous line on the screen of tube 170 is deflected.

The aperture of that mask, therefore, must directly represent the function between positive density and the exposure to which the positive sensitized sheet is subjected.

The shape of this curve is well known, and a family of curves representing this function is, for example, shown in Figure 12.5 on page 210 of the book "Fundamentals of Photographic Theory" by James and Higgins, John Wiley and Sons, New York, 1948. It is known that the shape of this curve depends not only upon the grade of paper selected, but also upon its development, and in the case of some papers upon the color of the light to which it has been exposed. Since it is the purpose of the apparatus to determine the optimum print conditions, it is desirable to use a mask with an aperture with an adjustable shape so that the operator can adjust this aperture to various shapes until the best print conditions are obtained as indicated by an indicating member which will be described in the following paragraph. A mask of adjustable shape is shown in Figs. 5 and 6.

The mask consists of a base 201 which is placed immediately in front of the screen of the cathode ray tube 170. All other components of this adjustable mask are mounted on this base. These components comprise a number of slidable members 202 each carrying a roller 204 on its lower and a roller 205 on its upper end, all of which are adapted to slide in vertically arranged grooves forming part of the base 201. The lower rollers are in contact with parts 206 which are shown in detail in Fig. 8. Parts 206 are linked together in a chain-like manner and are individually biased by springs 203 as shown in Figs. 5 and 6. In the interest of clarity only one of these springs has been shown in Fig. 5. Depending upon the positions which the various members 202 assume, the shape of this chain can be adjusted. As can be seen in Fig. 8, these chain-like members are equipped with fins which prevent the passage of light between them, but still make it possible to move them relative to each other. In like manner the various members 202 have fins, as shown in Fig. 7, again to prevent the passage of light. The base 201 has a rectangular aperture 208 which is partly covered by the parts 202 and the chain formed by parts 206. For mechanical reasons this rectangular aperture is placed in an angular position with respect to the horizontal, but the deflecting means of the cathode ray tube 170 are so positioned that deflection plates 179 deflect the luminous line 210 in the direction of the arrow 179''.

A mechanism is provided to actuate all members 202 in unison. This mechanism comprises a shaft 220 which carries hand wheel 221 and a number of cams 222. Hand wheel 221 is identical with the right hand wheel shown in Fig. 1 which coacts with a dial calibrated in "contrast factor" values. The cams 222 are in operative contact with cam following rollers 223 which are mounted on levers 224. One end of levers 224 is supported by a stationary pivot 225, and the other end of the levers is in contact with the aforementioned rollers 205 which are attached to the upper ends of members 202.

It will be clear that rotation of hand wheel 221 will cause these levers to assume different positions in accordance with the configuration of the

various cams 222. These positions are again transferred to members 202, and result in different shapes assumed by the chain formed by elements 206. Various shapes are shown in dotted lines in Fig. 5, and each of these shapes represents the relation between exposure and positive densities of a selected grade of sensitized sheet under the selected contrast conditions, for example, for a given time and temperature of development.

The length of the luminous line 210 represents the positive density D_P, and its distance from a point of origin 230, Fig. 5, in the direction of arrow 179' represents the magnitude $(\log E_o) - D_n$, where E_o is an exposure time and D_n a negative density. It is, therefore, clear that any change of exposure merely causes any of the curves shown in dotted lines to move parallel to itself in the direction of arrow 179'. While it would be possible to move the entire cathode ray tube in this manner relative to the mask, it is more convenient to perform this movement electrically by impressing additional bias upon the deflection plates 179. It is for this reason that potentiometer 184 is constructed differently from the other potentiometer and is connected to the left hand wheel of Fig. 1 which coacts with a dial calibrated in exposure time values.

The photo electric cell which receives that part of the light emitted by the luminous line 210 formed upon the screen of cathode ray tube 170 passing the mask 200 may again be of any desirable type, and I have again shown a photo multiplier tube 172, the various electrodes of which are again connected to corresponding taps of a potentiometer 150 energized by a battery 151. The current circulating in the last loop causes certain voltage to pile up on resistor 152. This voltage then represents and is proportional to the positive density which is to be expected from a given negative as placed in front of cathode ray tube 30'' under the conditions determined by the configuration to which mask 200 has been adjusted by the operator. A filter 153 shown in dotted lines is desirable if the luminous line on the screen of cathode ray tube 170 is formed by a high frequency sweep circuit impressed upon one pair of the deflection plates. If the line is formed by focusing members of suitable configuration, this filter may be omitted.

Indicating cathode ray tube

The last member of the apparatus is an indicating member which shows the density of a positive print as expected under the condition to which the adjustable mask is adjusted as a function of the corresponding density of the original object. This indicating member is again a cathode ray tube and is shown in Fig. 4 at the extreme right end. This tube is called 122 and contains again the usual elements; i. e., filament, an indirectly heated cathode, a control grid, two focusing members and two pairs of deflection plates 121 and 120. The various elements with the exception of the deflection plates are connected to taps of a potentiometer 123 which receives voltage from the battery 124. One of the deflection plates 120 is connected by means of a wire 240 to point 112', and the other deflection plate of the same pair is connected to a potentiometer 128 which is energized by a battery 126, the center point of which is grounded. The deflection induced into the electron beam of tube 122 by the deflection plates 120 is, therefore, proportional to the voltage between points 113' and 112', or, in other words, it is proportional to the density of the original object at the point which is being scanned by cathode ray tube 30' at any given instance.

One of the deflection plates 121 is connected by means of a wire 241 to the lower end of resistance 152. The other deflection plate of this pair is connected to a potentiometer 127 which is energized by a battery 125, the center point of which is again grounded. Consequently the deflection induced in the electron beam of tube 122 by the deflection plates 121 is proportional to the voltage impressed upon resistance 152, or to the positive density to be expected from a negative placed in front of cathode ray tube 30'' and printed upon a positive print material of the characteristics determined by the shape to which mask 200 has been adjusted.

The curve appearing upon the screen of tube 122, therefore, represents directly positive densities as functions of the corresponding densities of the original object, and the shape of this curve enables the operator to judge the character of the reproduction obtained under these conditions.

Operation

The function of the device will be obvious from the foregoing description. The test specimens of 40', 40'' are scanned and illuminated by the moving luminous spot appearing upon the screens of cathode ray tubes 30', 30''. Light transmitted by these test specimens impinges, respectively, upon photoelectric cells 51', 51''. The current passing these photocells as a result of the incident light, is modified by the modifying circuit which in a preferred embodiment of this invention, comprises second cathode ray tubes 70', 70'', and second photoelectric cells 72', 72''. Between the two last named elements, there are masks 71', 71'', and due to the coaction of the three last named parts, i. e., cathode ray tubes 70', 70'', photoelectric tubes 72', 72'' and masks 71', and 71'', a voltage is impressed upon the output resistors 104', 104'' which, when fed back into the control grids 33', 33'' of the two original cathode ray tubes 30', 30'', modulates their light output in such a way that differences of the currents passing the photocells 51', 51'' are rendered directly proportional to density differences of the test specimens 40', 40''. The networks comprising resistors 61', 61'' and potentiometers 111', 111'' convert these differences into voltages which are proportional to absolute density values.

The voltage between points 113'' and 112'' is then, by means of the negative-positive converting unit, transposed into positive densities. The condition under which this is done can be adjusted two-fold by means of the potentiometer 184, left hand wheel of Fig. 1, and by means of adjustable mask 200, right hand wheel of Fig. 1. The additional bias, as determined by potentiometer 184, has the effect of simulating different exposure times and the change of the mask 200 has the effect of simulating different contrast factors, for example, different development times.

A curve appears then on the screen of tube 122 which is visible through an aperture of the front panel of the cabinet, Fig. 1, and the shape of this curve predicts the character of the reproduction to be expected under the chosen conditions.

It is, of course, a matter of judgment when selected conditions result in a satisfactory reproduction as predicted by this device. From a purely theoretical point of view, a completely

truthful and correct reproduction is predicted when the function between the positive densities and original object densities is formed by a straight line passing through the point of origin under an angle of 45° with respect to the axis of a co-ordinate system. In view of the limited contrast range of all photographic material such a perfectly correct reproduction, however, is in the vast majority of all cases neither possible or desirable, and a certain amount of a contrast compression will be necessary to accommodate a negative with even a reasonably narrow range of contrast.

The operation of the device makes it possible for the operator to adjust time and contrast conditions by manipulating the two hand wheels shown in Fig. 1 which, respectively, control potentiometer **184** and mask **200**, until in his judgment a satisfactory reproduction is predicted. A print can then be made under the conditions for which the apparatus has been set; i. e., for the exposure time as indicated on the left and for the contrast factor as indicated on the right dial of Fig. 1.

Modifications

A number of modifications pertaining to the electrical circuit have already been mentioned in a previous paragraph. It will be clear to anyone skilled in the art that other modifications can be inserted without departing from its purpose. For example, while it has been presupposed up to this time that the original object and negative were transparencies, this is not strictly necessary, and opaque specimens can be accommodated if so desired. The optical system must then, of course, be modified and an image of the luminous spot appearing upon the screen of tubes **30'** and **30''** must be projected upon the specimen to be screened by a lens. An arrangement of this type has, for example, been shown in Fig. 5 of my previously filed application, Serial #17,537.

The performance of the photoelectric cells placed in front of the various cathode ray tubes can be improved by the arrangement of light-collecting elements between the two tubes. These light-collecting elements may, for example, be truncated cones or pyramids with internal reflecting surfaces.

In the appended claims, the terms "contrast condition" or "contrast factor" shall denote any condition or factor which influences the contrast of a positive print, for example, the selection of the preferred sensitized paper of a family of similar papers with different contrast grades; or development time and temperature; or, in the case of some papers with variable contrast, the color of the light to which said paper has been exposed.

What I claim as new, is:

1. A device for determining optimum conditions for photographic printing processes, comprising: means to illuminate simultaneously an original object and a photographic negative made therefrom by two moving pencils of light, including means to synchronize the movements of said pencils of light whereby corresponding points of original and negative are always illuminated simultaneously; two photoelectric cells including electric circuits operatively connected thereto, and including means causing said cells to receive light coming from said pencils and modified by the respective densities of original and negative; means to render the output voltages of said photocell circuits proportional to the respective densities of original and negative; means to convert the voltage proportional to the density of said negative to a voltage proportional to the density of a positive print made from said negative on a selected grade of sensitized material under selected exposure time and contrast conditions; a cathode ray tube including means to form a beam of electrons, first means to deflect said beam in one direction, second means to deflect said beam in a direction perpendicular to said first direction, means to accelerate said electrons, and a screen capable of light emittance when struck by electrons; means to actuate said first deflecting means by the output voltage of the photocell that receives light from the original object; means to actuate said second deflecting means by the voltage that is proportional to the density of a positive print as delivered by said converting means, whereby automatically on the screen of said cathode ray tube a curve is plotted which represents positive densities as a function of corresponding densities of said orignal object; and means, under control of the operator, to select exposure time and contrast conditions for which said aforementioned converting means are adjusted, until a satisfactory reproduction is predicted by said curve appearing on the screen of said cathode ray tube.

2. A device according to claim 1, said means to illuminate said negative and said original, respectively, comprising two cathode ray tubes.

3. A device according to claim 1, said means to illuminate said negative and said original, respectively, comprising two cathode ray tubes, including means to form a beam of electrons, means to deflect said beam of electrons, means to accelerate said electrons, and a screen capable of light emittance when struck by electrons, and said means to synchronize the movement of said pencils of light comprising a sweep circuit and means to actuate said deflecting means of both cathode ray tubes simultaneously by said sweep circuit.

4. A device according to claim 1, said means to illuminate said negative and said original, respectively, comprising two cathode ray tubes, each including means to form a beam of electrons, means, including a grid, to control the number of said electrons, means to deflect said beam of electrons, means to accelerate said electrons, and a screen capable of light emittance when struck by electrons; and said means to render the output voltages of said photocell currents proportional to the respective densities of the negative and of the original comprising two modifying circuits, each fed by the respective current of one of said photocells, and delivering an output voltage substantially according to the formula

$$e = A\left(1 - \frac{i.10^{-\frac{i}{B}}}{C}\right)$$

where

e is the output voltage of one of said circuits,
i is the corresponding photocell current, and
A, B and C are constants,

and means to impress the two output voltages, respectively, upon the two grids of said cathode ray tubes, whereby the brightness of the two luminous points on the two respective screens is automatically modulated in accordance with the respective densities of the two corresponding

points of negative and original which are illuminated at any given instance.

5. A device according to claim 1, said means to illuminate said negative and said original, respectively, comprising two cathode ray tubes, each including means to form a beam of electrons, means, including a grid, to control the number of said electrons, means to deflect said beam of electrons, means to accelerate said electrons, and a screen capable of light emittance when struck by electrons; and said means to render the output voltages of said photocell currents proportional to the respective densities of the negative and of the original comprising two modifying circuits, each fed by the respective current of one of said photocells, and each comprising a cathode ray tube, independent of the cathode ray tubes named above and in claim 1, and with a screen capable of light emittance, a supply circuit for said cathode ray tube, including means to excite a straight line on said screen to light emittance, means to deflect said line substantially at right angles to itself in accordance with the current passing the photocell connected to this modifying circuit, an apertured mask made from opaque material placed in front of the screen of said cathode ray tube, the width of said aperture in a direction substantially parallel to said light emitting line varying substantially according to the formula

$$Y=D\left(1-\frac{x10^{-\frac{X}{E}}}{F}\right)$$

where

Y is the width of said aperture,
X the distance from a point of reference, in a direction at right angles to said light emitting line, and
D, E and F are constants,

a photoelectric cell, independent of the cells named in claim 1, placed in front of said mask and connected to a supply circuit, and a resistor adapted to be passed by the current passing said photocell, the voltage thereby impressed upon said resistor being used to bias the control grid of one of the first named cathode ray tubes which are used as illuminating means.

6. A device according to claim 1, said means to convert a voltage, proportional to said negative density, to a voltage, proportional to a positive density, comprising a cathode ray tube, distinguished from the tube mentioned in claim 1, a mask, and a photoelectric cell, distinguished from the cells mentioned in claim 1, said cathode ray tube comprising means to form a beam of electrons, means to accelerate said beam, a screen capable of light emittance when struck by electrons, means causing said beam to form a straight luminescent line upon said screen, and means, actuated by said voltage which is proportional to said negative density, to deflect said beam and thereby said luminescent line in a direction at right angles to itself, said mask being opaque, placed in front of said screen, and having a light transmitting aperture of such configuration that its width parallel to said line at different points bears the same relation to its distance from a given point of reference, in a direction at right angles to said line, as the density of the sensitized material selected for the positive print bears to different logarithmic exposure values, and said photoelectric cell placed in front of said mask, adapted to receive that portion of the light emitted from said luminescent line which passes said aperture, operatively connected to an electric circuit, and delivering an output adapted to actuate said second deflecting means of the cathode ray tube mentioned in claim 1.

7. A device according to claim 1, said means to convert a voltage, proportional to said negative density, to a voltage, proportional to a positive density, comprising a cathode ray tube, distinguished from the tube mentioned in claim 1, a mask, and a photoelectric cell, distinguished from the cells mentioned in claim 1, said cathode ray tube comprising means to form a beam of electrons, means to accelerate said beam, a screen capable of light emittance when struck by electrons, means causing said beam to form a straight luminescent line upon said screen, means actuated by an independent voltage to deflect said beam in a direction at right angles to itself in accordance with a selected logarithmic exposure time value, including means to adjust said voltage, and additional means actuated by the voltage which is proportional to said negative density, to deflect said beam in the opposite direction, the two voltages being in series but of opposite polarity and said first-named voltage being higher than said second-named voltage, said mask being opaque, placed in front of said screen, and having a light transmitting aperture of such configuration that its width parallel to said line at different points bears the same relation to its distance from a given point of reference in a direction at right angles to said line, as the density of the sensitized material selected for the positive print bears to different logarithmic exposure values, said mask including a mechanism adapted to adjust the shape of said aperture in accordance with a selected contrast factor, and said photoelectric cell placed in front of said mask, adapted to receive that portion of the light emitted from said luminescent line which passes said aperture, operatively connected to an electric circuit, and delivering an output voltage adapted to actuate said second deflecting means of the cathode ray tube mentioned in claim 1.

8. A device according to claim 1, said means to convert a voltage, proportional to said negative density, to a voltage, proportional to a positive density, comprising a cathode ray tube, distinguished from the tube mentioned in claim 1, a mask, and a photoelectric cell, distinguished from the cells mentioned in claim 1, said cathode ray tube comprising means to form a beam of electrons, means to accelerate said beam, a screen capable of light emittance when struck by electrons, means causing said beam to form a straight luminescent line upon said screen, means actuated by an independent voltage to deflect said beam in a direction at right angles to itself in accordance with a selected logarithmic exposure time value, including means to adjust said voltage, and additional means actuated by the voltage which is proportional to said negative density, to deflect said beam in the opposite direction, the two voltages being in series but of opposite polarity and said first named voltage being higher than said second-named voltage, said mask being opaque, placed in front of said screen, and having a light transmitting aperture of such configuration that its width parallel to said line at different points bears the same relation to its distance from a given point of reference in a direction at right angles to said line, as the density of the sensitized material selected for the positive print bears to different logarithmic exposure values, said mask

including a mechanism adapted to adjust the shape of said aperture in accordance with a selected contrast factor, and comprising an apertured frame, placed in front of the screen of the cathode ray tube and supporting the other elements of said mechanism, a plurality of movable cams, including means to move them in unison, a plurality of elongated members, each with two ends, said members adapted to slide in parallel tracks, a plurality of links, attached to each other and forming a chain adjacent to said aperture and covering part of it, and means, including spring biasing means operating on said links, adapted to establish operative contact between

said chain and the first ends of said slidable members, and between the second ends of said slidable members and said cams, said photoelectric cell placed in front of said mask, adapted to receive that portion of the light emitted from said luminescent line which passes the aperture of said mask, operatively connected to an electric circuit, and delivering an output voltage adapted to actuate said second deflecting means of the cathode ray tube mentioned in claim 1.

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No references cited.