

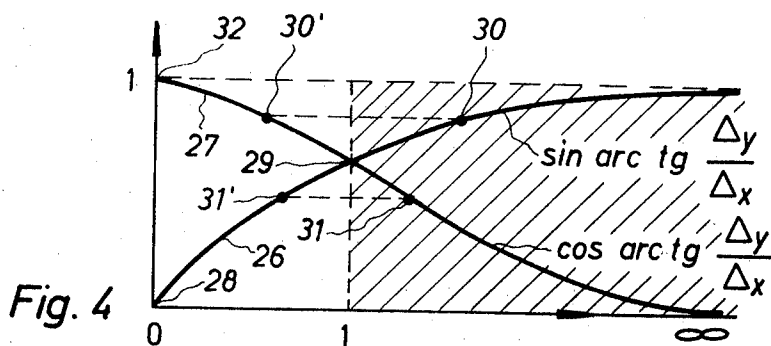
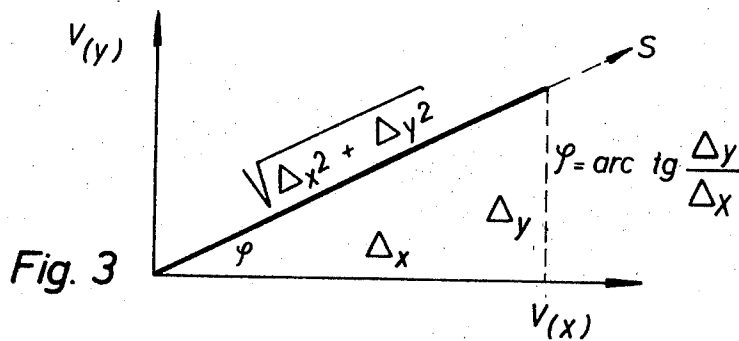
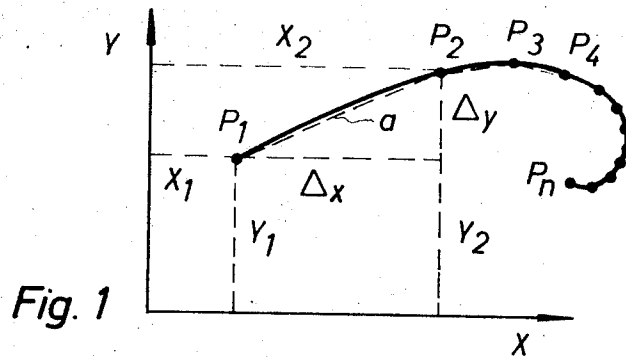
- 3,252,045 5/1966 Griffin 340/324 A

3,430,207	2/1969	Davis	340/324 A X
3,434,135	3/1969	Granberg et al.	315/18 X
3,488,483	1/1970	Freedman	340/324 A X
3,482,309	12/1969	Bourchard	315/22
3,320,409	5/1967	Larowe	340/324 A
3,333,147	7/1967	Henderson	340/324 A X
3,459,926	8/1969	Heilweil et al.	340/324 A X
3,473,079	10/1969	Adornetto et al.	315/22
3,510,865	5/1970	Callahan et al.	340/324 A

Attorney—Hill, Sherman, Meroni, Gross & Simpson

Curves are plotted and displayed on the screen of a cathode ray tube by deriving control voltages from the differences between the coordinates of adjacent points of a curve, controlling the plotting of line portions with the derived voltages, maintaining the speed and current of the recording electron beam of the CRT constant and maintaining a uniform brightness of the several portions of a trace.

A graph illustrating a curve in the xy -plane. The curve starts at point P_1 (with coordinates x_1, y_1) and ends at point P_n . Points P_2, P_3, P_4 are marked on the curve. The horizontal distance between P_1 and P_2 is labeled Δx , and the vertical distance is labeled Δy . The curve is labeled a .



INVENTOR
Friedrich Redecker
Rüdiger Sommer
BY *Hill, Sherman, Menon, Grosshupfer* ATTORNEYS

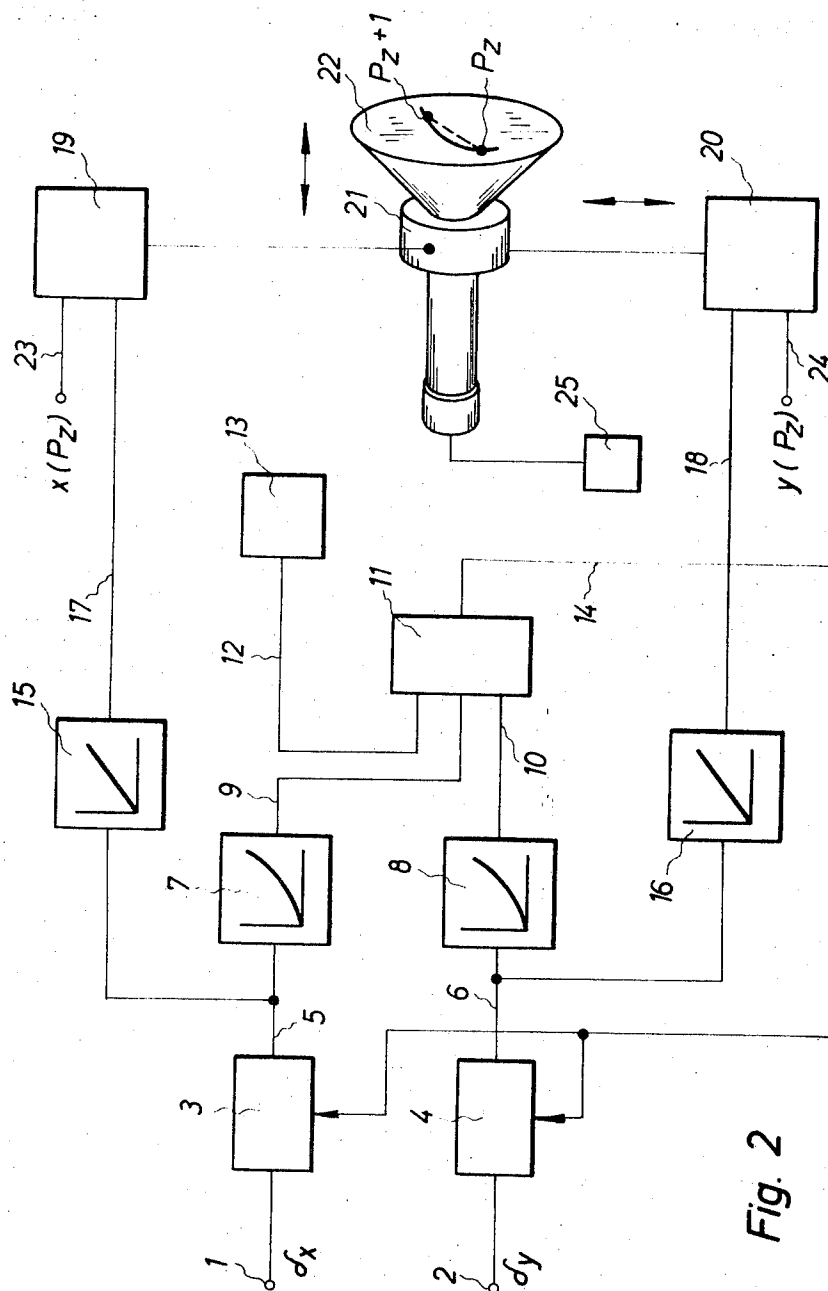


Fig. 2

BY

Hill, Sherman, Meroni, & Associates

INVENTOR
Friedrich Redecker
Ruediger Sommer
ATTORNEYS

Patented July 17, 1973

3,746,912

7 Sheets-Sheet 3

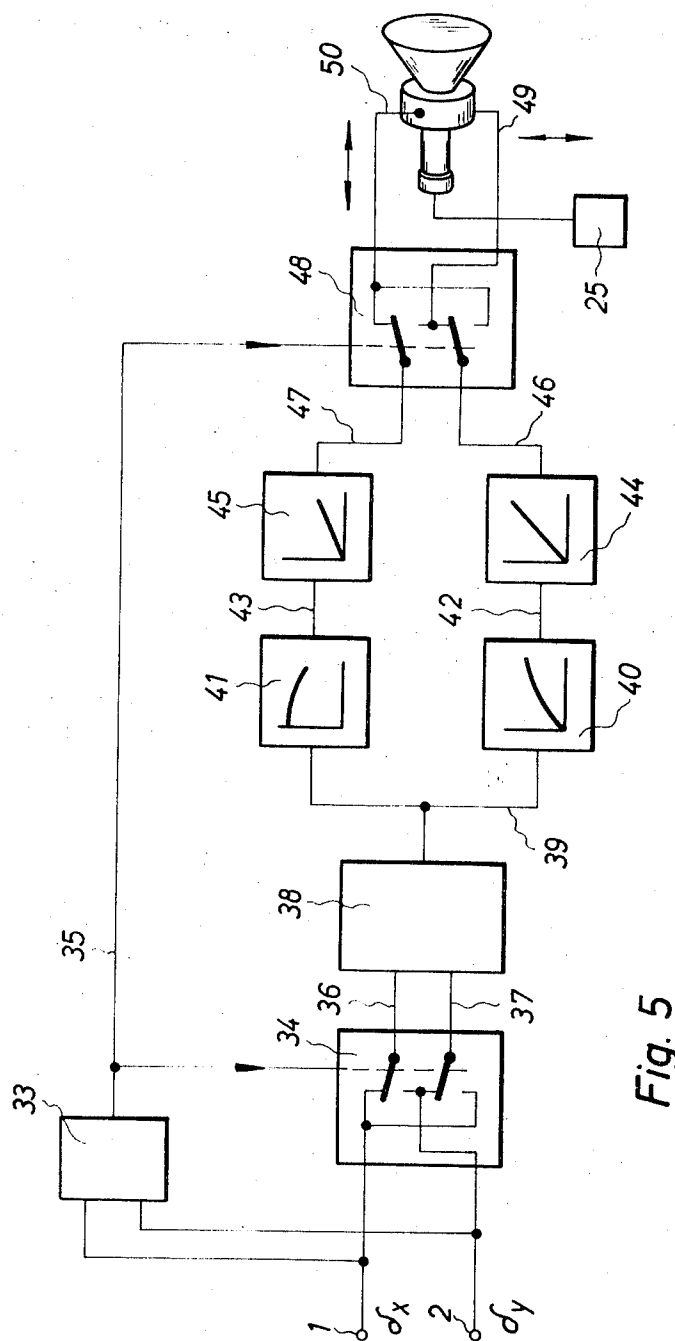


Fig. 5

INVENTOR.

Friedrich Redecker
Rüdiger Sommer

133-

BY *Hill, Sherman, McLean, Goss & Huber* ATTORNEYS

ATTORNEYS

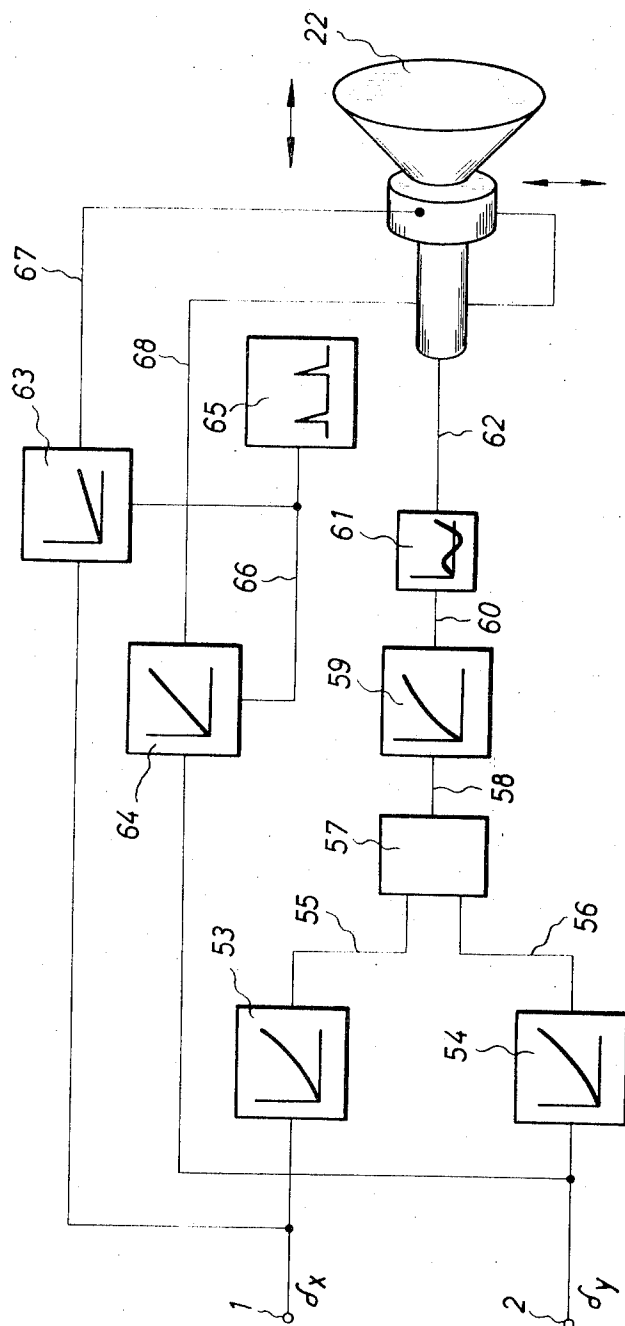
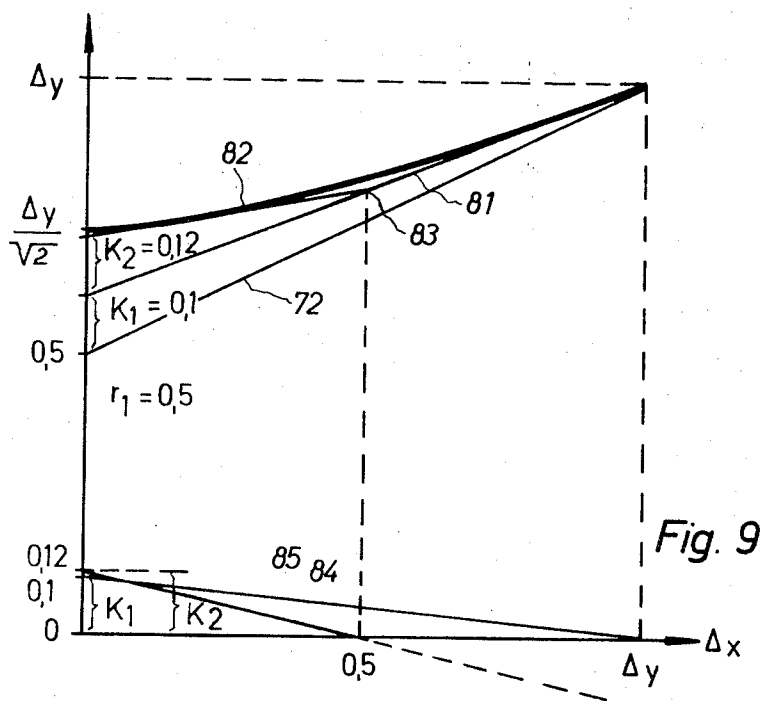
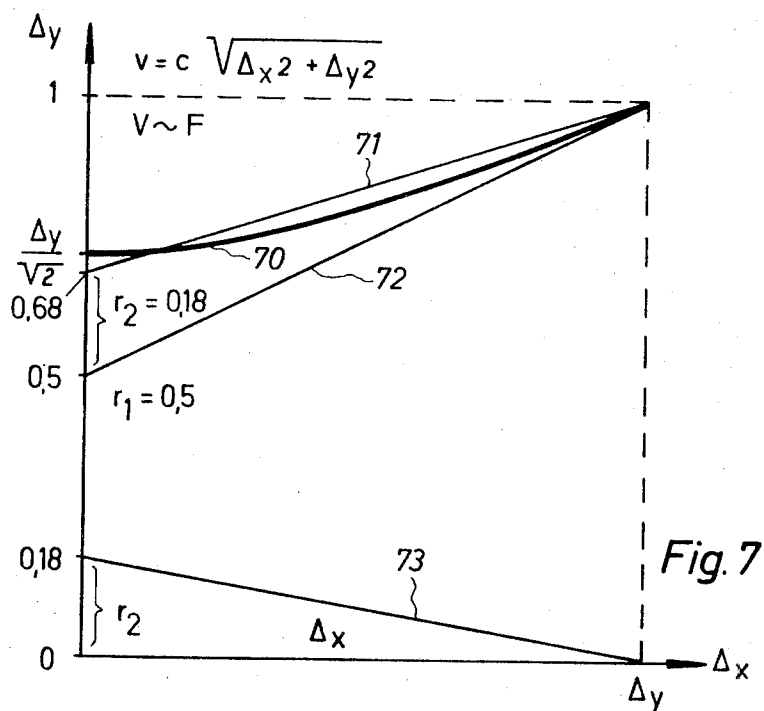


Fig. 6

BY

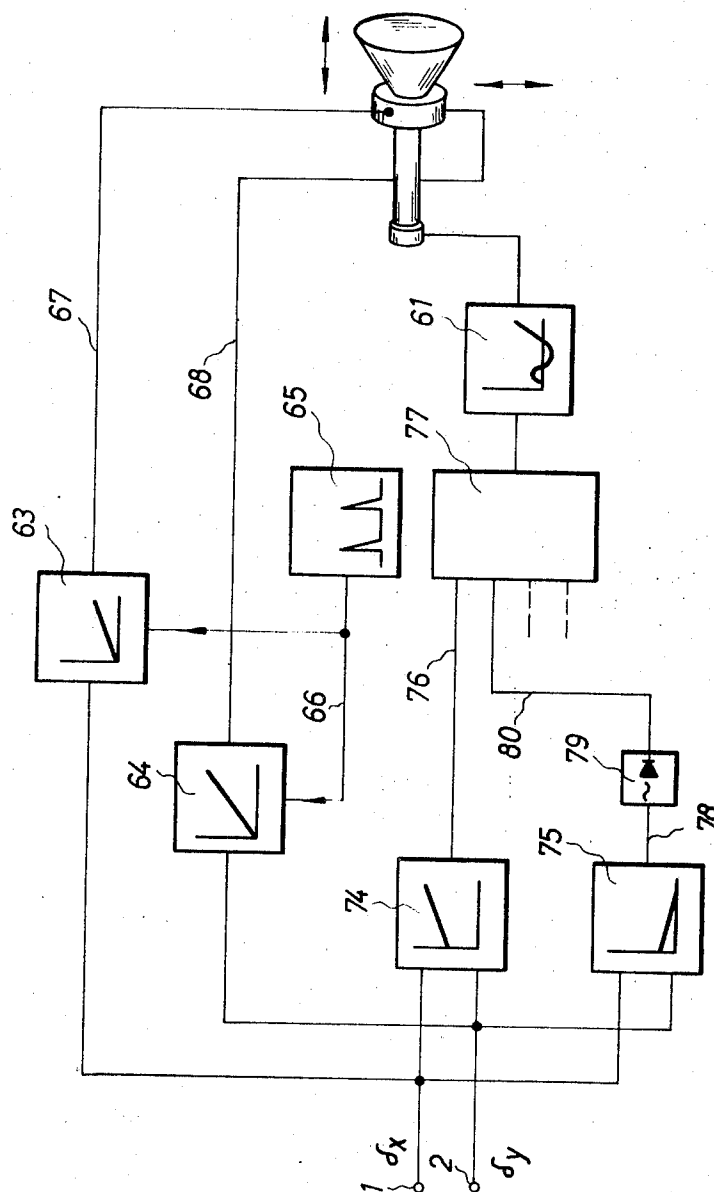
Hill, Sherman, Meroni, Gross & Simpson

INVENTOR
Friedrich Redecker
Ruediger Sommer
ATTORNEYS



INVENTOR
Friedrich Redecker
Ruediger Sommer

BY *Hill, Shuman, Dierous, Grosshupfer* ATTORNEYS



INVENTOR,

Friedrich Redecker
Ruediger Sommer

ATTORNEYS

137 Hill, Shannon, Merwin, Ross & Simpson

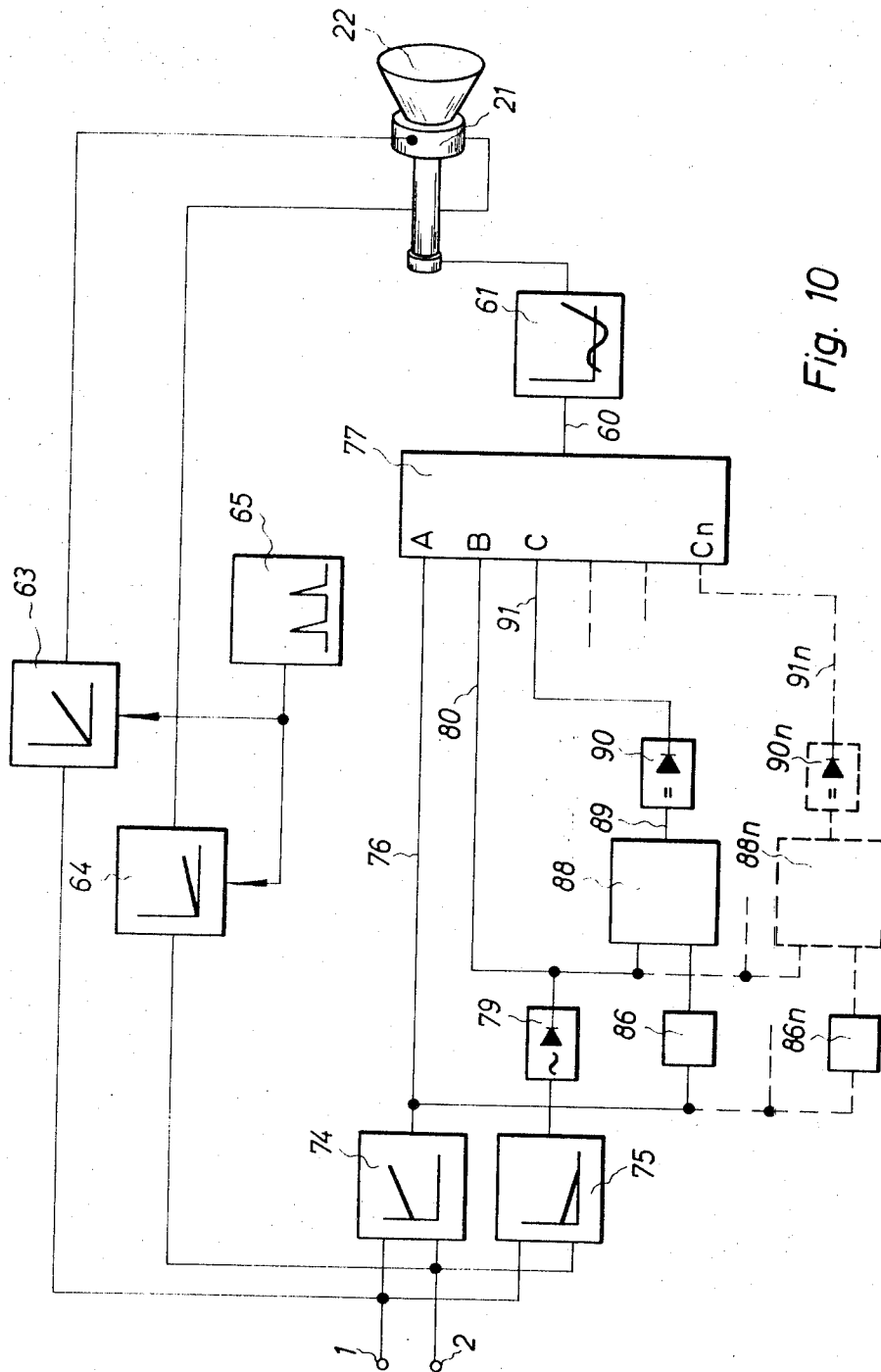


Fig. 10

INVENTOR
 Friedrich Redecker
 Rüdiger Sommer
 BY *Hill, Shannan, Meroni, Grosshupfer* ATTORNEYS

METHOD OF AND MEANS FOR RECORDING LINE DRAWINGS ON THE SCREEN OF A CATHODE RAY TUBE UNDER COMPUTER CONTROL

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a method of and means for recording line drawings on the screen of a cathode ray tube under computer control, the coordinates of individual points on the lines of the drawings being spaced at differing intervals and continuous line series being represented by straight lines connecting these points, said lines approximating the line drawing.

2. Description of the Prior Art

Cathode ray tubes are frequently used to display information calculated by a computer. Such illustrations are generally constructed from a limited number of symbols, i.e., numbers, letters and characters, whose recording data are distributed in an electronic memory of the recording apparatus or in the computer. These data consist of binary numbers of coordinates for positioning on the screen of the cathode ray tube and of binary coded numbers giving details of the length pieces of the individual picture lines from which the symbols are constructed. Each picture line piece is built up from a whole multiple of a minimum piece whose size is barely preceivable by the eye. The symbols thus have a raster structure. The data from the symbols are distributed under certain addresses in the memories. Upon call-up of this address they control, by means of the computer, the recording of the symbols on the screen of the cathode ray tube.

Often it is desired to plot not only symbols but also so-called "line drawings," i.e. drawings that are made up of continuous series of lines of the same line thickness and shape. For example, a weather map can be used which, in addition to the symbols and meteorological signs, also contain continuous series of lines of varying shapes, i.e., coastlines and iso-lines. Apparatus which plot weather maps are referred to as "plotters." Also during scientific computer calculations, functions often result which can be advantageously recorded with the aid of the plotter so that they are directly visible as curves and can be photographically fixed for evaluation.

The plotting of such curves can be particularly simply effected by plotting rows of points close to one another so that the eye observes a continuous solid line. Plotting of this kind has the disadvantage that a large number of points have to be displayed on the screen of the cathode ray tube. Each point has to be determined by an X- and a Y-coordinate which, in turn, have to be determined in a plurality of individual calculations and possibly stored in some form of memory.

In order to decrease this large amount of data, in an improved method of plotting, small lines of fixed length are employed instead of points. A definite number of line units having various angles of inclination is fixed. By lining up a plurality of these lines of appropriate inclination in any series and amount, approximation to the required curve can be attained.

However, it has been obligatory to compromise in the case of line plotting. If the continuous series of lines has to be plotted with few line units of greater length, then less information and storage room is necessary, however, a rectangular, rugged and unpleasant series of lines was obtained. If the lines are, however, suffi-

ciently small to overcome this disadvantage, then the amount of data which has to be plotted, addressed and stored increases proportionally.

In an advantageous method of recording, as small as possible a number of points on the continuous series of lines is determined, at differently sized and advantageously chosen spacings, and these points are connected to one another by straight line portions. This gives rise to a polygonal trace approximating the actual curve required. In order to achieve as good as possible an approximation, many points must be laid down close to one another in curved pieces having small radii of curvature, fewer points being necessary in curved pieces having a large radius of curvature and in straight members, and these need be provided only on the periphery and end. The line drawings thus produced have a smooth effect despite the enormously varying spacing between the points making up these lines. With a relative small number of points they satisfy the requirements for accuracy and satisfy the requirements to take up as little data and storage space as possible.

One important requirement is, however, not fulfilled. The line thickness must be uniform over the total length of the line series, if the latter is to have a satisfactory appearance. It is very difficult to achieve such uniformity, due to the very great difference in length of the part pieces, and the recording times, so that uniform illumination is not achieved and thus there is no equality in the line thickness. Two faults arise: firstly, the speed and brightness of the scanning point is not constant between the points delineating the line so that line pieces appear as commas, i.e., thicker to one side; and secondly, the brightness of the total line series is also not uniform due to the varying basic brightness of the individual line pieces. Therefore, the appearance of the line series is poor.

SUMMARY OF THE INVENTION

The straight union a of two points on the curve determined by the coordinates x_1, y_1 and x_2, y_2 is:

$$a = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} = \sqrt{\Delta x^2 + \Delta y^2}$$

The electron beam has to move over this path a during plotting of the curved piece. In order to achieve equally bright recording of the whole line series, each individual piece of the trace must be recorded at constant speed and beam intensity, and the beam intensity must be such that a uniform brightness is attained.

To this end, and according to the invention, voltages are derived from the differences between the coordinates of adjacent points and these voltages are fed to control means operative during plotting of individual line pieces, to keep the speed and current of the recording electron beam constant, and during the plotting of all the line members, to achieve uniform brightness on the screen of the recording tube.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features and advantages of the invention, its organization, construction and operation will be best understood from the following detailed description, taken in conjunction with the accompanying drawings which show some embodiments of the invention by way of example, and in which:

FIG. 1 shows a polygon, which is approximated to a curved path;

FIG. 2 shows a circuit diagram of a first proposal providing a uniform and constant speed and constant current of the electron beam for all the line pieces;

FIGS. 3 and 4 show graphical illustrations for developing the following circuit arrangement of FIG. 5;

FIG. 5 shows a circuit diagram of a second proposal providing constant speed and constant electron beam current;

FIG. 6 shows a circuit diagram of a first proposal for recording line pieces of different length in equal times and at controlled speed and beam current;

FIG. 7 shows a graphical illustration for an approximation method for solving the problem referred to in connection with the circuit of FIG. 6;

FIG. 8 shows a circuit diagram for carrying out the approximation method of FIG. 7;

FIG. 9 shows graphical illustrations for a further method according to FIG. 7; and

FIG. 10 shows a circuit diagram for carrying out the further approximation method of FIG. 9.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The plotting of any representations on the screen of a cathode ray tube is conventionally carried out by deflecting an electron beam, focussed to a point, in two orthogonal coordinate directions and preferably horizontally (x -direction) and vertically (y -direction), and at the same time the beam intensity is appropriately controlled. By establishing a pair of coordinates x and y , the position of a point on the screen is determined and can be controlled by deflection currents or voltages which are allocated to these coordinates.

If a definite point on the screen is to be controlled by a computer or memory, then this is achieved by the numerical values of the coordinates x and y of the point, which are offered in binary numbers depends on the degree of resolution which the electron beam point is to attain on the screen. The following numbers are of interest as a practical example. The usable diameter of this screen should amount to approximately 210 mm. so that a square field of 150 mm. can be used. The electron beam point should have a diameter of 0.05 mm. Then for instance 3,000 positions are possible in each coordinate direction, in the whole field 9×10^6 . For detailing the position of, or expressed in data technique parlance, "addressing" a point in the field, a twelve-digit binary number is required for x and y .

Referring now to the drawings, FIG. 1 represents any curved path which is to be plotted on the screen.

In order to be able to use as little control data as possible, a few points $P_1, P_2, \dots, P_n$ are selected on the curved path. The spaces are of different sizes and chosen so that straight connecting pieces between adjacent points (shown dashed) offer as good as possible an approximation to the real curve.

The curved piece $P_1 - P_2$ is determined by the coordinates x_1, y_1 for point P_1 and x_2, y_2 for point P_2 . In order visibly to plot the connecting line $P_1 - P_2$, the electron beam must follow the path from $P_1 - P_2$ at a finite speed and a fixed constant brightness.

The path which the beam is to take is the hypotenuse of the right-angled triangle having the short sides Δx and Δy , wherein: $\Delta x = x_2 - x_1$ and $\Delta y = y_2 - y_1$.

In order to move the electron beam along the straight path a uniformly from P_1 to P_2 , the deflection voltages for both the coordinates must change uniformly at the

same time from x_1 to x_2 or from y_1 to y_2 . With a constant electron beam current, the line portion is recorded at an even brightness.

The line portions $P_2 - P_3, P_3 - P_4, \dots, (P_n - 1) - P_n$, succeed the line portion $P_1 - P_2$. They form a continuous line which adapts itself closely to the curved path. So that the whole continuous line shall have an even line thickness, the individual line portions must be recorded at an even brightness. If the concession is made that large line pieces be recorded at the same speed as small ones, then the point brightness will also be equal for all the line pieces and the whole line series is evenly recorded. Corresponding to a second proposed solution the time for recording the individual line portions is to be equal. From the criteria of constant time intervals, which are given by a timing pulse generator, the control values for the beam speed and current can be derived by the distance between two points determined by the differences in the coordinates.

For implementing the first of the alternatives the following equation is to be fulfilled:

$$V = R \sqrt{\Delta x^2 + \Delta y^2} = \text{constant} \quad (a)$$

ps V signifying speed, and R a normal size, by which a constant real speed is adjusted.

FIG. 2 shows a circuit diagram of an electronic arrangement with whose assistance the above function of expression a is simulated. The circuit design implements the function obtained by squaring the expression

$$V^2 = R^2 \Delta x^2 + R^2 \Delta y^2. \quad (b)$$

It is assumed that the differences Δx and Δy of the x and y coordinates of both the points between which the curved portion is recorded have already been calculated and are available as proportional difference voltages, δx and δy . These difference voltages reach input terminals 1 and 2 of the circuit arrangement. Firstly, they pass variable gain amplifiers 3 and 4 without change and, via circuit connections 5 and 6, arrive at function amplifiers 7 and 8 which square the voltages according to the equation b . The output voltages at conductors 9 and 10 are added in an adder 11, simultaneously compared with a control voltage supplied via line 12. It originates from a controllable voltage source 13 and represents the value V^2 . The voltage simultaneously amplified and obtained in the adder 11 passes over a line 14 simultaneously to the control inputs of the variable gain amplifiers 3 and 4 and so regulates these latter that in the regulating system the adjusted and regulated values are equal to one another.

The voltages appearing in lines 5 and 6 control a sawtooth generator 16 for horizontal deflection and a sawtooth generator 26 for vertical deflections, in such a manner that voltages arise in lines 17 and 18, whose differential quotient is proportional to the control voltages in lines 5 and 6. These voltages pass via adders 19 and 20 to deflection coils 21 of a cathode ray tube 22 and effect movement of the electron beam from one point P_z to its adjacent point P_{z+1} . The movement therefore emanates from a basic position which is determined by the coordinates of the point P_z , namely $x(P_z)$ and $y(P_z)$. Voltages corresponding to these coordinate values pass via lines 23 and 24 to second inputs

of the adders 19 and 20 and determine the initial position for the movement of the electron beam. The adders 19 and 20 in the example shown also simultaneously transform the controlling voltages into deflecting currents. The brightness of the electron beam is adjusted to a desired value by means of an adjustable voltage source 25 and the deflection time of the individual saw-tooth phases is proportional to the line portions to be recorded. A suitable switch (not shown) is provided for this purpose.

A second solution of the object of recording line series at a constant recording speed and constant brightness is shown in FIG. 5. This arrangement avoids electronic control (feedback) loops and is therefore free from any tendency to set up interfering control oscillations. The circuit design is modeled on the equation as in the aforementioned example.

In the triangle formed in FIG. 3 from Δx and Δy , $\Delta y/\Delta x$ is the tangent of the angle formed by Δx and $2\sqrt{x^2 + y^2}$

$$\phi = \arctg \Delta y/\Delta x$$

(c)

The speed at which the electron beam moves in the x-direction is:

$$V_{(x)} = V_s \cdot \cos \phi = (\cos \arctg \Delta y/\Delta x) \cdot V_s$$

(d)

and in the y-direction:

$$V_{(y)} = V_s \cdot \sin \phi = (\sin \arctg \Delta y/\Delta x) \cdot V_s$$

(e)

V_s being the desired constant beam speed in the reproducing direction S.

Both the functions can be simulated electronically. It is, however, advantageous to limit the range of the variables $\Delta y/\Delta x$ to be used to the region between 0 and 1, because the functions in this interval are approximately rectilinear and can be simulated electronically more easily than in the total area from 1 to ∞ . The range $\Delta y/\Delta x > 1$ is considered, $\cos \arctg \Delta y/\Delta x$ being replaced by $\sin \arctg \Delta x/\Delta y$ and $\sin \arctg \Delta y/\Delta x$ being replaced by $\cos \arctg \Delta x/\Delta y$.

FIG. 4 shows in the two curves 26 and 27, the functions $\sin \arctg \Delta y/\Delta x$ and $\cos \arctg \Delta y/\Delta x$. In the range from 0 to 1, $\sin \arctg$ increases from the point 28 along the branch of the curve 26 to point 29. One point, e.g., 30 on the branch of the curve in the region of 1 to ∞ corresponds to the point 30' of the curve 27 for the range 1 to 0. The whole branch of the curve 26 in the range of 1 to ∞ can be replaced by the branch 27 in the range of 1 to 0 between point 29 and 32. The same also applies inversely. The point 31 on the branch of the curve 27 in the range of 1 to ∞ corresponds to point 31' on the branch 26 in the range of 1 to 0 between the points 29 and 28. The functions $\sin \arctg \Delta y/\Delta x$ are therefore replaced by $\cos \arctg \Delta x/\Delta y$ and $\cos \arctg \Delta y/\Delta x$ are replaced by $\sin \arctg \Delta x/\Delta y$ when $\sin \arctg \Delta y/\Delta x$ is greater than $\cos \arctg \Delta y/\Delta x$ so the branches of the curve are avoided in the range of 1 to ∞ shown hatched.

This exchange of functions in the electronic production of the proposed solution occurs after comparison in size between Δx and Δy by simple switching.

FIG. 5 shows a suitable circuit arrangement to accomplish the foregoing proposal. The difference voltages δx and δy pass from the input terminals 1 and 2 simultaneously to a comparator 33 and a switch 34. If $\delta x < \delta y$, the switch 34 remains in the position shown. The voltage δx is applied to a line 36 and the voltage δy to a line 37. If, however, $\delta x > \delta y$, the switch 34 is reversed. The voltage δy reaches the line 36 and the voltage δx the line 37. The voltage on the line 36 is therefore always smaller than that on the line 37.

A dividing circuit 38 divides the voltage at its one input 36 by the voltage applied to its other input 37. The quotient voltage on the output line 39 is simultaneously fed to two function generators 40 and 41. The function generator 40 forms the function $\sin \arctg$ and the function generator 41 the function $\cos \arctg$. The output voltage on lines 42 and 43 control the saw-tooth generators 44 and 45 which supply the currents for deflection of the electron beam in the cathode ray tube.

The deflection currents are, however, fed through a switch 48 which is simultaneously with and similarly to the switch 34, controlled by the comparator 33 via line 35. If, therefore, $\delta x < \delta y$, then the connection shown exists, and the deflection current passes through a line 47 to a terminal 50 of the deflection coils for horizontal deflection. Thus, the current controls the vertical deflection via a terminal 49 through a line 46. The horizontal deflection follows the function $\cos \arctg$ and the vertical deflection the function $\sin \arctg$.

If $\delta x > \delta y$, the comparator 33 responds and actuates the switches 34 and 48. As a result, 1 is connected to 37 and 2 to 36 at the input, furthermore 46 is connected to 50 and 47 to 49. The horizontal deflection now follows the function $\sin \arctg$ and the vertical deflection the function $\cos \arctg$.

For adjusting a desired brightness of the electron beam an adjustable voltage source 25 is also used in this case. A basic positioning is required, which details the initial point during the recording of each line member. These basic deflection currents have the same function as is described in FIG. 2 and was shown at the lines 23 and 24 and are mixed with the deflection currents in the lines 49 and 50. Re-representation is therefore in this case unnecessary.

The switches 34 and 48 shown in the drawings as mechanical contacts for case of illustration, are actually constructed from logic components including diodes or transistors.

The second alternative solution of the invention consists in plotting the connecting lines between adjacent points always in the same time. This solution has the result that the recording speed differs very greatly and the brightness of the light spot i.e., the intensity of the electron beam has to be controlled so that all the line pieces are plotted equally brightly or approximately equally brightly. The beam current I_s is therefore dependent upon the deflection speed:

$$I_s = E \sqrt{\Delta x^2 + \Delta y^2} \cdot f_{tm} \quad (f)$$

where E is an adjustment constant and f_{tm} a function for correcting the non-linearity between control voltage and beam current as well as between beam current and spot brightness on the screen.

Simulation of the function f is made possible with the aid of the arrangement shown in FIG. 6. The difference

voltages δx and δy are applied to the terminals 1 and 2 and pass to function generators 53 and 54, which form the squares δx^2 and δy^2 . The resultant voltages on lines 55 and 56 are added by means of adder 57, and the square root is extracted from the total by means of a function generator 59 so that at the output from a line 60 there is produced a voltage proportional to the size $\sqrt{\delta x^2 + \delta y^2}$. This voltage is to control the beam current of the cathode ray tube 22 and therefore the brightness of the light spot to be plotted. In this way, proportionality remains guaranteed. The control voltage is pre-distorted by the correcting member 61 = f_{lin} in such a manner that non-linear distortions are compensated between the control voltage and beam current, as well as between beam current and light intensity of the tube. The pre-distorted voltage passes via a line 62 to the control electrode of the tube.

Simultaneous with the function generators 53 and 54, saw-tooth generators 63 and 64 are controlled by δx and δy . The slopes of the saw-tooth currents supplied to lines 67 and 68 are proportional to the voltages δx or δy . A timing pulse generator 65 supplies start- and stop-pulses at regularly equal intervals simultaneously to both the deflection amplifiers over a line 66. During each interval, a line piece is plotted between two adjacent points. The deflection currents for the basic position are also added in this case in the manner already described, to lines 67 and 68.

This aforementioned proposal can lead to technical difficulties in cases at the limits. If the ratio between the maximum and minimum possible beam speed is very great then it is difficult to simulate the expression f with sufficient precision. When electronically squaring and subsequently forming the square root, considerable errors can occur more particularly at low beam speeds. The following proposal avoids these calculation operations by using an approximation method. It offers, using only additive calculation operations and with minimal electronics, a sufficiently satisfactory result. The following reasons lead to the new solution.

It should be

$$V \sim F \sqrt{\Delta x^2 + \Delta y^2} \quad (g)$$

in the following all expressions Δx , Δy , δx and δy are absolute values that means their signs are always positive. The constant F is attributed to the value $1/\sqrt{2}$ for standardizing the calculation. With a constant Δy , Δx increases from 0 to $\Delta x = \Delta y$. V then follows the path shown in FIG. 7 at curve 70. Its smallest value is $\Delta y/\sqrt{2} \approx 0.7\Delta y$ at $\Delta x = 0$, its greatest Δy at $\Delta x = \Delta y$. The curve 70 is applicable for any value from Δx and Δy , Δx and Δy being interchangeable.

A straight line 71 is laid through the curve 70 in such a manner that as good as possible approximation to the curve 70 is achieved. For example, the straight line 71 is located by the point $\Delta x = \Delta y = 1$. It intersects the ordinate at 0.68.

The straight line 71 can be obtained by adding straight lines 72 and 73. The straight line 72 is represented by the equation:

$$A = r_1 (\Delta x + \Delta y) \quad (h)$$

whereby $r_1 = 0.5$, and the straight line 73 by the equation:

$$B = r_2 |\Delta x - \Delta y| \quad (i)$$

where r_2 is equal to the amount r_2 enclosed on the ordinate between the straight lines 71 and 72, namely ~ 0.18 .

The electronic execution of the addition of both the equations h and i is shown in the circuit arrangement according to FIG. 8.

The difference voltages δx and δy are applied to the inputs 1 and 2. δx is simultaneously fed to a first input of an adder 74, a subtractor 75 and the saw-tooth generator 63 for horizontal deflection, and δy is fed to the second input of the adder 74 and the subtractor 75 as well as to the saw-tooth generator 64 for vertical deflection. In the device 74 a simple adder, the total $\delta x + \delta y$ is formed and fed to an adding device 77. The difference $\delta x - \delta y$ is formed in the subtractor 75, and is passed via a line 78, a rectifier 79 and a conductor 80 to the second input of the adder 77. The rectifier 79 is provided to make the difference $\delta x - \delta y$ effective according to their amount.

Correction of the non-linearity between the control voltage and brightness of the cathode ray tube occurs, as already described, with the aid of the correction amplifier 61. The saw-tooth generators 63 and 64 supply the current for the horizontal and vertical deflection via lines 67 and 68. They are, as already explained in the description of FIG. 6, steadily increasing (or falling) currents, whose rates of change dI/dt are proportional to δx or δy . The timing pulse generator 65 supplies start- and stop-pulses to the saw-tooth generator at regularly equal intervals via line 66. During each interval, one line piece is plotted between two adjacent points.

The approximation achieved with the straight line 71 is sufficient in many cases because it is controlled according to the brightness of the electron beam, and the eye is not very sensitive to depth or width deviations of the lines recorded. Nevertheless a requirement for better approximation to the real curve 70 can be fulfilled. Instead of the straight line 71, a continuous line is produced from two or more smaller straight pieces which adapt themselves as a polygonal path to the real curve with increasing exactitude as the number of pieces increases.

FIG. 9 shows the improvement when using two straight pieces, namely 81 and 82. The knee 83 at which the members meet, is located for example at $\Delta x = 0.5\Delta y$.

The line series 81/82 is, as apparent from the drawing, obtained by the addition of the straight lines 72, 84, and 85, the negative branch of straight line 85 (shown by dots) having to be suppressed. The addition of the straight lines 72 and 84 is effected in the same manner as has been described in FIG. 8 in connection with straight lines 72 and 73. In addition an equation j (below) of the straight line 85 has to be added. For the equation h the factor $r_1 = 0.5$, for equation i the factor $K_1 = 0.1$ and equation j receives the factor $K_2 = 0.12$. These values are divided on the ordinate.

The equation for the straight line 85 is as follows:

$$C = K_2 |\Delta y - 2\Delta x| \quad (j)$$

For this it is necessary that its value from $K_2 = 0.12$ at $\Delta x = 0$ takes off with an increasing Δx until, at $\Delta x = 0.5\Delta y$, the value nil is obtained. With further increasing Δx values the sign changes until at $\Delta x = 1$ the value be-

comes $C = -K_2$. This negative (shown in dots) branch is not to be used.

The straight line 85 therefore intersects the ordinate at $\Delta x = 0.5\Delta y = 0.5$. The knee of the polygonal path is located above this point. The knee is given by the equation:

$$Z = |\Delta x - \Delta y| / \Delta x + \Delta y \quad (k)$$

In the case of our example it should be located at $\Delta x = 1/2 \Delta y$,

$$Z = 1 - 1/2 / 1 + 1/2 = 1/3$$

For the practical execution of the operation by electronic means it is advantageous to transform the equation k as follows:

$$|\Delta x - \Delta y| - Z(\Delta x + \Delta y) = 0,$$

receiving the equation of the straight line 85 intersecting the zero line in the knee $\Delta x - 1/2 \Delta y$. Only the left hand positive branch located above the zero line is to be used. The right hand branch (not used) having a negative value is blocked in electronically by a diode.

FIG. 10 shows an electronic circuit arrangement which implements the improved approximation method explained with reference to FIG. 9. The adders 74, 75, the rectifier 79, as well as the summing device 77 and the correcting device 61 are understood from FIG. 8. The equations of additional lines are to be added to the sum $A + B$ which is formed in the adding device 77. The polygonal path of the approximation curve consists of the total sum of the equations of the additional lines and the sum $A + B$. These equations are $C, C_1 \dots C_n$. Firstly, we satisfy ourselves with C ; that means an approximation according to FIG. 9 having only one knee. The factors calculated and assumed from the drawing (FIG. 9) are:

$$r_1 = 0.5; K_1 = 0.1; K_2 = 0.12 \text{ and } Z = 1/3$$

The terms of a sum $r_1(\Delta x + \Delta y)$ and $K_1|\Delta x - \Delta y|$ are available at lines 76 and 80 as electric potentials. A corresponding voltage passes through the voltage divider 86, which forms the factor Z/K_1 , to the second negative input of the subtractor 88, at whose first input the unipolar voltage $|\Delta x - \Delta y|$ is applied, via the line 80. The resultant voltage on the line 89 can be positive or negative. However, only the positive value is to be used corresponding to the left hand positive branch of the straight line 85 in FIG. 9. The negative voltage is blocked by means of the blocking diode 90. The positive voltage passes over line 91 to the summing device 77. The sum voltage on the line 60 subsequently passes through the correcting member 61 and controls in a known manner the beam current from the cathode ray tube. Deflection of the beam occurs at always the same times by means of the deflecting amplifiers 63 and 64, as already described.

The circuit may be developed to achieve ever greater precision, in any desired fashion. At each knee at which the polygonal path increased, the number of aggregates 86, 88 and 90 is increased by one. The factors $K_1 \dots K_n$ and also the values for $Z_1 \dots Z_n$, are advantageously determined graphically. In addition, a drawing is to be prepared which must be extended logically with respect

to FIG. 9. The individual line portions of the polygonal path are extended up to the intersection point with the ordinate. The lengths divided up on the ordinate, result in corresponding scale in the values $K \dots$. The projections of the knees to the abscissa give the values for $Z \dots$.

Two modifications of the embodiments according to the invention will now be described. If the differences between the points become too large, it is advantageous to change the adjustment values, namely the recording speed and the associated beam brightness according to FIGS. 2 and 5, or the recording time and the beam current according to the circuits of FIGS. 6 and 10 in matched stages; criteria for these inversions are the difference voltages δx and δy .

A predetermined beam speed and beam current is adjusted in the first case up to a fixed limit value δx or δy . If one of the values δx or δy or both exceed this limit at greater point distances, the saw-tooth generators 15 and 16 in FIG. 2 or 44 and 45 in FIG. 5 and in addition the beam current control 25 in FIG. 5 are switched over to the next fixed operational range. It is also possible to extend this switching over to more than only two ranges.

In the second case which is implemented by the circuit arrangement in FIGS. 6 and 8 and 10, switching over effects upon exceeding the distance limit that the intervals between the start- and stop-pulses from the timing pulse generator 65 become larger, so that with larger point spacings, the recording time is not disproportionately small and the beam current is not too great. In addition, the difference voltage values δx δy at the input terminals 1 and 2 are reduced by one factor or if more operational ranges are desired, selectively by additional factors. The time intervals supplied by the generator 65 are increased by the same factor.

However, the switching over of the operational range within one these described methods is only one of the possible modifications. Cases can be conceived in which it is advantageous, dependent of the point spacings between which the line member is to be plotted, to change the arrangement or even the method. Very large line pieces are advantageously plotted at constant speed, whilst with short pieces constant recording time is at least preferable.

Although we have described our invention by reference to specific examples, many changes and modifications of the invention may be made by one skilled in the art without departing from the true spirit and scope of the invention, and it is to be understood that we intent to include within the patent warranted on this invention all such changes and modifications as may reasonably and properly be included within the scope of our contribution to the art.

We claim:

1. Apparatus for recording line drawings on the screen of a CRT which has horizontal and vertical deflection circuits, a horizontal and a vertical deflection coil, a recording beam emission circuit, the line drawings represented by a plurality of individually spaced coordinate points, each line drawing recorded by the recording beam connecting an initial coordinate point and an end coordinate point, means to produce deflection voltages representing the initial coordinate point, means to produce deflection voltages for connecting the initial coordinate point with the end coordinate point, and means to produce difference voltages repre-

senting the difference between initial coordinate point and the end coordinate point comprising:

adding means for adding the deflection voltages to the deflection coils, said adding means connected between the deflection coils and the means to produce the deflection voltages which represent the initial coordinate point and the means to produce the deflection voltages for connecting the individual coordinate point with the end coordinate point, sawtooth generating means producing constant slope sawtooth voltages which represent the deflection voltages for connecting the initial coordinate point and the end coordinate point, said slope being dependent upon the difference voltages derived from the initial coordinate point and the end coordinate point of the line drawing,

comparator means having an output and a pair of inputs for receiving respective horizontal and vertical difference signals and operable to provide a first signal at its said output when the horizontal difference voltage is less than the vertical difference voltage and a second signal at its said output when the horizontal difference voltage is greater than the vertical difference voltage,

dividing amplifier means having a pair of inputs and an output and operable to provide at its said output the quotient of the voltage on a first of said pair of inputs divided by the voltage on a second of said pair of inputs,

first switching means having a first input for receiving the horizontal difference voltages and a second input for receiving the vertical difference voltage, a pair of outputs connected to said pair of inputs of said dividing amplifier means, and a control input connected to said output of said comparator means and operable in response to said first and second signals to selectively connect said horizontal and vertical difference voltages to the input of said dividing amplifier means, and

second switching means having a pair of inputs for receiving said sawtooth voltages, a pair of outputs connected to said deflection circuits and a control input connected to said comparator means and operable in response to said first and second signals to selectively connect said horizontal and vertical sawtooth voltages to the horizontal and vertical deflection circuits.

2. Apparatus according to claim 1, comprising function amplifier means connected between said output of said dividing means and said saw-tooth voltage generating means for selectively operating said sawtooth generating means in accordance with $\sin \arctan t_g$ and $\cos \arctan t_g$ functions.

3. Apparatus according to claim 1 comprising means for dividing said difference voltages by one another to provide quotients that are less than unity and means for forming $\sin \arctan t_g$ and $\cos \arctan t_g$ functions from said quotients, and wherein said sawtooth generator means is linearly responsive to said $\sin \arctan t_g$ and $\cos \arctan t_g$ functions to control the deflection circuits.

4. Apparatus for recording line drawings on a screen of a CRT which has horizontal and vertical deflection circuits, a horizontal and a vertical deflection coil, a recording beam emission circuit, the line drawings represented by a plurality of individually spaced coordinate points, each line drawing recorded by the recording beam connecting an initial coordinate point and an end

coordinate point, means to produce deflection voltages representing the initial coordinate point, means to produce deflection voltages for connecting the initial coordinate point to the end coordinate point, and means to produce difference voltages representing the difference between the initial coordinate point and the end coordinate point comprising:

adding means for adding the deflection voltages to the deflection coils, said adding means connected between the deflection coils and the means to produce the deflection voltages which represent the initial coordinate point and the means to produce the deflection voltages for connecting the individual coordinate point with the end coordinate point, sawtooth generating means producing constant slope sawtooth voltages which represent the deflection voltages for connecting the initial coordinate point and the end coordinate point, said slope being dependent upon the difference voltages derived from the initial coordinate point and the end coordinate point of the line drawing,

a timing pulse generator for producing repetitive pulses,

said sawtooth generating means including timing pulse input connections connected to said timing pulse generator, said sawtooth generating means being responsive to successive timing pulses to turn on and off,

means for controlling beam current of the CRT including means for squaring said difference voltages, means for adding the squared voltages, means for extracting the square root of the added square voltages, and means for distorting the square root voltage connected to the recording beam emission circuit, means for adding the difference voltages, means for subtracting the difference voltages including means for rendering the subtraction effective without regard to sign, means for adding the sum and difference of said difference voltages connected to said means for distorting for distortion of said difference voltages.

5. Apparatus according to claim 4 comprising at least one voltage divider connected to the output of said means for adding the difference voltages, a second means for subtracting connected to the first mentioned means for subtracting and to said voltage divider for subtracting to provide the absolute value difference between the voltages provided by said voltage divider and said first-mentioned means for subtracting, said second means for subtracting also connected to said means for adding the sum and difference of said difference voltages.

6. Apparatus for recording line drawings on the screen of a CRT which has horizontal and vertical deflection circuits, a horizontal and a vertical deflection coil, a recording beam emission circuit, the line drawings represented by a plurality of individually spaced coordinate points, each line drawing recorded by the recording beam connecting an initial coordinate point and an end coordinate point, means to produce deflection voltages representing the initial coordinate point, means to produce deflection voltages for connecting the initial coordinate point with the end coordinate point, and means to produce difference voltages representing the difference between the initial coordinate point and the end coordinate point comprising:

13

adding means for adding the deflection voltages to the deflection coils, said adding means connected between the deflection coils and the means to produce the deflection voltages which represent the initial coordinate point and the means to produce the deflection voltages for connecting the initial coordinate point with the end coordinate point, sawtooth generating means producing constant slope sawtooth voltages which represent the deflection voltages for connecting the initial coordinate point to the end coordinate point, said slope being dependent upon the difference voltages derived from the initial coordinate point and the end coordinate point of the line drawing, two variable gain amplifier means each having an input for simultaneously receiving the difference voltages, a control input, and an output connected to said sawtooth generators, two function amplifiers, each of said function amplifiers including an input connected to the output of one of said variable gain amplifier means, said

14

function amplifiers operable to square the output voltages of said variable gain amplifier means, an adjustable voltage source representing the desired value of the drawing speed of the recording beam between adjacent points of the drawing, and an adder circuit including an output connected to said gain control inputs of said variable gain amplifier means, and a plurality of inputs connected to said adjustable voltage source and said outputs of said function amplifier means for adding said squared output voltages and comparing such voltages with the voltage of said adjustable voltage source to provide control voltages to said variable gain amplifier means, whereby said variable gain amplifier means regulates the slope of a sawtooth voltage of said sawtooth generating means for each difference voltage with respect to both difference voltages and the voltage of the adjustable voltage source.

* * * * *

25

30

35

40

45

50

55

60

65