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(54) Track curve lining method and apparatus

(57) A railroad track curve is plotted by measuring ordinates (58) at a fixed point (61) of a fixed length reference line that is moved to a series of incremental points spaced around the curve (59), and the ordinates (58) are stored in a data processor memory. The data processor calculates theoretical ordinates for an ideal curve which most closely fits the measured ordinates (58), and the track is shifted at the incremental points under control of the processor a distance and direction corresponding to the deviation between the measured and calculated ordinates. The system permits determination of transition points for simple and compound curves, and allows superelevation values to be selected and intermediate values calculated for smooth transition between tangent and constant curve track. The reference line may be established by a light beam (14), and the processor may be part of a self-propelled, on-track lining machine.

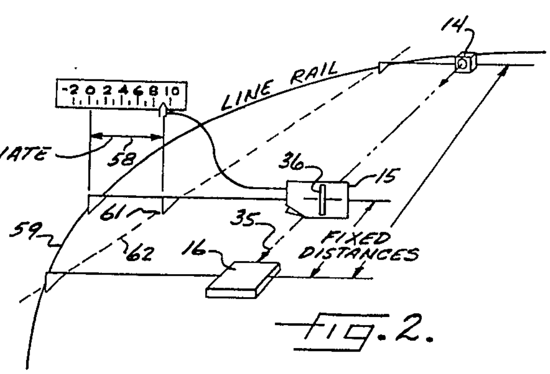

FIG. 2.

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The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.
This print takes account of replacement documents later filed to enable the application to comply with the formal requirements of the Patents Rules 1982.

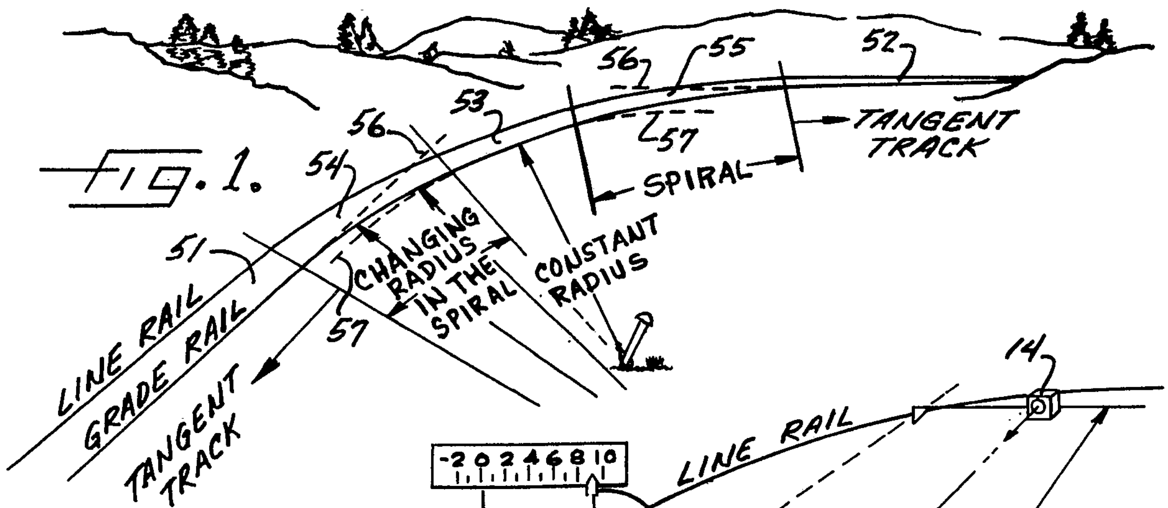


FIG. 1.

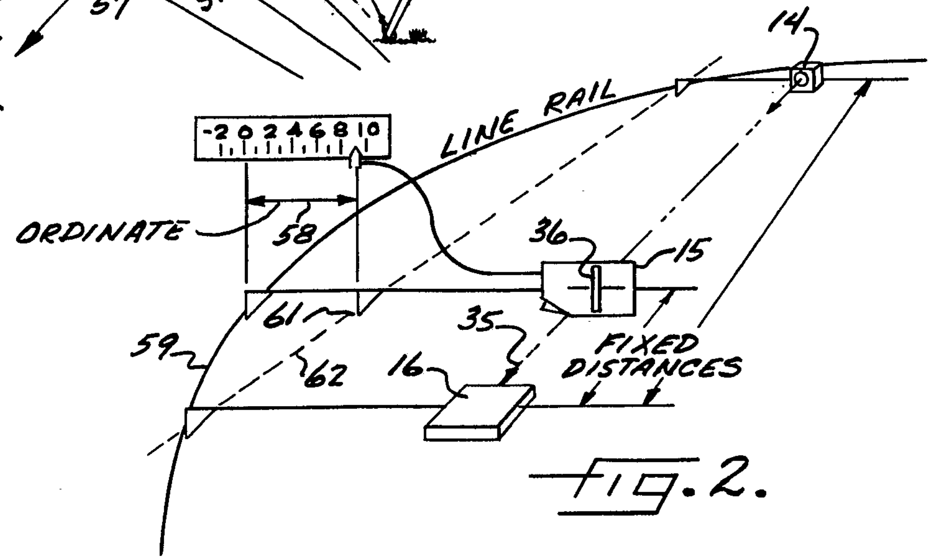


FIG. 2.

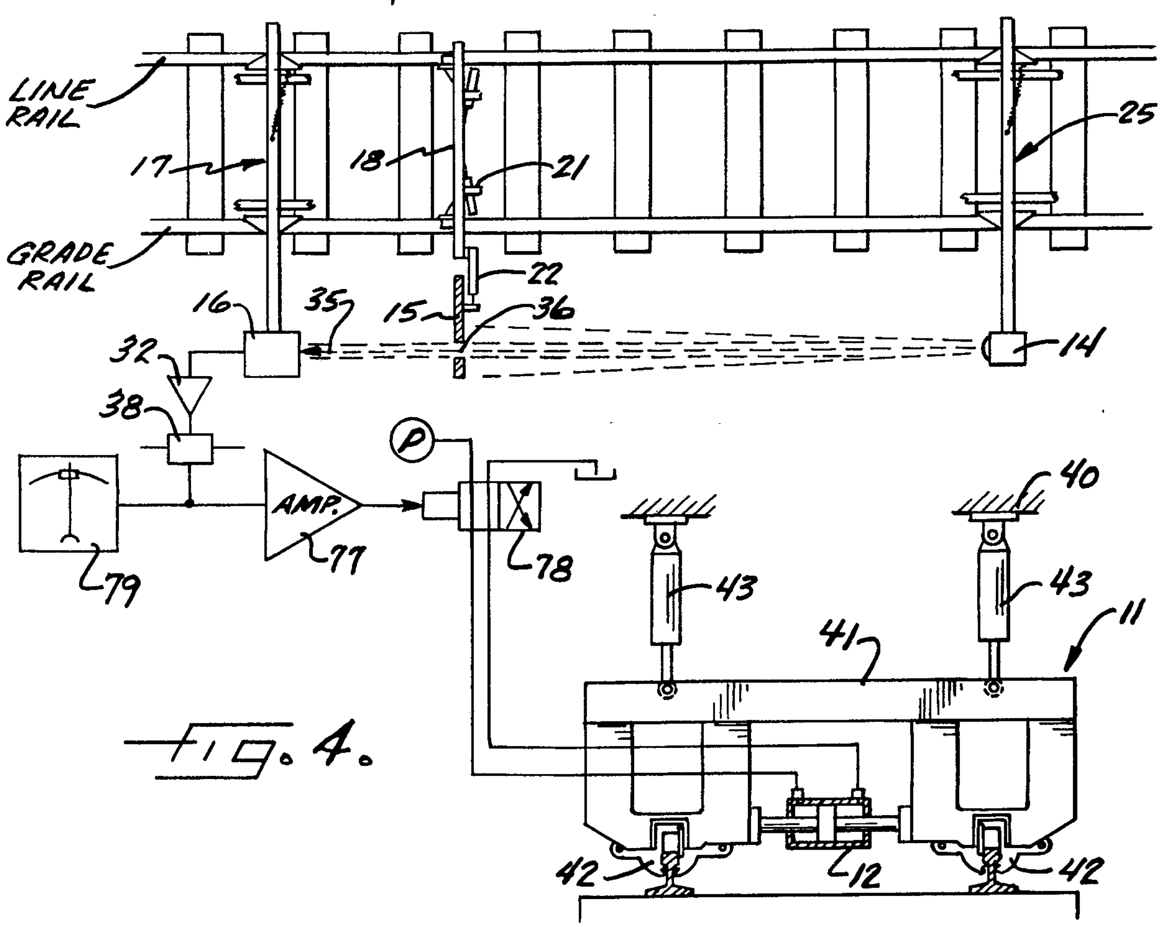
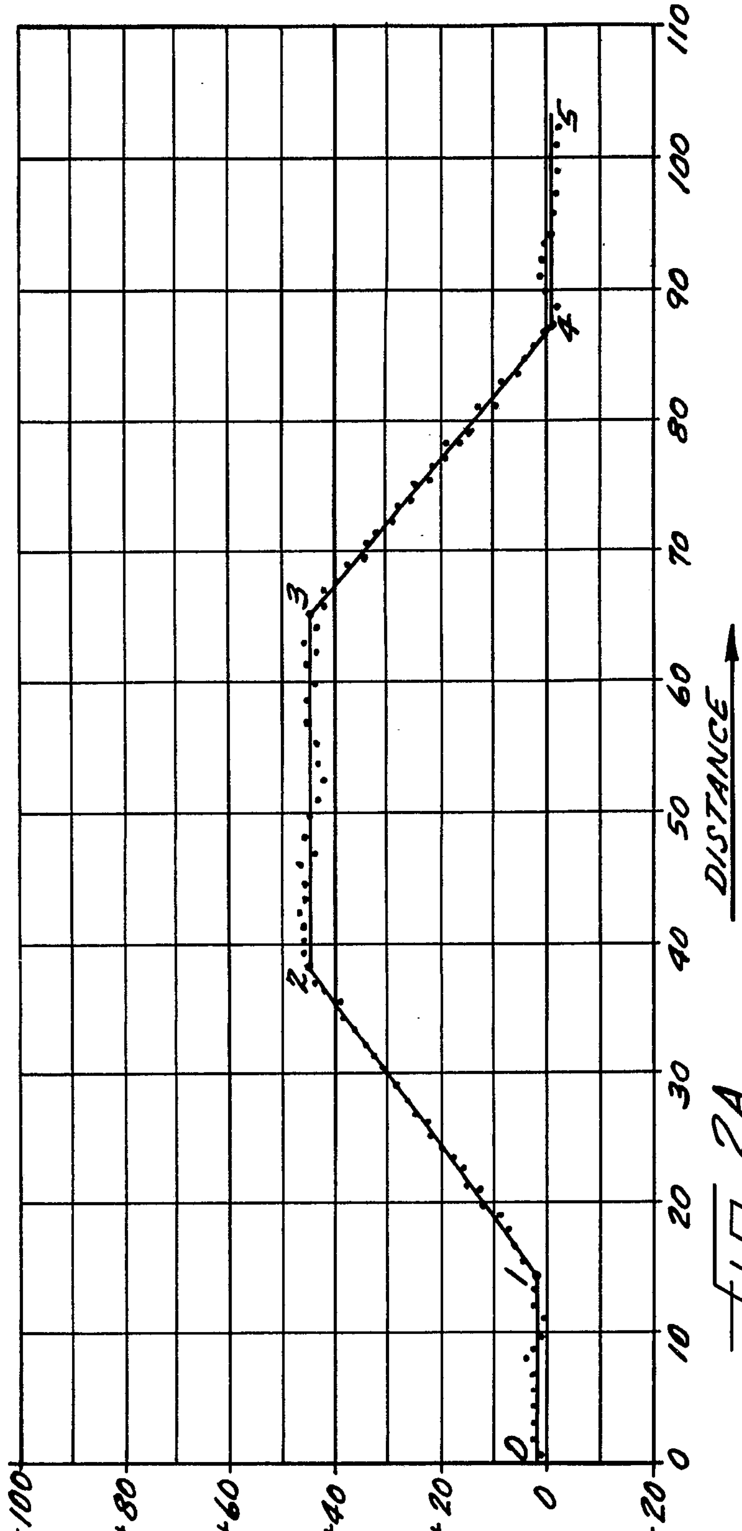
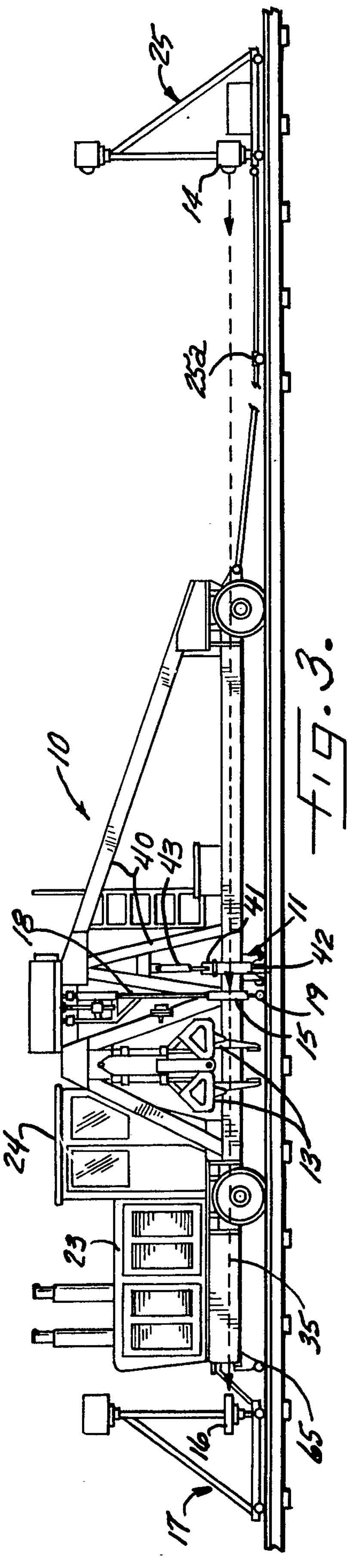


FIG. 4.



+100
+80
+60
+40
+20
0
-20
ORDINATE VALUES
0
10
20
30
40
50
60
70
80
90
100
110
DISTANCE
0
1
2
3
4
5

FIG. 2A.



10
11
13
14
15
16
17
18
19
23
24
25
25a
35
40
41
42
43
65

FIG. 3.

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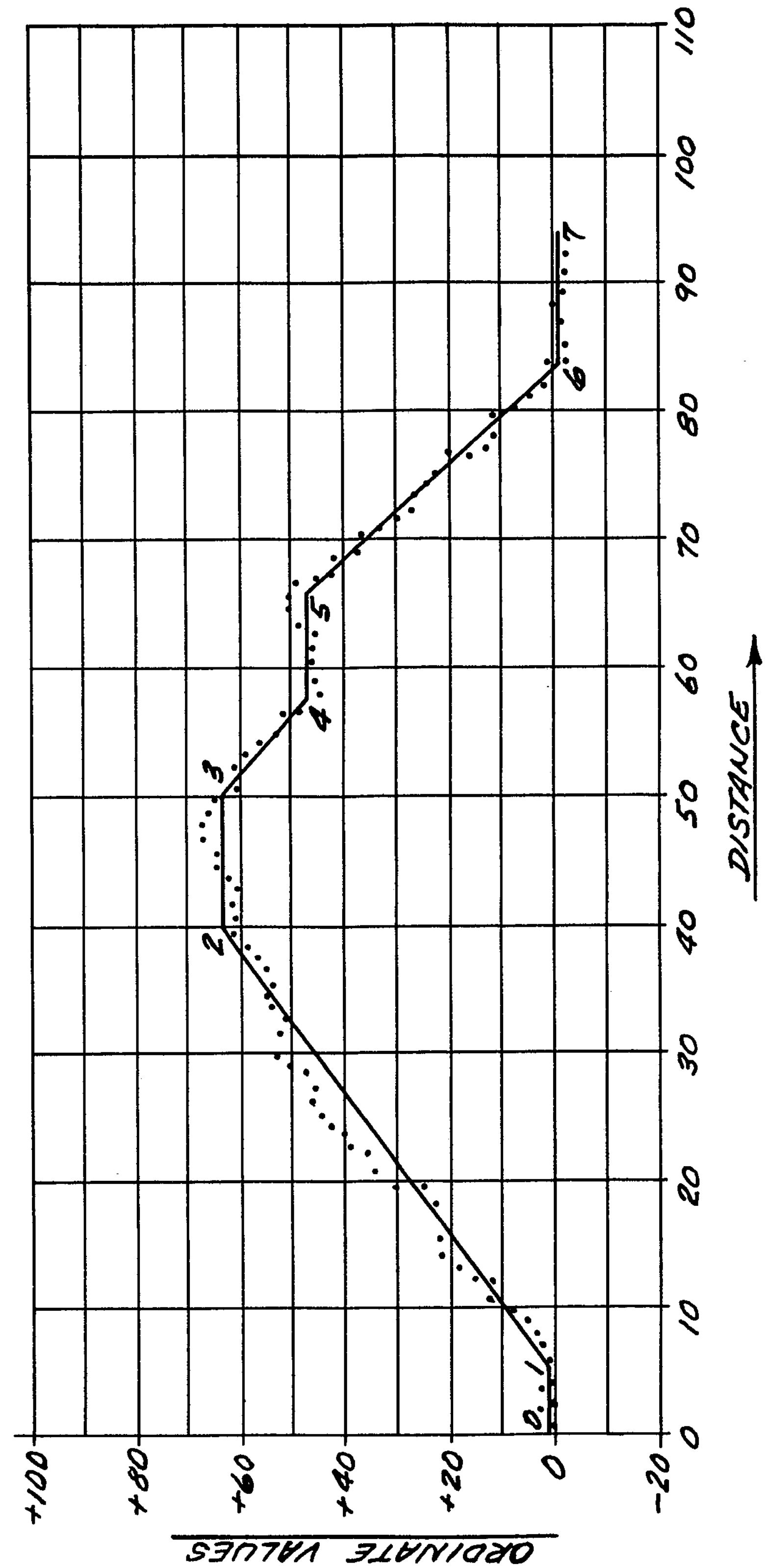

FIG. 2B.

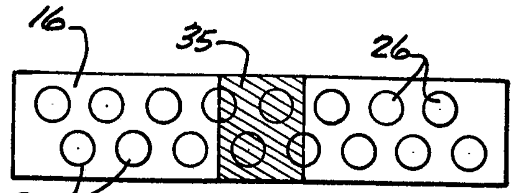

Fig. 6.

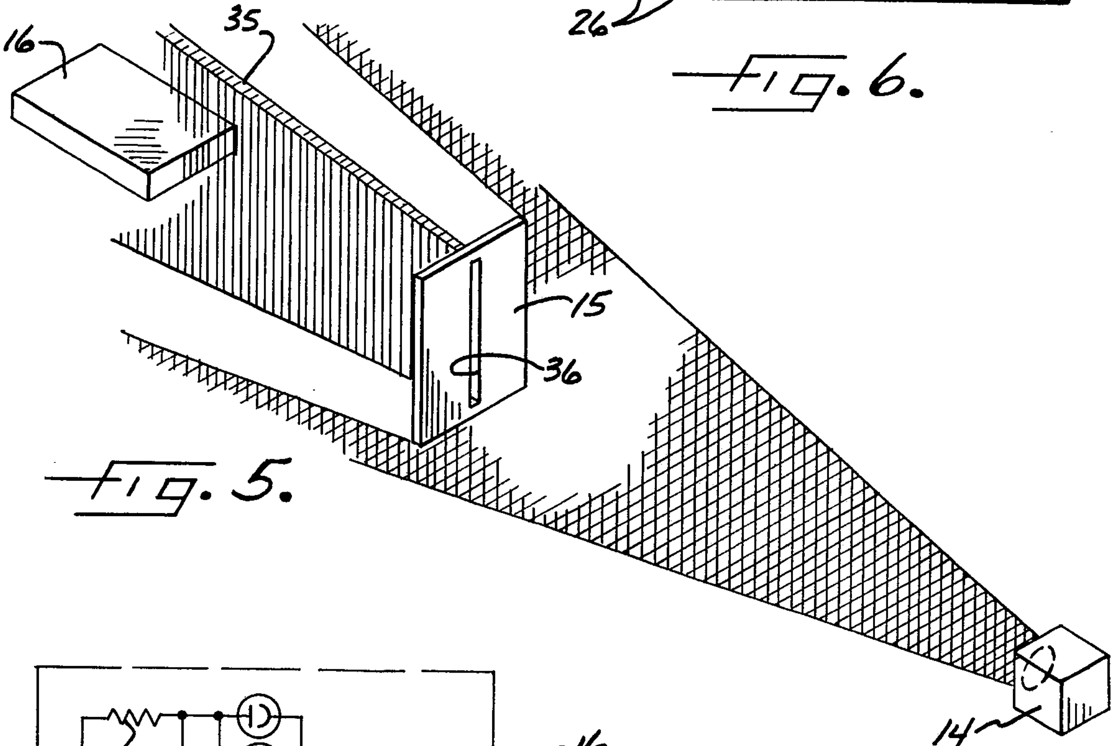

Fig. 5.

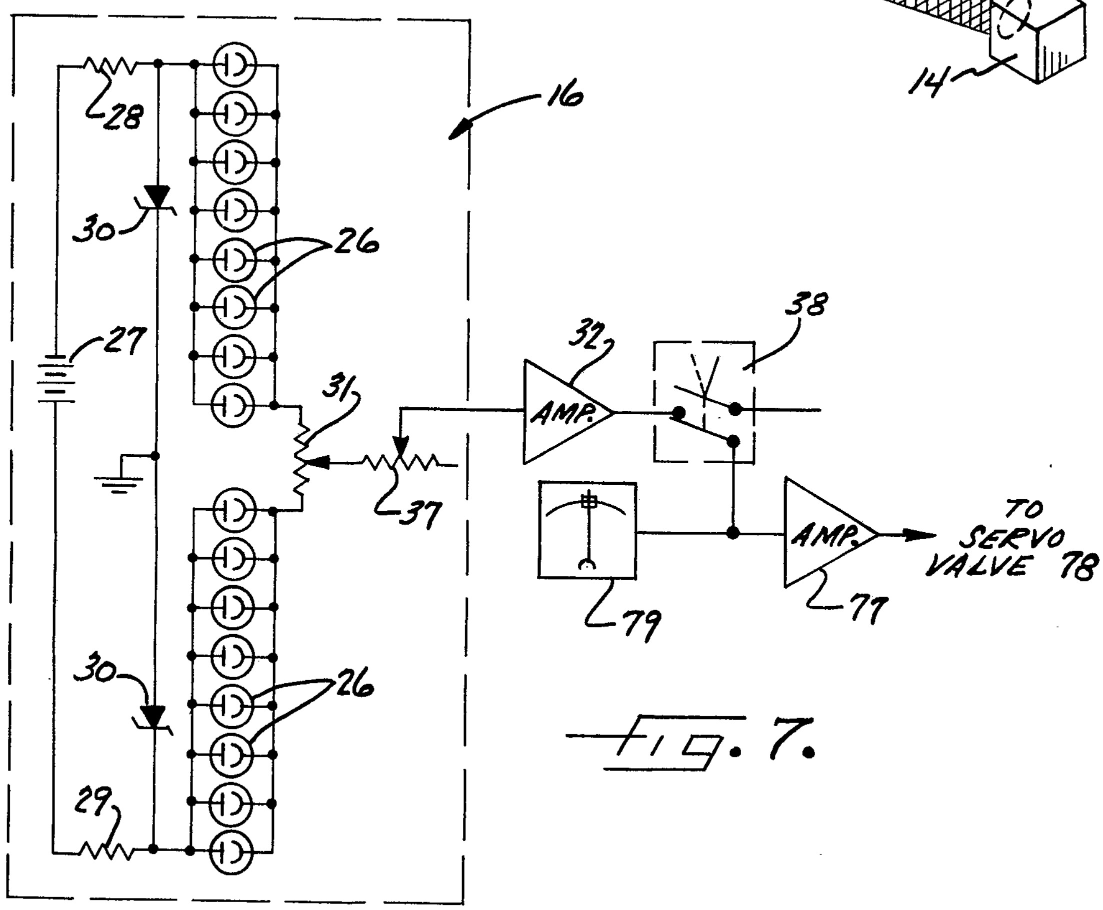

Fig. 7.

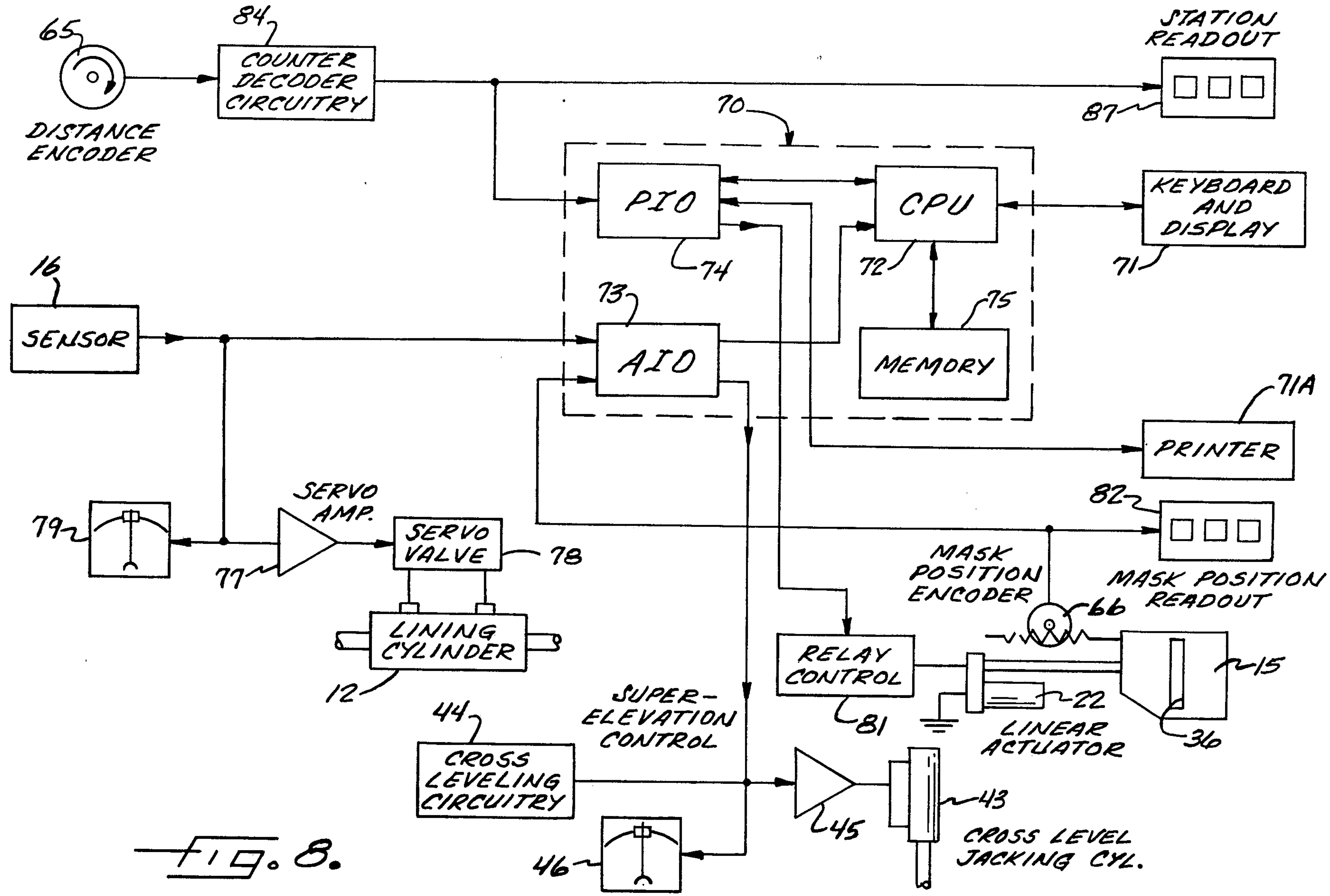
65
DISTANCE ENCODER
84
COUNTER DECODER CIRCUITRY
STATION READOUT
87
70
PIO
74
CPU
72
KEYBOARD AND DISPLAY
71
16
SENSOR
73
AID
MEMORY
75
71A
PRINTER
82
79
SERVO AMP.
77
SERVO VALVE
78
LINING CYLINDER
12
MASK POSITION ENCODER
66
MASK POSITION READOUT
RELAY CONTROL
81
15
22
LINEAR ACTUATOR
36
SUPER-ELEVATION CONTROL
44
CROSS LEVELING CIRCUITRY
45
43
CROSS LEVEL JACKING CYL.
46

FIG. 8.

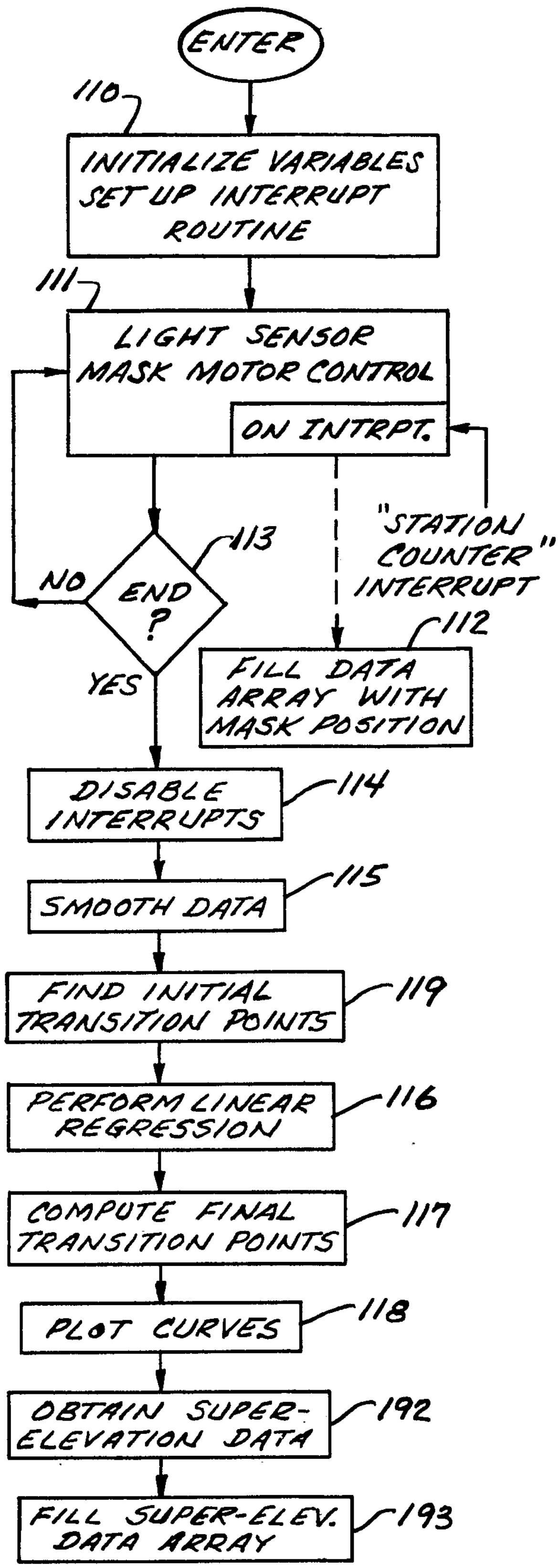

Fig. 9.

PLOT SUBROUTINE

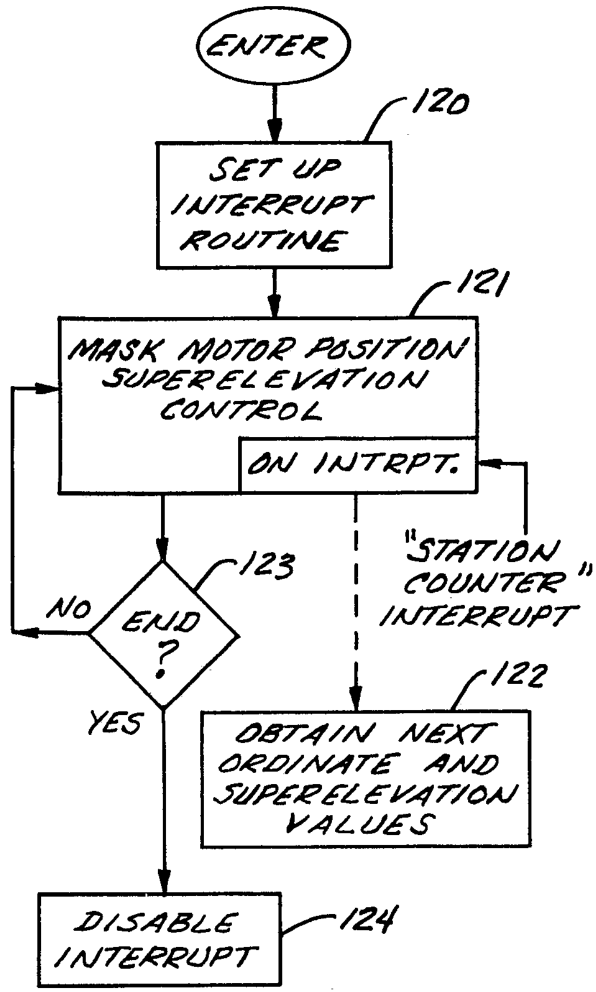

Fig. 10.

WORK SUBROUTINE

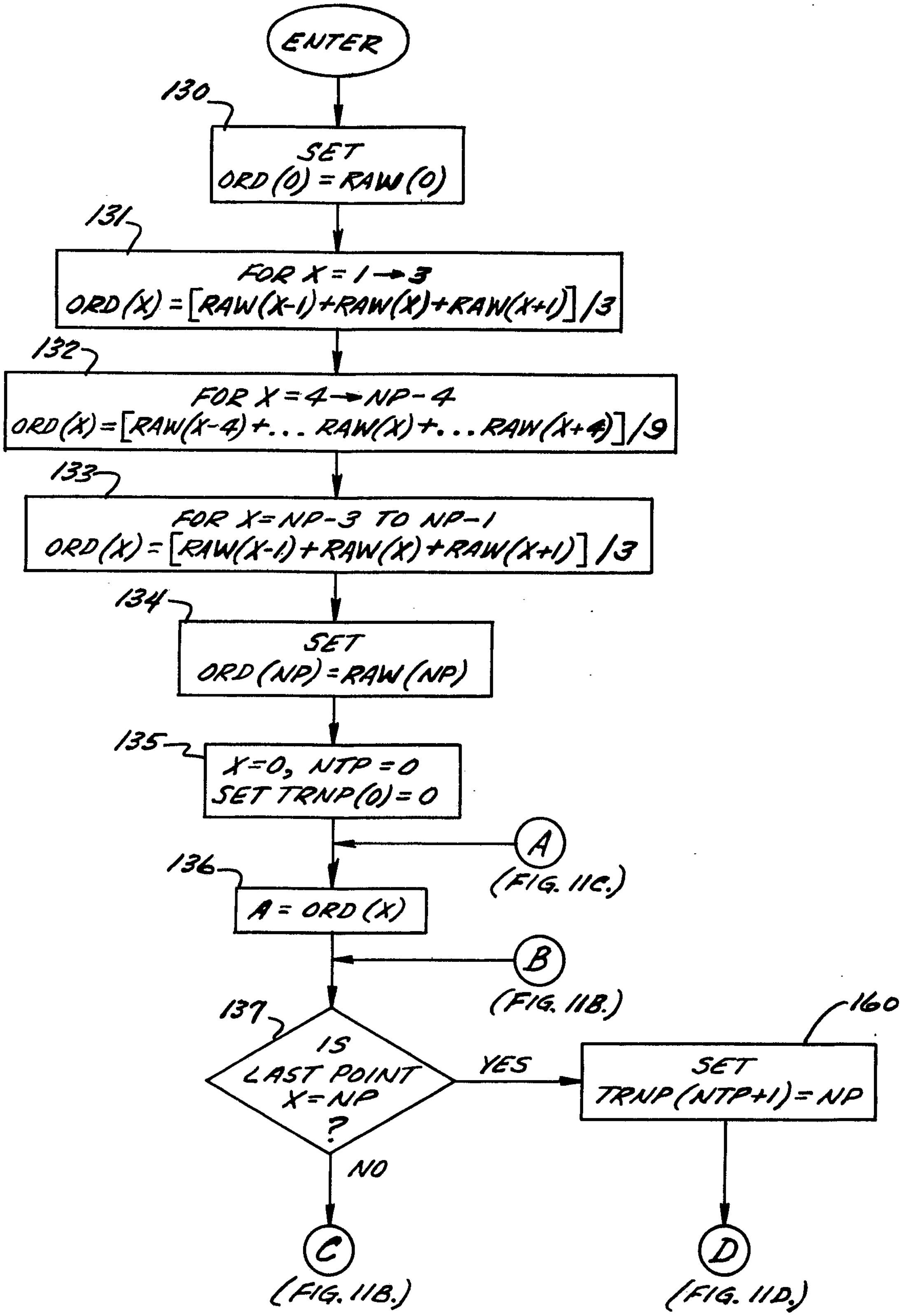
ENTER
130
SET
ORD (0) = RAW (0)
131
FOR X = 1 → 3
ORD (X) = [RAW(X-1)+RAW(X)+RAW(X+1)] /3
132
FOR X = 4 → NP - 4
ORD (X) = [RAW(X-4) + . . . RAW(X) + . . . RAW(X+4)] /9
133
FOR X = NP-3 TO NP-1
ORD (X) = [RAW(X-1)+RAW(X)+RAW(X+1)] /3
134
SET
ORD (NP) = RAW (NP)
135
X=0, NTP = 0
SET TRNP(0) = 0
A
(FIG. 11C.)
136
A = ORD (X)
B
(FIG. 11B.)
137
IS LAST POINT X=NP ?
YES
160
SET
TRNP(NTP+1) = NP
NO
C
(FIG. 11B.)
D
(FIG. 11D.)

FIG. 11A.

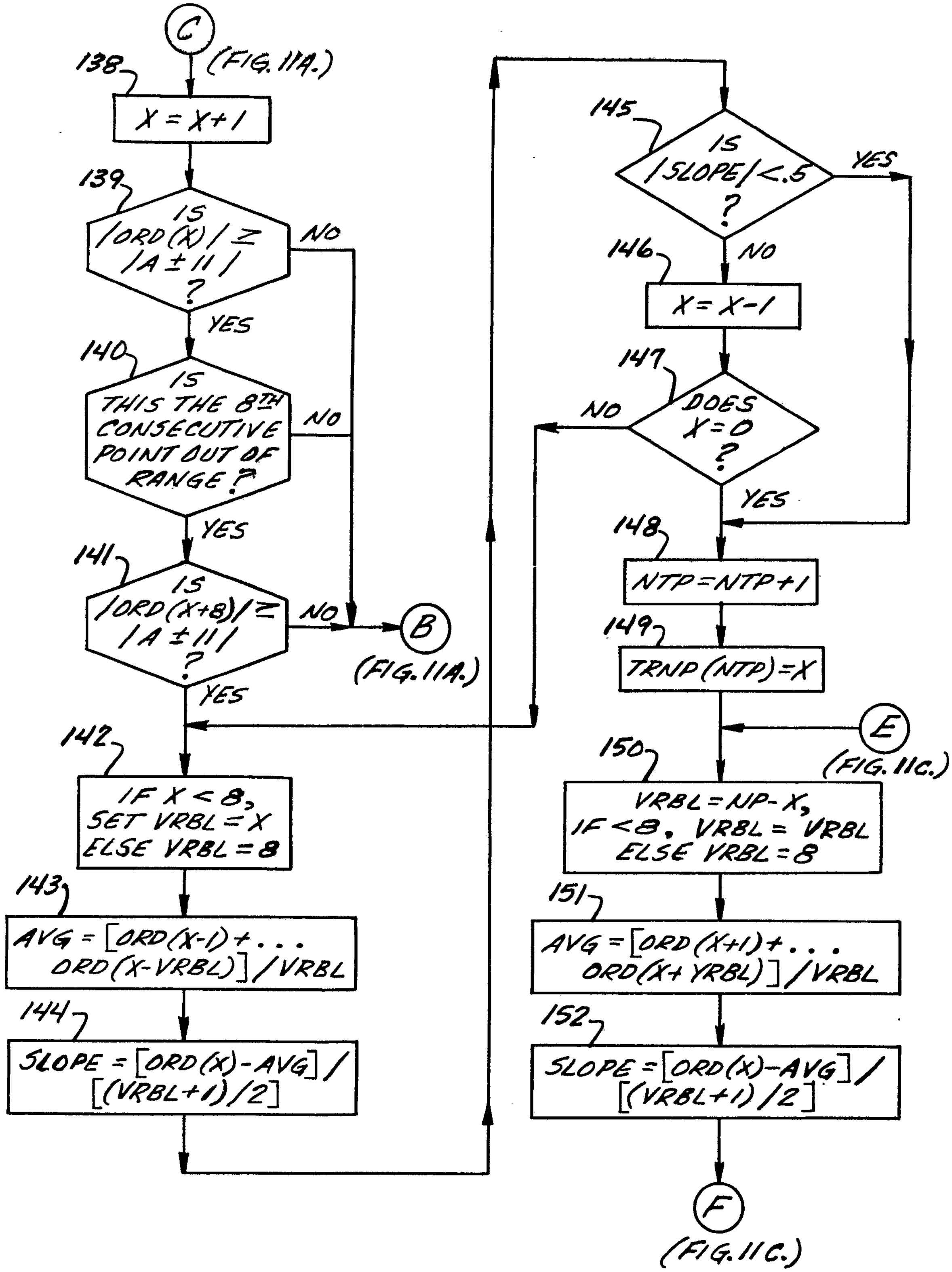
C
(FIG. 11A.)
138
X = X+1
139
IS |ORD(X)| ≥ |A ± 11| ?
NO
YES
140
IS THIS THE 8TH CONSECUTIVE POINT OUT OF RANGE?
NO
YES
141
IS |ORD(X+8)| ≥ |A ± 11| ?
NO
B
(FIG. 11A.)
YES
142
IF X < 8, SET VRBL = X ELSE VRBL = 8
143
AVG = [ORD(X-1) + . . . ORD(X-VRBL)] / VRBL
144
SLOPE = [ORD(X) - AVG] / [(VRBL+1)/2]
145
IS |SLOPE| < .5 ?
YES
NO
146
X = X-1
147
DOES X = 0 ?
NO
YES
148
NTP = NTP+1
149
TRNP(NTP) = X
E
(FIG. 11C.)
150
VRBL = NP-X, IF < 8, VRBL = VRBL ELSE VRBL = 8
151
AVG = [ORD(X+1) + . . . ORD(X+ YRBL)] / VRBL
152
SLOPE = [ORD(X) - AVG] / [(VRBL+1)/2]
F
(FIG. 11C.)

FIG. 11B.

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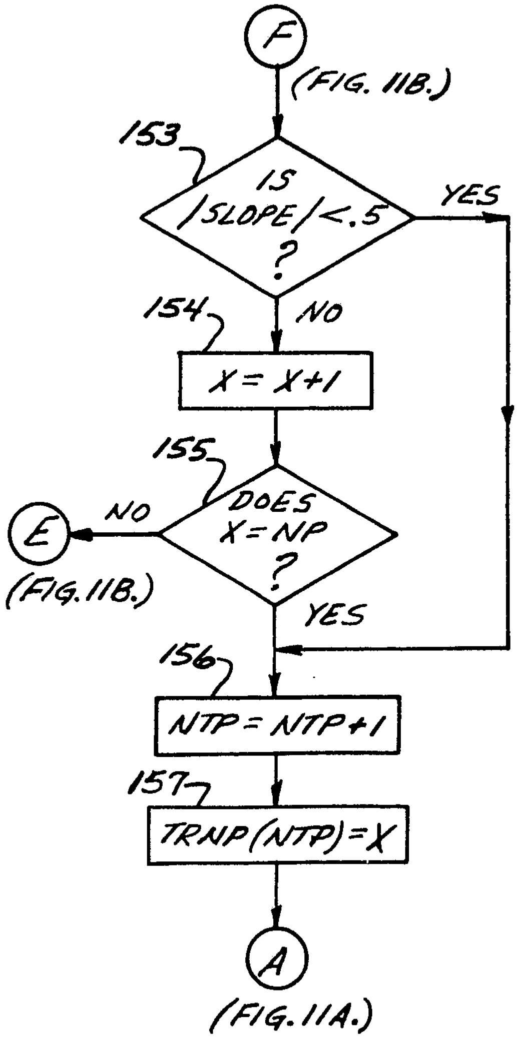

FIG. 11C.

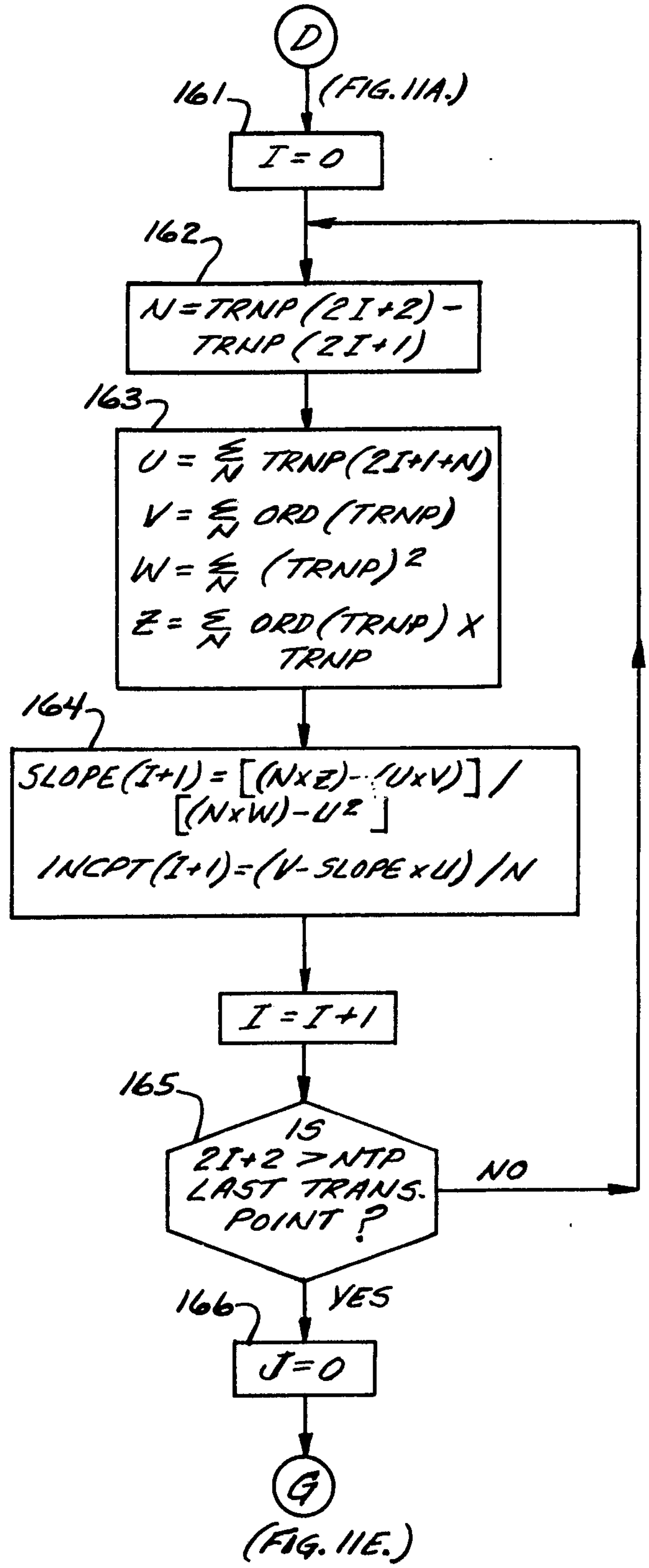

FIG. 11D.

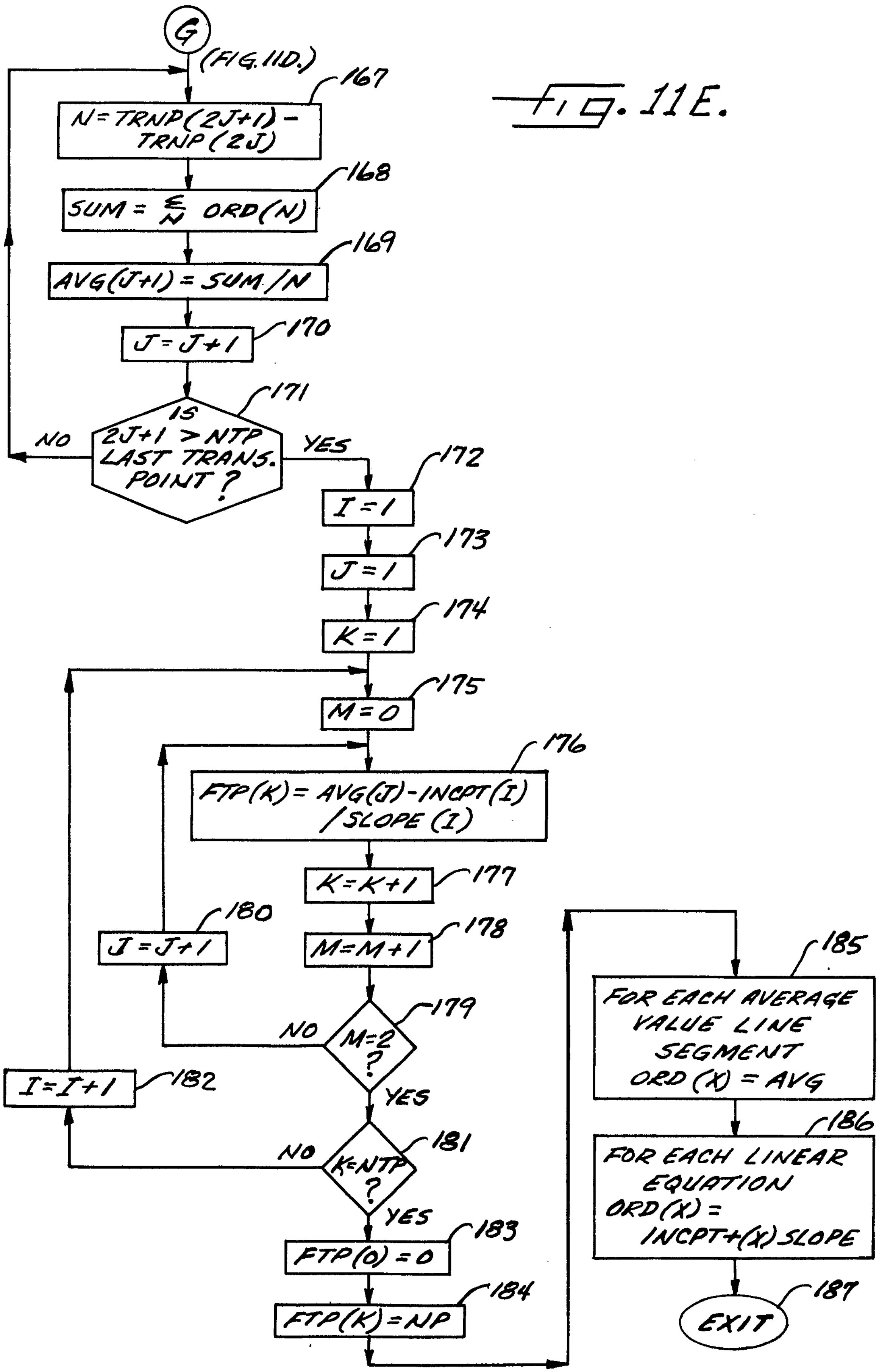
G
(FIG. 11D.)
167
N = TRNP(2J+1) - TRNP(2J)
168
SUM = Σ N ORD(N)
169
AVG(J+1) = SUM/N
170
J = J+1
171
IS 2J+1 > NTP LAST TRANS. POINT ?
NO
YES
172
I = 1
173
J = 1
174
K = 1
175
M = 0
176
FTP(K) = AVG(J)-INCPT(I) /SLOPE (I)
177
K = K+1
178
M = M+1
180
J = J+1
179
M=2 ?
NO
YES
182
I = I+1
181
K=NTP ?
NO
YES
183
FTP(0) = 0
184
FTP(K) = NP
185
FOR EACH AVERAGE VALUE LINE SEGMENT ORD (X) = AVG
186
FOR EACH LINEAR EQUATION ORD(X) = INCPT+(X) SLOPE
187
EXIT

FIG. 11E.

SPECIFICATION

Track curve lining method and apparatus

This invention relates generally to railroad track maintenance equipment and more particularly concerns a track cuve lining method, and apparatus for carrying out that method.

Lining is the horizontal positioning of railroad track, both rails and the connecting ties considered as an entity, so that tangent or straight track is truly straight and that curved track, connecting lengths of tangent track, smoothly spirals into the desired constant radius curve and then smoothly spirals out into the next length of tangent track. In theory, a simple track curve has a four transition points; the point where tangent track starts to spiral, the point where the spiral reaches the curve of constant radius, the point where the constant radius starts to spiral out, and the point where the spiral again becomes tangent.

In the United States, curve transition points are not normally marked, as with survey monuments. Instead, a track curve to be lined is first measured and plotted to determine its existing configuration. Then, an ideal curve configuration is laid out over the actual plot and the deviations noted. Finally, the track is laterally shifted by the amount of the deviations by track lining apparatus, often working with resurfacing and tamping equipment so as to fix the track in its new configuration.

In lining, one rail of a track is designated the line rail to be measured and repositioned, with the other rail and ties being attached and following along. In a curve, the outer rail is normally the line rail. Curvature measurements are typically in terms of an ordinate from a chord of fixed length taken at a fixed point along the chord. If the track is tangent, the ordinate would be substantially zero, with the value becoming larger the greater the curvature. Typically, measurements for curve lining are made once along each rail length, i.e., every 39 feet.

The greatest amount of track misalignment can be expected at the transition points where the track must resist the momentum of train traffic. This, and the absence of survey defined transition points, make interpretation of a curve plot a matter of considerable experience and skill. Likewise, laying out a best fit, ideal curve over an actual plot requires high skill.

Some efforts to automate lining have been made. For example, U.S. patent 3,547,038 to Strasser shows an apparatus for automatically plotting an existing track configuration, but this device does not reach the subsequent steps of laying out a correcting plot and controlling a liner to make the corrections.

Accordingly, it is the primary aim of the invention to automatically plot an existing track curve, calculate an overlying best fit ideal curve configuration, and control lining apparatus to shift the existing track to the calculated configuration. It is an object of the invention to provide a method and apparatus to accomplish the foregoing and thus minimize the need in curve lining operations for persons highly skilled in plot interpretation and in laying out corrective curves.

Another object is to provide a method and apparatus of the above type to be used in connection with on-track lining equipment so that a plot of an existing track curve configuration can be made during one relatively rapid pass travelling through the curve, and then the equipment can be automatically controlled to line the curve on a second working pass through the curve.

According to one aspect of the invention, it is also an object to automatically adjust cross level of the track in the working pass to smoothly apportion the required superelevation.

A further object is to provide a method and apparatus as characterized above that provides greater accuracy in curve lining by being able to take more closely spaced data, such as every 10 feet rather than every 39 feet along the track, and being better able to calculate the curve transition points and thus approach more closely the originally intended track orientation.

Yet another object is to provide a method and apparatus as referred to above which functions as described for both simple and compound curves.

Other objects and advantages of the invention will become apparent upon reading the following detailed description and upon reference to the drawings, in which:

Figure 1 is a sketch intended to illustrate typical railroad track curve geometry;

Fig. 2 is a diagram illustrating how track curves are measured;

Fig. 2A is a representative plot of a simple railroad track curve;

Fig. 2B is a representative plot of a compound railroad track curve;

Fig. 3 is a side elevation of an apparatus intended to operate in accordance with the invention;

Fig. 4 is a fragmentary diagram embodying both plan and transverse sectional views of portions of the apparatus illustrated in Fig. 3;

Fig. 5 is a perspective diagram of the light beam reference line utilized with the apparatus of Fig. 3;

Fig. 6 is a diagram showing the face of the sensor illustrated in Fig. 5;

Fig. 7 is a circuit diagram of a portion of the apparatus of Fig. 3;

Fig. 8 is a diagram of the system utilized to operate the apparatus of Fig. 3;

Fig. 9 is a flow diagram illustrating the plot made of the apparatus;

Fig. 10 is a similar flow diagram illustrating the work made; and

Figs. 11A—11E are more detailed flow diagrams illustrating aspects of the plot made.

While the invention will be described in connection with a preferred embodiment and procedure, it will be understood that we do not intend to limit that invention to that embodiment or procedure. On the contrary, we intend to cover all alternatives, modifications and equivalents as may be included within the spirit and scope of the invention as defined by the appended claims.

Turning now to the drawings, there is shown in Fig. 3 an apparatus for lining railroad track including an on-track, self-propelled machine 10 carrying a track jacking assembly 11, a hydraulic lining cylinder 12 for laterally shifting jack supported track (see also Fig. 4), and tamping devices 13 for tamping the track ballast to secure the track in its new position. The apparatus 10 includes a light source 14, a mask 15 and a lining sensor 16 for establishing a reference line.

The sensor 16 is mounted on a carriage 17 that is coupled to the machine 10 and which holds the sensor 16 at a fixed lateral distance from a rail of the track. The mask 15 is floatingly mounted on the machine 10 through a support 18 having flanged wheels 19 and a rail following positioning cylinder 21 to keep the mask support 18 at a fixed lateral relationship to a rail of the track. The mask 15 can be laterally shifted on the support 18 by a linear actuator 22. The machine 10 also includes a power plant 23 and an operator's cab 24 which contains, in addition to the usual controls, a data processor, printer and control circuitry.

Preferably, the light source 14 is a sealed beam incandescent lamp mounted on a light carriage 25 travelling on the track. In the illustrated apparatus, the carriage 25 is pushed ahead of the machine 10 by a plurality of buggies 25a which ride on the track and extend between the machine 10 and the carriage 25.

The preferred sensor 16 develops a proportional signal from a plurality of closely arrayed photoelectric cells 26 coupled in electrically balanced circuits (see Fig. 7). In the preferred construction, the cells 26 are disposed in two adjacent lines, with the cells being staggered so that a light pattern across the narrow dimension of the sensor overlaps several cells (see Fig. 6). Shifting movement of the light band along the length of the cell array thus energizes the same total number of cells, but different cells are illuminated depending upon the light band position.

The preferred electrically balanced circuit couples the cells on each side of the sensor center or null position in parallel groups, and the two groups of cells in series. A d-c voltage source 27 is connected across the cells 26 through load resistors 28 and 29. A pair of oppositely poled zener diodes 30 connected to ground, and at each end of the cell array, establishes fixed plus and minus voltages at the opposite ends of the cell array. In use, all of the cells 26 receive some ambient light reflected by the sensor surroundings. However, since the cells receive equal amounts of light, their resistances in the circuit are equal and the voltage drop is uniform across the cell array.

A variable resistor 31 is interposed in the series connection between the cells on opposite sides of the null position so that the cell circuit can be exactly balanced to impose a zero voltage input to a sensor amplifier 32 when the cells are uniformly illuminated.

The reference line is established by the mask 15 shielding the sensor 16 from light emitted by the source 14 except for a vertical beam 35 that passes through a vertical slot 36 in the mask. When the beam 35 falls on the null position of the sensor 16, the absence of a signal from the sensor indicates a reference line in a horizontal plane has been established between the source 14 and the sensor 16.

When the beam 35 strikes the sensor photocells 26 to one side of the null position, the resistance of the illuminated photocells changes. The preferred cells are of the photo resistance type, and thus, if the light band strikes only cells to the left of the center, for example, the resistance of the positive side of the balancing resistor 31 will greatly increase, causing a negative, with respect to ground, voltage signal to be fed to the amplifier 32. As the light band moves to the right, some of the cells on the other side of the null position will be illuminated and fewer of the cells to the left of the null position will remain illuminated. Therefore, the negative voltage signal becomes less, until an equal number of cells on each side of the null position receive light. At that time, the circuit is again in balance and the output signal is zero. If the light band continues to move to the right, a positive voltage signal is fed to the amplifier 32. Preferably, the magnitude of the output signal from the sensor can be initially controlled by a variable resistor 37. In the preferred circuit, the output of the amplifier 32 is directed to a switch 38 which permits selection of a work mode and a plot mode.

The track jacking assembly 11 depends upon the elongated, truss-like frame 40 of the machine 10 and includes a jack beam 41 supporting rail clamps 42 over each rail with the beam 41 being suspended by a pair of lifting hydraulic cylinders 43; the entire assembly 11 being near the center of the frame 40. Actuation of the clamps 42 grips the rails, and the clamps and the rail can be lifted by the cylinders 43 which are pivoted to permit lateral shifting of the jack beam 41. The lining cylinder 12 is anchored to the frame 40 and its actuation permits the jack beam, and thus the clamped track, to be shifted to one side or the other.

As is conventional, the track is elevated or surfaced by jack cylinders 43 as well as lined by lateral shifting. One of the jack cylinders 43 is controlled from a surface reference line, not shown, and the other cylinder 43 is the cross level jack cylinder controlled by a cross level circuit 44 (see Fig. 8). On tangent track, the cross level circuit 44 controls the cross level cylinder through an amplifier 45 so as to keep the rails level. Through a curve, the outside rail in the curve should be higher than the inside rail, a configuration called superelevation. Conventionally, track is superelevated by manually causing the circuit 44 to signal the cross level cylinder 43 to lift the rails unequally, using a meter 46 to observe the amount of superelevation being put in.

As sketched in Fig. 1, a railroad track curve typically connects two stretches of straight tangent track 51 and 52. At the center of the curve, there is a stretch of track 53 having a constant radius like an arc of a circle. Interconnecting the constant radius section 53 with the tangent track portions 51, 52 are spiral track portions 54 and 55 wherein the track changes from a straight line 56 to the curve 57 which is the constant radius of the section 53.

The amount of curve in a railroad track is measured in terms of the lateral displacement or ordinate 58 of the track reference or line rail 59 at a fixed point 61 on a fixed length line 62 adjacent the track (see Fig. 2). On perfectly straight tangent track, the ordinate 58 would be zero. As the track starts to curve, the ordinate increases, and the sharper the curve the greater the ordinate.

In the apparatus of the invention, the line 62 is created by the reference line established by the light source 14, mask 15 and sensor 16 since there are fixed distances between these elements.

A plot of ordinates through a railroad track curve is shown in Fig. 2A. The horizontal axis represents distance along the track. The vertical axis represents ordinate values from —20 to +100. A perfect curve should show zero ordinate values for the tangent track at each end of the curve and, at the center of the curve, there should be a series of constant ordinates representing the constant radius portion of the curve. Between the tangent track at the ends of the curve and the constant radius portion at the center, the ordinates should vary at a constant rate. The plotted result should be substantially as indicated by the line drawn on Fig. 2A with the curve having end sections on the zero line, a center section at a constant value, which in the illustrated case is an ordinate value of approximately 45, and straight line curve shoulders connecting the tangent track with the constant curve track. The curve transition points are numbered 1 through 4.

If there is more than one region of constant radius track, the curve is compouned and the plot can be as shown in Fig. 2B with there being six transition points numbered 1 through 6. In Fig. 2B, the track between 0 and 1 is tangent, it spirals between 1 and 2 to a constant radius between 2 and 3, spirals out slightly between 3 and 4, stays a wider constant curve between 4 and 5, and spirals out again between 5 and 6 to tangent track between 6 and 7.

In accordance with the invention, a track curve is first measured by measuring and storing ordinates at a succession of incremental points along the track, a computer calculation is made to develop a plotted curve and transition points most closely fitting the actual ordinate measurements, and then the apparatus is moved again around the curve and the track is shifted to the plotted curve ordinate values. To measure travel of the apparatus along the track and establish the succession of incremental points, the machine 10 carries a rail engaging wheel 65 which, upon rotation, produces pulses reflecting the distance the wheel has travelled. Ordinates are measured by using the actuator 22 to vary the lateral position of the mask 15 on its support 18, with the mask position being sensed by an encoder 66 giving a signal corresponding to ordinate units from —20 to +100.

The measurement information is stored, the calculations made, and the lining control information delivered, from a data processor 70 preferably including an operator keyboard and display unit 71 and a printer 71A. The processor 70 includes the usual central processing unit (CPU) 72, an analog-input-output (AIO) card 73, a parallel-input-output (PIO) card 74, and a data storage and program memory 75.

In the normal lining work mode, the sensor 16 signal is connected to a servo amplifier 77 and a lining servo valve 78 which controls the hydraulic lining cylinder 12 (see also Fig. 4). If the light beam 35 is not on the null portion of the sensor 16, then a signal is generated through the amplifier 77 to the servo valve 78 causing the lining cylinder 12 to shift the track laterally until the mask 15 causes the beam 35 to reach the null position on the sensor 16. Preferably, a meter 79 is included to display the signal from the sensor 16. Control of the cylinder 12, and thus the lateral position of the track relative to the machine 10, is therefore dependent upon the position of the mask 15 on the machine.

To initially measure a curve, a plot switch on the keyboard 71 is pressed. The sensor 16 and the processor 70, through the AIO board 73, thus monitor the lateral position of the track. If the light beam 35 moves off the null position of the sensor, a signal is sent to an actuator controller 81, through the PIO board 74, which operates the actuator 22 to shift the mask in the proper direction to reposition the light beam on the null position of the sensor. The change in mask position is sent as a signal by the encoder 66 to an operator's mask position meter 82 and to the processor 70 through the AIO card 73.

As the apparatus moves along the track, the wheel 65 generates pulses which are counted by a counter/decoder 84 and, when a sufficient number of pulses have been counted to indicate movement to a desired incremental point, in the preferred case a distance of ten feet, an interrupt signal is sent to the processor through the PIO board 74. Preferably, the decoded count is also displayed on a station readout meter 87. The signal at the PIO card 74 causes the processor 70 to read the position of the mask 15, through the AIO card 73, and store it and the station number in the processor memory 75. In this way, the ordinates at a successive number of points around the curve, in this case every ten feet, are measured and stored in the processor.

It is one aspect of the invention to permit the operator of the machine 10 to select the amount of superelevation he wishes for the constant radius portion of a curve, whereupon a computer calculation is made of a linear progression of superelevations through the spiral portion from the true cross level of the tangent track to the selected superelevation of the constant radius. The data processor 70 receives the desired superelevation value, and after the transition points are calculated, the intermediate superelevation values are calculated and stored, and then during the working pass, the intermediate superelevation values are sequentially fed to the cross level circuit 44 to smoothly raise the outside rail through the spiral to the curve superelevation selected.

The manner in which all of the foregoing is accomplished is illustrated by the flow diagram of Fig. 9 which shows the elements of the subroutine PLOT. An initial housekeeping step 110 simply initializes variables, sets up interrupt routines, clears registers, tables and the like. The storing of ordinates described above is accomplished in the step 111 which is illustrated as being interrupt driven. The "station counter" interrupt is the signal produced by the counter/decoder 84 (Fig. 8) which is coupled to the PIO card 74 for interrupting the CPU 72 at predetermined X intervals, in the present instance 10 feet. In accomplishing the step 111, the light sensor/mask motor control is monitored via the position encoder 66, and each time the CPU is interrupted, the ordinate value produced by the encoder is stored in a data array 112 in sequential locations relating to the X position at the time. The program continues to fill the array 112 each time the distance encoder travels the predetermined incremental distance until the operator presses the end button on the keyboard 71. At that point, a test 113 determines that the end button has been pressed, and diverts the program to a step 114 which disables the interrupts, freeing the processor to deal with the data which has been acquired. In a preliminary step 115, the data is smoothed in order to remove the effects of noise and the like. This data is then used to determine the points where the ordinate value patterns begin to change (step 119). These points are the initial transition points.

The program then performs a linear regression on the data between each set of initial transition points (step 116) in order to produce a curve which is a best fit to the ordinate data acquired in previous steps. Having accomplished that, the program computes the final transition points (step 117), namely, the points 1, 2, 3 and 4 (Fig. 2A) where tangent track changes to spiral track, where spiral track changes to constant radius track, where constant radius track changes to spiral track, and where spiral track again changes to tangent track. It should be noted that in the case of a compound curve (Fig. 2B), there will be more than one point where spiral track changes to constant radius track and more than one point where constant radius track changes to spiral track, the result of which is more than four transition points. In Fig. 2B the transition points are designated 1—6. With the information developed from steps 116 and 117, the program then produces a plot at step 118 similar to that illustrated in Figs. 2A or 2B. It will be appreciated that the program produces a best fit ideal curve which most closely corresponds to the actual measured ordinates. As typified by Figs. 2A and 2B, the actual curve data is represented by a succession of dots and the best fit curve data is represented by solid lines.

After the graph has been produced, the operator will be instructed to enter via the keyboard 71 the desired superelevation for the curve (step 192). In the case of a compound curve, the operator will be required to enter all values of superelevation. Using this value, along with the length of the spirals from the best fit curve, the program will then compute the required amount of superelevation to be added at each station along the spiral, and fill an array 193 with that data. In effect, the system sets the tangent track entering and leaving the curve at level, sets the constant radius curve off level by the entered superelevation amount, and linearly interpolates between the two values to set the superelevation for each station in the spiral track sections.

To line the track, the apparatus is again run through the curve starting from the same point, typically the zero position on the station counter. The work button on the keyboard 71 is then pressed. The distance measuring wheel 65 functions in the same manner, and when the processor 70 receives a signal indicating that the desired incremental distance has been travelled, the processor 70 will transmit a signal through the PIO card 74 representing the calculated best fit position at that station for the ordinate, whereupon the controller 81 and the actuator 22 will shift the mask 15 to that ordinate distance.

The processor 70 will also transmit a signal through the AIO card 73 representing the calculated amount of superelevation for that station. This signal is added to the signal produced by the cross leveling circuit 44 causing the track to be pulled the proper amount out of cross level.

Digressing briefly to Fig. 10, it is seen that in the WORK subroutine, after a housekeeping step 120 sets up the interrupt routine, the processor proceeds to a step 121 which is interrupt driven similar to the step 111. Whenever the "station counter" interrupt is coupled to the processor, the processor obtains computed ordinate and superelevation values from an array 122. These values are then used to position the mast actuator 22 and cross level jacking cylinder 43 in accordance with these values. That operation continues for each station point following which a test 123 disables the interrupts at 124 and terminates the subroutine.

As previously explained, if positioning the mask actuator 22 results in a shift of the light beam 35 from the center of the sensor 16, then the lining cylinder 12 is actuated to move the track until the beam 35 reaches the null position on the sensor. This track shifting is repeated at each tie throughout the curve and thus variations of the actual track position from the best fit computed track position are minimized.

The memory 75 associated with the CPU 72 is configured to contain a program of instructions to cause the apparatus to operate by the method and in the manner described above, the general flow of which is laid out in connection with Figs. 9 and 10. The manner in which the work mode is practiced will be apparent from the foregoing description. In addition, the ordinate collecting portion of the plot mode for filling the array 112 of Fig. 9 will also be apparent. The following is intended to provide additional detail on the manner in which the ordinate data is processed to produce a best fit curve with transition points for use in the work mode.

Before referring to Figs. 11A—11E, certain conventions used in connection with that flowchart will first be described. The unprocessed data collected in the array 112 of Fig. 9 is identified as RAW, and the number of data points or stations is identified as NP. In practicing the invention, that information is processed to produce two output arrays, ORD, containing the best fit ordinate points for each station and FTP identifying the station location for each transition point.

It is noted that the RAW array represents the data plotted as individual points on the Fig. 2A plot, and the ORD array is intended to represent the solid line of Fig. 2A which is the best fit data for the points stored in the RAW array.

It is recalled, from Fig. 9, that the first step after the interrupts are disabled and the system begins to produce the best fit curve is the step 115 of smoothing the data. That is illustrated in Fig. 11A, by the steps 130—134. It is seen that for the first and last station points, the RAW information is simply transferred to the ORD array (steps 130, 134), for the first and last few stations three RAW points are averaged for each ORD points (steps 131, 133) and for the majority of the data, nine RAW points are averaged for each ORD point (step 132).

Following smoothing, the program proceeds to determine transition points in the smoothed, measured ordinates now stored in the ORD array. In the èxemplary embodiment, advantage is taken of the fact that the initial ordinates within the array are relatively constant, and that transitions separate lengths of relatively constant ordinate (see Fig. 2A). Thus, at step 136, after setting initial conditions at step 135, the ordinate values stored in the first location in the ORD array is retained. A test 137, adapted to find the last point in the ORD array, produces a negative result, passing control to a step 138 which increments the index of the ORD array. A test at 139 compares the magnitude at the new index to the previously stored amplitude plus or minus some constant, selected in the exemplary embodiment as 11. Thus, whenever the ordinate value being examined is greater than the first value stored by more than the value 11, the program assumes that it has found a transition point, and begins further testing. If no transition is found, the test causes a return through the loop to again increment the index at 138 and test the next point. At some time, the test 139 will produce a positive result, indicating that the area of the ORD array being examined probably represents a transition point. To further verify that tests 140, 141 are performed. Test 140 requires that 8 consecutive out-of-range points be detected by test 139 before it passes control to test 141 which looks forward an additional 8 station points to assure that the ordinate value at that point is also greater than the arbitrary magnitude of A$\pm$11.

When all of those conditions are satisfied, it has been ascertained that a transition point has been passed, and it is then necessary to locate the transition point itself. In the exemplary embodiment, advantage is taken of the fact that the slope of the ordinate values at a transition point is less than 0.5, because track transitions are to or from a section of relatively constant ordinate. In order to compute the slope, it is first useful to compute the average of the ordinates of a number of sample points below the ordinate point being examined. Step 142 in connection with step 143 typically computes that average over 8 samples unless the ordinates being examined are within 8 samples of the beginning of the array, in which case fewer samples are used. The slope is then computed at step 144 by dividing the Y coordinate represented by the difference in ordinate values by the X coordinate represented by the number of station points. That slope is examined at step 145. If the slope is greater than 0.5, it is assumed that the transition point has not been reached, and the index for the ordinate array is decremented by 1 at step 146 to examine the next point down the curve. That operation continues until the test 145 detects a positive result (unless, of course, the test 147 determines that the program has stepped to the beginning of the ordinate array, causing the beginning station to be defined as a transition point. However, if the test 145 determines that the slope is less than 0.5, indicating that a transition point has been located, the program jumps to a step 148 which increments the number of transition points to register NTP, then stores the X coordinate for that transition point in the array TRNP.

Recalling that transition points interconnect lengths of fairly constant ordinate, the program then begins to examine ordinate magnitudes, stepping in the forward direction to detect the next transition point. Steps 150, 151 and 152 calculate the average of ordinates ahead of the point being examined and the slope for that segment in a manner similar to steps 142—4. The slope is tested at step 153, and if it is not found to be less than 0.5 the index for the array ORD is incremented at step 154. That loop continues to step through the ORD array until the test 153 produces a positive result, indicating that the next transition point has been located. It is noted that a step 155 determines when the last point in the ORD array has been found which results in the end station being defined as a transition point.

In normal operation, however, the test 153 proves positive at some point, locating the transition point, following which steps 156 and 157 increment the number of transition points index NTP and store the X value at that index in the TRNP array. The program then returns to step 136 (Fig. 11A) to detect the next trend from a relatively constant value and repeat the entire process. That loop is ultimately exited when the test 137 produces a positive result indicating that the last point in the ORD array has been examined, which causes execution of step 160 saving that last point as the final transition point.

In practicing the invention to produce a best fit curve for the ordinates originally measured, the program locates within the ORD array those areas of changing ordinate value and fits those ordinate values to a linear equation using a linear regression procedure. That is accomplished by first setting an I index to zero at step 161 then locating the previously stored transition points on either end of the line of changing ordinate value at step 162. It is noted that as an aid in understanding, transition point numbers have been noted on Fig. 2A, beginning with the zero transition point at the start of the chart and ending with the transition point 5 for the last value in the ORD array and in Fig. 2B from zero to 7. It is seen that the step 162 when first performed with I=0 will locate transition points 1 and 2, and will subtract the X coordinate previously stored at those locations to calculate a number N which is equal in value to the number of X coordinates encompassed between transition points 1 and 2. The standard linear regression formulas set out in step 163 are then computed for the area of the array identified in step 162. It is seen that four values are computed, u being the summation of the X coordinates over the identified region, v being the summation of the ordinates at those locations, w being the summation of the square of the X values over that area, and z being the summation of the product of the ordinate and X value over that area. The slope and intercept of the line is then computed in step 164 using the equations there set out. The index I is then incremented to identify the X and Y coordinates encompassed between transition points 3 and 4, and the linear regression applied to define that straight line. In the case of a simple curve (see Fig. 2A), a test 165 would prove positive after the second iteration, indicating that both areas of changing ordinate value have now been treated.

In the case of a compound curve (Fig. 2B) however, test 165 would not prove positive until all areas of changing ordinate value had been treated.

After linear regression is used to determine the best fit portion of the curve represented by the ordinates of changing value, the program computes the remainder of the best fit curve by taking advantage of the fact that the remaining sections of the curve are horizontal, since two of the sections are tangent track and the remaining section(s) are track of constant radius. Accordingly, the program locates the transition points bracketing each horizontal section, computes the average ordinate within that section, and later assigns that average computed ordinate to each point in the section. That is accomplished by first setting an index J to 0 at step 166, following which the step 167, using the previously determined transition points, calculates a number N which is equal to the difference between the X values stored at transition points 1 and 0. Thus, the program has identified the section of the array ORD represented by the horizontal line between transition points 0 and 1. The step 168 then sums the ordinate values in each of those locations, following which the step 169 determines an average of those ordinates. The J index is incremented at step 170 and the procedure repeated for the remaining horizontal sections of the plot. Finally, a test 171 determines that all horizontal sections have been treated, following which the program progresses to a determination of final transition points for output.

It is noted that the TRNP transition points discussed earlier represent transitions between sections of the partially processed (smoothed) ORD information, whereas the FTP transition points being considered here represent intersections between the segments of the best fit curve. In order to compute final transition points for output, the program makes use of the fact that the equation for each of the sloped sections of the curve has been determined, and the average value assigned to each of the horizontal sections has also been determined. The program first sets a series of indices, at step 172 and step 175 for the slope and intercept data, at step 173 for the average information, and at step 174 for the final transition points. An equation 176 then relates the average value assigned to the segment between transition points 0 and 1 to the slope and intercept determined for the segment between transition points 1 and 2 to determine the intersection of those two lines, the X coordinate of which is stored at final transition point (FTP(K), in this case K being 1.

K and m are then incremented at 177 and 178, and a test made at 179 to determine whether the X coordinate for both ends of a sloped section has been found. If the result is negative, J is incremented at 180 and the process repeated from step 176 to find the X coordinate for the next final transition point. When the result is positive, another test is made at 181 to determine whether all the final transition points have been found. If negative, I is incremented at 182, m is set to zero at 175 and the X coordinate for the next final transition point is found at 176. This procedure is repeated until test 181 is positive indicating all final transition points have been found. Steps 183 and 184 then set the beginning and end stations as final transition points.

In carrying out the invention, the partially processed information in the ORD array is then replaced by more precise information which will be used to actually line the track. In the step 185, for each location in the ORD array which represents a horizontal segment, the ORD information is replaced by the average previously calculated in iterating step 169. For the sloped sections of the best fit curve, the step 186 replaces each individual ordinate value by a value whose magnitude is determined by the computation in step 186. It is noted that the equation there set out is simply the equation of a straight line in which the ordinate (or Y coordinate) is equal to the slope of the line times the X coordinate plus the intercept. Since the slope and intercept have been determined by iterating the linear regression steps of 163, 164, the information for determining each individual ORD value for the sloped portion is available. The program then simply increments X and continues to perform the calculation, in each case replacing the information in ORD array with that calculated in step 186.

As a result of the foregoing procedure, the ORD array now contains best fit information defining the best fit curve for the sample points originally input in the RAW array. The best fit information is not only available in the ORD array illustrated at 122 in Fig. 10 but is also displayed in the form of a plot such as Fig. 2A or 2B. Thus, the amount by which the track should be moved at each station is readily available for use in the work mode, so that when the equipment is returned to the zero station, it can reline the track not only to obtain the best fit to the original points, but also to assure tangent track entering and leaving the curve, constant radius track at the center, and smooth spiral transitions. In addition, the actual transition points are available for survey, to check the accuracy of the work and the like.

If the curve to be lined is known to be substantially accurate, as might be expected of a section of high speed track, the operator of the machine 10 can elect to forego the initial measurement operation and simply enter through the keyboard and display 71 the desired ordinates around the curve representing the intended shape. The machine 10 then makes its working pass making whatever slight adjustments are required.

Occasionally, it might be desired to not line the track to a best fit shape, as when there is a transition point having a known location that it is desired to maintain. Again, the measured and computed data can be modified by manual entry through the keyboard and display 71 of the station and ordinate required to achieve the desired result. The best fit calculated ordinates can be smoothed into the set station by taking the difference between the manual setting and the calculated setting for the same station and spreading that difference in decreasing linear progressions over a few stations on either side of the manually set station. For example, if the calculated ordinate for a station is a +5 value and it is desired to leave the station where it is at a zero ordinate, then zero would be entered manually for that station and the calculated ordinates for four stations on either side of the set station would be reduced by values of −4, −3, −2 and −1, respectively. This could be done manually by the operator or automatically through a program subroutine of the data processor.

Claims

1. A method of automatically lining railroad track having a line rail around a curve comprising, in combination, establishing a reference line for movement along the track, measuring the horizontal ordinates from a point on the reference line to the line rail at successive incremental points along the track as the reference line is moved around the curve, storing said measurements for retrieval and comparison, calculating a plotted curve representing an ideal curve whose ordinates at said incremental points most closely fit within said measurements, storing said calculated curve for retrieval and comparison, and horizontally shifting said track an amount controlled by the deviation between the measured and the calculated ordinates so that the track approaches the position of an ideal curve.

2. The method of claim 1 in which said track is shifted at each of said incremental points by an amount controlled by the deviation at that point.

3. The method of claim 1 in which said reference line is a fixed length, and said incremental points are a fixed distance apart.

4. The method of claim 1 including the step of displaying both the measured ordinates and the calculated ordinates for operator review.

5. The method of claim 1 in which said reference line is established by a beam of light.

6. In an apparatus for lining curved railroad track including means for establishing a reference line along the track, means for measuring the horizontal ordinate from a point on the reference line to a rail of the track, and means for horizontally moving the track near said point on the reference line, the combination comprising, a data processor having a memory, means for feeding signals representing said ordinates from said means for measuring to said processor, means for measuring movement of the apparatus with said reference line along the track, means for sending a signal to said processor from said last named means at successive incremental points along the track as the reference line is moved, said processor having means for storing in said memory the incremental point signals and the then-existing ordinate distance signals, means in said processor to calculate theoretical ordinates for an ideal curve which most closely fits within said measured ordinates and to store those

theoretical ordinates in said memory, and means for switching from said foregoing operation to a mode wherein upon movement of the apparatus along the track for a second time, said processor, at each incremental point signal, sends a signal to said means for horizontally moving the track so as to move the track a distance and direction equal to the deviation at that point of the measured track position ordinate and the calculated ordinate.

7. The apparatus of claim 6 in which said apparatus is on-track and self-propelled, said reference line is a fixed length, and said incremental points are a fixed distance apart.

8. The apparatus of claim 6 including, in combination, means for displaying both the measured ordinates and the calculated ordinates for operator review.

9. The apparatus of claim 6 in which said means for establishing a reference line includes a light source, a light sensor, and a mask, said mask cooperating with said means for measuring the horiziontal ordinate.

10. The apparatus of claim 9 in which said light sensor develops a proportional signal upon displacement of a beam of light from a null position, and said mask has a slot to create a beam of light from said source falling on said sensor.

11. A method of automatically lining railroad track having a line rail around a curve comprising, in combination, establishing a reference line for movement along the track, measuring the ordinates from a point on the reference line to the line rail at successive incremental points along the track as the reference line is moved around the curve, storing said ordinates, locating transition points in said ordinates between segments of substantially constant ordinate and segments of changing ordinate, between transition points of changing ordinate using a linear regression to obtain a best fit line for said changing ordinates, between transision points of substantially constant ordinate determining the average ordinate, and using said determined ordinates as a best fit curve for horizontally shifting the track to approach the position of the best fit curve.

12. The method as set out in claim 11 further comprising the step of determining the intersections between the lines represented by said determined ordinates to locate transition points in the best fit curve, and displaying said transition points.

13. A method of finding a best fit line for a series of ordinates measured from a reference line moved along a railroad track to the track as it spirals between tangent and circular configuration comprising the use of a linear regression on the ordinate values.

14. A method of superelevating railroad track around a curve comprising, in combination, storing a desired value of superelevation for the constant radius portion of a curve, determining the transition points between tangent and spiral, and spiral and constant curve, track, calculating a linear progression of superelevations for a succession of points between said two transition points from zero to said desired value, and elevating the track round the curve using said calculated superelevations at the corresponding ones of said points.

15. A method of automatically lining railroad track, substantially as hereinbefore described with reference to the accompanying drawings.

16. Apparatus for lining a railroad track, substantially as hereinbefore described with reference to the accompanying drawings.

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