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(54) IMPROVEMENTS RELATING TO HIGH-ACCURACY, TWO-DIMENSIONAL ELECTRONIC POSITION MEASUREMENT

(71) We, DATA AUTOMATION CORPORATION, a corporation organised under the laws of the State of Michigan, United States of America, of P.O. Box 573, Farmington Hills, Michigan 48024, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

This invention describes improvements which increase the accuracy and simplicity of electronic position-measuring devices commonly known as data tablets or digitizers. Such devices generally employ a two-dimensional reference surface (similar to a drafting board) and a stylus or cursor to point to the specific X, Y position that is to be digitized. The output of these devices is a digital representation of the analog X, Y position that the pointer designates.

Previous inventions in this field include numerous electronic schemes for moderate accuracy over small distances, such as 0.01 inch over 12 by 12 inches (Computek, Shintron, Summagraphics); and somewhat higher accuracy over larger distances, say 0.005 inch over 60x60 inches (Farrand and Bendix). However, the Farrand scheme is basically one-dimensional. The Bendix scheme is expensive, measures distances only in an incremental manner, and has inherent repetitive errors. All of these disadvantages are overcome, or at least much reduced, in the preferred form of the invention to be described.

Farrand and Bendix employ two reference-grid windings and one cursor winding. The principal differences between the two are the width of the reference grids and the shape of the cursor. Referring now to Bendix (Bailey's United States Patent No. 3,647,963), the basic grid winding is shown in Figure 1, where the vertical conductors are equally spaced and obviously carry current in opposite directions (up or down). The usual pointer (cursor) is a round coil, shown as a dotted line in Figure 1. Either the grid winding or the cursor coil can be the driven element, and a signal whose amplitude varies with coil position is induced in the other element. In practice, Bendix drives the coil with a 3 khz. sine wave.

Actually, the configuration of Figure 1 does not function for several reasons. One is that, in the positions as shown in Figure 1, there is no net coupling between the grid and cursor. This was, of course, recognized by Bailey, who added a second grid winding, 90° out of space phase with the first. The result is shown in Figure 2. Here, one of the windings always receives a non-zero signal from the cursor. Further, if the signals are properly combined (as shown by Bailey) a composite output signal is obtained whose amplitude is constant and whose phase advances or retards as the cursor coil is moved to the right or left in Figure 2.

Unfortunately, the linearity of the phase dependence on cursor position depends on the induced signal amplitude in a grid winding varying sinusoidally as a function of cursor position. In practice, this is not so, and inherent errors thus exist in the measuring scheme.

The present invention seeks to provide apparatus for determining position coordinates in which the grid winding and excitation allows the grid-to-cursor coupling to approach sinusoidal variation as nearly as desired.

Accordingly the present invention consists in one form in apparatus for determining position coordinates along a coordinate axis, comprising a grid winding having conductive segments extending perpendicularly to the axis and a cursor including an inductive winding adapted to be moved along the axis and to deliver an induced signal indicative of the cursor position, wherein the conductive segments of the winding are arranged in groups which are repeated regularly across the winding with the conductive segments of each group being disposed at a predetermined spacing relative to each other and wherein the grid winding is connected to a source of exciting current which distributes current in a predetermined manner over the conductive segments of each group, the predetermined spacing of the conductive segments and the predetermined distribution of current being such that the resulting magnetic field of the winding varies substantially sinusoidally as a function of displacement along the axis with one cycle corresponding to one group of conductive segments.

In another form the present invention consists in apparatus for determining position coordinates on a work surface, comprising a first grid winding disposed in a plane parallel to the work surface and having conductive segments extending perpendicularly to a first coordinate axis; a second grid winding disposed in a plane parallel to the work surface and closely adjacent the first grid winding and having conductive segments extending perpendicularly to a second coordinate axis; and a cursor including an inductive winding adapted to be moved across the work surface and to deliver an induced signal indicative of the cursor position, wherein the conductive segments of each grid winding are arranged in groups which are repeated regularly across the winding with the conductive segments of each group being disposed at a predetermined spacing relative to each other and wherein each grid winding is connected to a source of exciting current which distributes current in a predetermined manner over the conductive segments of each group, the predetermined spacing of the conductive segments and the predetermined distribution of current being such that the resulting magnetic field of each grid winding varies substantially sinusoidally as a function of displacement along the associated coordinate axis with one cycle corresponding to one group of conductive segments.

The invention will now be described by way of example with reference to the accompanying drawings in which:-

Figures 1 and *2* show windings used hitherto,

Figure 3 shows diagrammatically the current distribution in the winding of Figure 1,

Figures 4 and5 show diagrammatically the current distribution in respective windings according to the invention,

Figures 6 and 7 show the windings according to this invention which produce the current distributions shown respectively in Figures 4 and 5,

Figure 8 shows a further winding according to this invention,

Figure 9 shows diagrammatically the current distribution of the winding of Figure 8,

Figure 10 shows a polyphase winding according to a preferred form of this invention in which each phase winding is understood to represent a distributed current winding such as those shown in Figures 6 and 7,

Figure 11 illustrates the manner in which current pulses are supplied to the phase windings of Figure 10,

Figure 12 illustrates the variation with time of the cursor signal for four different positions in the grid cycle,

Figure 13 shows a coarse grid winding and associated circuitry which are employed in a preferred form of this invention and,

Figure 14 is a block diagram showing a complete apparatus for determining position coordinates in accordance with this invention.

For reference purpose, the current distribution in a grid such as in Figure 1 is shown in Figure 3. The arrows represent direction and magnitude of current in the grid conductors. The dotted line represents the envelope of induced signal amplitude in the cursor. Depending somewhat on the design of the cursor, the envelope tends to be more nearly a triangular wave than sinusoidal. Two examples of distributed current according to the invention are shown in Figures 4 and 5.

The grid-winding patterns which produce these current patterns are shown respectively in Figures 6 and 7. These figures show the grid conductors as evenly spaced: 6 per cycle in Figure 6 and 4 per cycle in Figure 7. In principle, however, the spacing can be non-uniform, as shown in Figure 8. The current pattern for this spacing is shown in Figure 9. The current amplitudes can also be chosen in any manner desired. Those shown turn out to be useful and very simple to implement, but it may be desirable to choose other distributions to suit a particular cursor configuration or for other reasons.

A preferred feature disclosed herein greatly simplifies the excitation and detection circuitry in comparison to other known methods of highly accurate electronic digitizing. The methods described below can be implemented almost entirely with inexpensive, digital switching circuits instead of precision analog amplifiers, filters, and phase shifters.

According to this preferred feature the grid winding is constructed in the form of a polyphase winding. In principle, any number of phases can be used; in practice, the analog circuitry becomes less critical as the number of phases increases. For purposes of illustration, a five phase system will be described.

Each of the five phases requires a separate grid winding which can be of the types shown in Figures 6 and 7. The principle is much easier to see, however, if the winding of Figure 1 is used for illustration only, with the understanding that superior accuracy can be obtained with Distributed Current windings.

For illustration, Figure 10 shows five grid windings of the Figure 1 configuration, properly spaced for five-phase drive. Each grid winding is driven by a current-source switch, with the current waveforms turned on and off in sequence as shown in Figure 11.

The drive waveforms are turned on and off at any convenient repetition rate, and one cycle of this repetition frequency is divided into n parts (10 for this illustration) where n is twice the number of grid windings. As Figure 11 shows, the current sources are turned on in sequence for 1/2 of a repetition cycle,and then they are turned off in the same sequence for the second half of the cycle.

The cursor coil which senses these current pulses need not be designed to provide faithful reproduction of the current or voltage waveforms in the grid windings. Quite good performance is obtained with a coil that differentiates the current signals i. That is, the voltage V generated in the cursor coil is just $V = k\, {}^{di}/_{dt}$. The time response of such a cursor coil as a function of position within one grid cycle is shown in Figure 12. It can be seen that the cursor coil responds strongly to the conductor that is nearest to it, and the response falls off rapidly to conductors more distant from the coil. Therefore, as the coil is moved along the grid surface, a pulse envelope moves in time. This envelope can be processed by simple analog circuits to provide a signal that indicates the cursor position within a grid cycle.

The preceding discussion explains basic techniques that can provide measurement within one grid cycle in one dimension. A second dimension is obtained by adding a second grid-winding array. The same cursor assembly, if it is built with circular symmetry, can detect the excitation waveforms in both grid arrays. Well-known time-sharing techniques can be used to prevent confusion between the signals from the two grid arrays.

With appropriate cycle-counting logic, the above techniques can provide a useful digitizer with any number of grid cycles in both dimensions. It would have the disadvantages of many incremental systems, however, in that there is no way to determine what grid cycle the cursor is pointing to except by counting cycles from some zero-reference position. Thus, if power were interrupted, or the cursor was lifted from the grid surface, or if some logic component failed momentarily, it would be necessary to re-index the cursor at the zero-reference point and then trace back to the current position of interest.

To overcome the disadvantages of incremental digitizing techniques, a coarse position-measurement technique which can share much of the same electronics is described below. This technique requires an additional, very simple grid array for each dimension. Each coarse array contains approximately 2 n parallel conductors, where n is the number of grid cycles in the high-accuracy array. Thus, if the high-accuracy array had a typical dimension of 1 inch, the coarse array would have only 2 conductors per inch. These could have a very loose tolerance on their location, such as ±0.1 inch from true position.

A diagram of the coarse measurement array for one axis is shown in Figure 13. The conductors 6 of the array are connected with selection circuits 2 and 3; ann number of well-known selection and switching schemes could be employed in this example, but the circuits employed for magnetic-core memories seem particularly applicable. A pulse source 5 is connected with the selection circuits 2 and 3 so that each of the conductors is energized by a current pulse, separately, at least once. The address of the conductor that causes a response from the pulse amplifier 1 appears in the address register 4 and denotes the coarse position of the cursor 7. In practice, it is probable that several adjacent conductors will cause response pulses. Some convention is then necessary to choose just one address. In the system to be described later, the lowest address was chosen because of convenience in implementation, but other conventions could just as well apply.

It is also necessary to employ some form of anti-ambiguity logic to correlate the coarse measurement with the fine measurement from the high accuracy arrays. Otherwise, one might obtain erroneous measurement sequences such as: 11.996, 11.997, 12.998, 12.999, 12.000, 12.001 when the proper sequence is: 11.996, 11.997, 11.998, 11.999, 12.000, 12.001. This is a well-known problem with coarse-fine measurement systems, and many methods of solution are available in existing art. The provision of two coarse conductors per fine cycle provides sufficient redundant information to solve the problem.

In this preferred feature of the invention techniques from several disciplines are combined to solve a problem in absolute digitizing by electronic means that has not been solved before.

A block diagram of a complete apparatus according to this invention is shown in Figure 14. The illustration shows four separate grids, 11, 12, 13 and 14 respectively, in exploded view. These would actually be constructed so as to be nearly coplanar. The fine X and fine Y grids 13 and 14 respectively are each an array of equally spaced parallel conductors with their ends connected together to form five windings of the type shown in Figure 7. The windings are spaced, in relation to each other, according to the principle illustrated in Figure 10. The illustrated system logic assumes that 1 fine grid cycle equals 1 unit of distance, such as 1 inch.

The coarse X and Y grids 11, 12 are constructed according to the principle shown in Figure 13. Each grid is an array of parallel conductors spaced approximately 1/2 inch apart. The system logic is such as to allow digitizer dimensions up to 499 inches in X and Y, which is much larger than necessary for most applications. However, the concept puts no limitation at all on size.

The pulse generator 31 supplies the whole system with high frequency clock pulses; in the example, the clock frequency is 5 MHz. The clock pulses are fed to the counter control 33 and to the frequency divider 35.

The frequency divider 35 delivers submultiples of the clock frequency, in this example pulse frequencies of 5 kHz, 50 and 500. The outputs of the frequency divider serve for the required measurement resolution and output number system. In the example illustrated the resolution is 0.001 inch and the number system is decimal.

The 5 kHz pulse frequency is fed to the sequence control 39 which ensures the correct sequence in time of the control and exciting operations. Thus the sequence control 39 ensures that only one of the grid windings is excited at a time. In addition, the sequence control ensures the transmission of the position information from the position counter 44 to the six-place X position register 46 and Y position register 47 which can be regarded as the output of the apparatus.

The counter control 33 ensures that the position counter 44 is cleared at the beginning of a measuring cycle and that then clock pulses are introduced into the position counter until a coarse or fine stop pulse is received from the sequence control 39; in this example the position counter 44 is a 3-decade decimal counter. The X and Y position registers 46 and 47 are static digital registers which hold a number for display or for transmission to a further device.

The cursor 7 is connected to a pulse amplifier 10 which transmits the amplified cursor signal to the counter control 33 and to a linear filter amplifier 53. The linear filter amplifier 53 converts a pulse train such as that shown in Figure 12 into a waveform that represents the amplitude envelope of the pulse train, a 5 khz sine wave in this example. The 5 khz sine wave is passed to a zero passage detector which produces a pulse at a pre-selected instant during the cycle of the sine wave, here the passage through zero amplitude in a positive-going sense.

The X coarse selector matrix 57 and the Y coarse selector 58 are both multi-output switches which energize one output after another in synchronism with the 500 khz pulse frequence. The X fine current switch 59 and Y fine current switch 60 are in this example five-output switches which turn a fixed current on or off at each output in synchronism with the 50 khz pulse frequency to obtain the current-drive sequence of Figure 11.

The circuit arrangement described above works as follows. In this example it is assumed that the sequence control 39 causes four measurements to be made in a never-ending repetitive sequence; many other sequences could be used. Each step in the sequence could for example consist of one or more of the 5 khz pulse intervals defined by the frequency divider 35. Several pulse intervals may be necessary to permit the analogue circuits to reach steady-state AC conditions after each grid-drive cycle is first started. For the sake of illustration, assume that 10 of the 5 khz periods are spend on each step of the sequence; also assume that the measuring sequence is:- (1) Fine X, (2) Coarse X, (3) Fine Y, and (4) Coarse Y.

During the Fine X sequence, the Fine X current switches 59 sequence through ten excitation cycles at a 5-khz repetition rate. During the tenth excitation cycle, the position counter 44 starts at 000 and runs until a Fine Stop Pulse is received. This will occur at some count between 000 and 999 as a function of cursor position. At the end of the tenth excitation cycle, whatever count is stored in the position counter is transferred into the least significant three digits of the X position register 45 and the position counter is cleared.

The coarse X sequence can also consist of ten periods of the 5 khz frequency from the frequency divider 33. This allows sufficient time for the coarse X selection matrix 57 to supply 1000 grid lines (500 inches) in sequence at a 500 khz stepping rate. While this stepping sequence is occurring, the position counter 44 is running at a 250 khz rate until a Coarse Stop Pulse is received. At this point, the position counter contains cursor position to the nearest inch. (Anti-ambiguity logic in the counter control 33 coordinates the Coarse and Fine counts to prevent erroneous indications, such as 12.997 when 11.997 is correct). At the end of the Coarse X sequence the count in the position counter 44 is transferred into the most significant digits of the X position register and the position counter is cleared. The X position of the cursor has been completely determined at this stage in the measuring sequence.

The Y position is determined in two more sequence control steps that are completely analogous to those described above.

WHAT WE CLAIM IS:-

1. Apparatus for determining position coordinates along a coordinate axis, comprising a grid winding having conductive segments extending perpendicularly to the axis and a cursor including an inductive winding adapted to be moved along the axis and to deliver an induced signal indicative of the cursor position, wherein the conductive segments of the winding are arranged in groups which are repeated regularly across the winding with the conductive segments of each group being disposed at a predetermined spacing relative to each other and wherein the grid winding is connected to a source of exciting current which distributes current in a predetermined manner over the conductive segments of each group, the predetermined spacing of the conductive segments and the predetermined distribution of current being such that the resulting magnetic field of the winding varies substantially sinusoidally as a function of displacement along the axis with one cycle corresponding to one group of conductive segments.

2. Apparatus for determining position coordinates on a work surface, comprising a first grid winding disposed in a plane parallel to the work surface and having conductive segments extending perpendicularly to a first coordinate axis; a second grid winding disposed in a plane parallel to the work surface and closely adjacent the first grid winding and having conductive segments extending perpendicularly to a second coordinate axis; and a cursor including an inductive winding adapted to be moved across the work surface and to deliver an induced signal indicative of the cursor position, wherein the conductive segments of each grid winding are arranged in groups which are repeated regularly across the winding with the conductive segments of each group being disposed at a predetermined spacing relative to each other and wherein each grid winding is connected to a source of exciting current which distributes current in a predetermined manner over the conductive segments of each group, the predetermined spacing of the conductive segments and the predetermined distribution of current being such that the resulting magnetic field of each grid winding varies substantially sinusoidally as a function of displacement along the associated coordinate axis with one cycle corresponding to one group of conductive segments.

3. Apparatus as claimed in Claim 1 or Claim 2, wherein the or each grid winding is constructed in the form of a polyphase winding and means is provided for repetitively supplying current pulses in succession to the individual phase windings in a fixed sequence in time.

4. Apparatus as claimed in any one of the preceding claims, wherein there is associated with the or each grid winding a coarse grid winding having conductive segments arranged parallel to the conductive segments of said grid winding, means being provided for supplying current to the or each coarse grid winding so that the signal thereby induced in the cursor may be used to resolve ambiguities of position.

5. Apparatus as claimed in Claim 3, wherein the duration of each current pulse is one half of the repetition cycle.

6. Apparatus as claimed in Claim 3 or Claim 5, wherein the cursor provides a differentiated signal.

7. Apparatus as claimed in Claim 4, wherein said means for supplying current to the or each coarse grid winding serves to energise the conductive segments sequentially.

8. Apparatus as claimed in Claim 4 or Claim 7, wherein the or each coarse grid winding has 2n conductive segments where n is the number of groups of conductive segments in the associated grid winding.

9. Apparatus for determining position coordinates constructed arranged and adapted to operate substantially as hereinbefore described with reference to and as shown in Figure 14 of the accompanying drawings.

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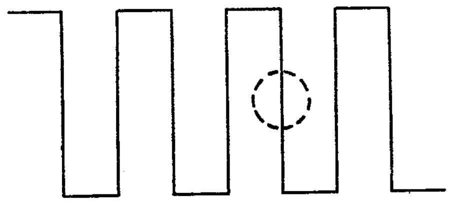

FIG.1

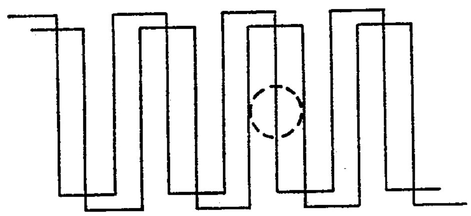

FIG.2

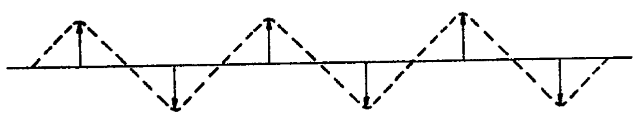

FIG.3

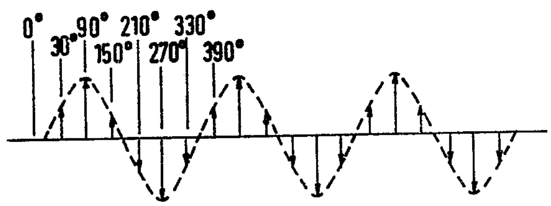

FIG.4

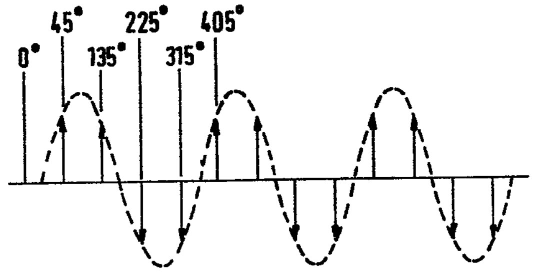

FIG. 5

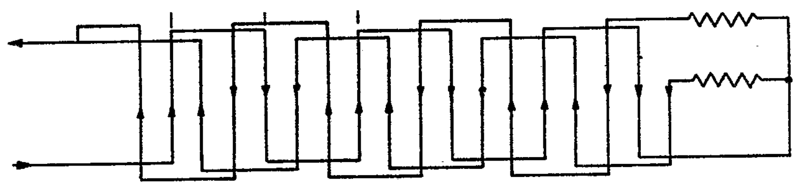

FIG. 6

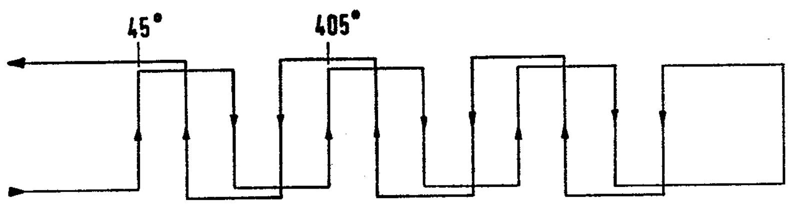

FIG. 7

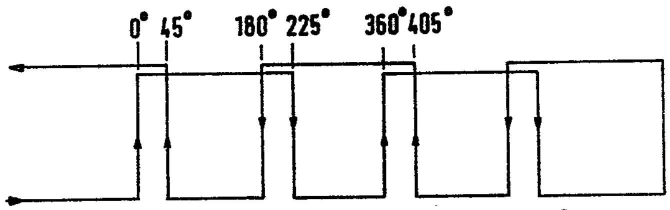

FIG. 8

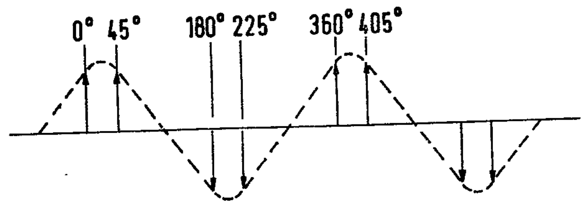

FIG.9

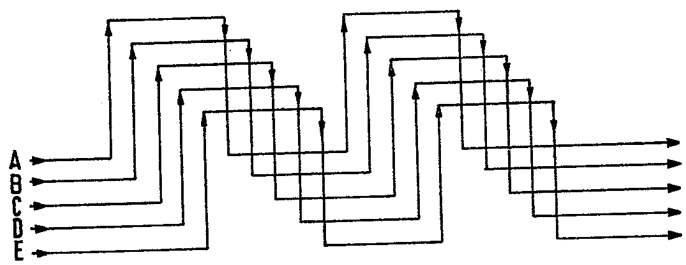

FIG.10

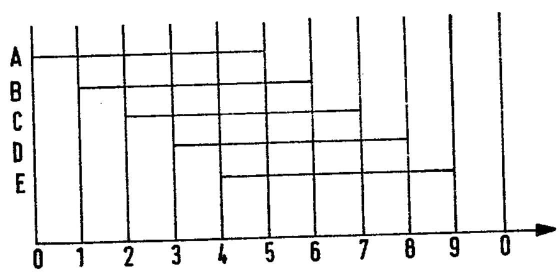

FIG.11

1565836 COMPLETE SPECIFICATION

5 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 4

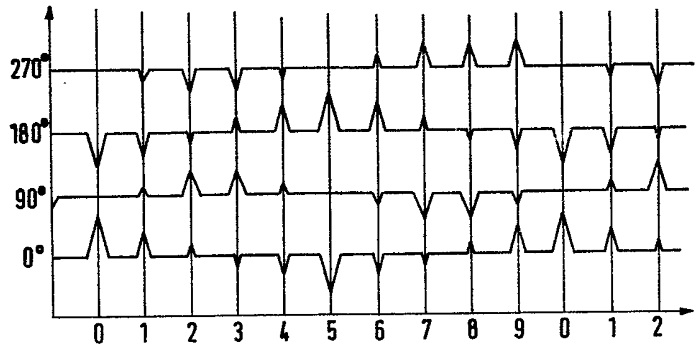

FIG.12

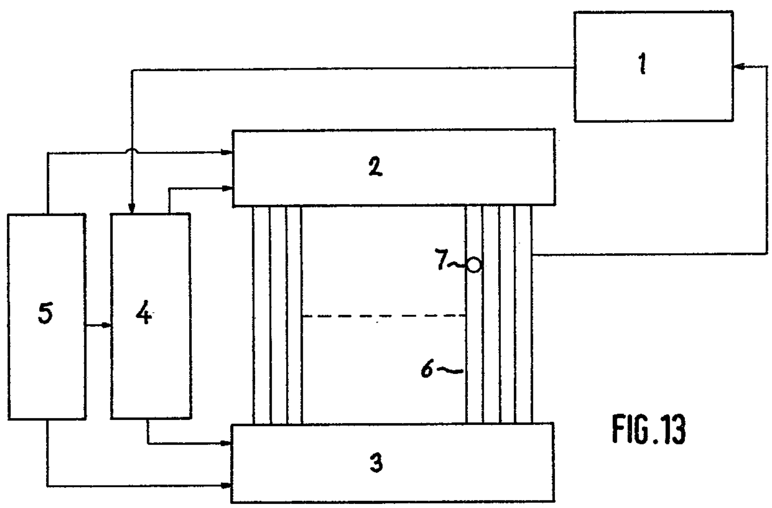

FIG.13

1565836 COMPLETE SPECIFICATION

5 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 5

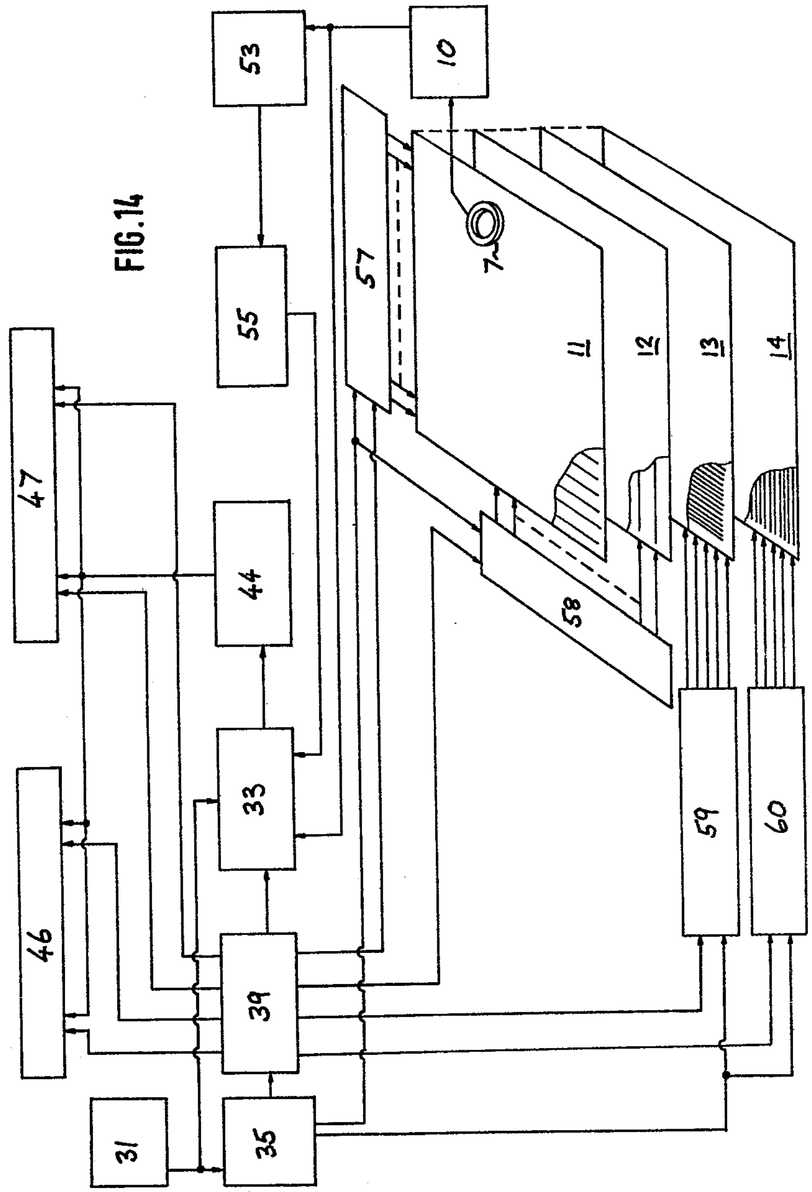

FIG.14