

PATENT SPECIFICATION

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(54) IMPROVEMENTS IN OR RELATING TO RADIOGRAPHY

(71) We, EMI LIMITED, a British company of Blyth Road, Hayes, Middlesex, 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:—

The present invention relates to radiology.

Techniques are now known by means of which it is possible to obtain a highly accurate representation of the absorption or transmission coefficients of a two-dimensional array of elements notionally delineated in a cross-sectional plane through a body, or part of a body, being examined. One such technique is disclosed in our British Patent Specification No. 1,283,915.

In some circumstances it can be advantageous to have a visual representation of the aforementioned coefficients substantially as soon as the acquisition of the information used in forming the representation has been completed.

According to the invention there is provided radiological apparatus including means for operating an respective electrical signals, indicative of absorption values for each of a plurality of co-planar paths traversed by penetrating radiation through a body, some of said paths being arranged to intersect, to produce respective altered signals which are susceptible to additive superposition, charge storage tube means having charge storage target means, input scanning means, associated with said storage tube means, for depositing upon said target means a respective line of charge indicative of each altered signal, the disposition of each such line of charge on said target means being indicative of the disposition, relative to the body, of the path to which the respective altered signal relates, output means for deriving from said target means output signal indicative of the accumulated charge deposited at different

locations of said target means, and means for displaying said output signals.

In order that the invention may be clearly understood and readily carried into effect, it will now be described by way of example only with reference to the accompanying drawings, of which:—

Figure 1 shows in block diagrammatic form apparatus in accordance with one example of the invention,

Figure 2 shows, in block diagrammatic form, apparatus in accordance with a second example of the invention,

Figure 3 shows a charge storage tube for use with apparatus according to said second example, and

Figure 4 shows the charge storage target of the tube shown in Figure 3.

Referring now to Figure 1, an X-ray scanning machine, for example of the kind described in the aforementioned patent specification, is indicated at 1. This machine is arranged to direct radiation from a source through the body along many sets of co-planar linear paths towards detector means located on the other side of the body to the source. Each set of paths may comprise parallel or mutually divergent paths. The detector means is arranged to detect the radiation emergent from said body along each of said paths and thus provides so-called edge readings which represent the absorption suffered by the radiation on traversing each path through the body.

The edge readings, in digital form, are passed to a store 2, which can conveniently comprise a magnetic disc store, although any other kind of digital store could be used instead. The store 2 operates in co-operation with a digital computer 3, which can either be a general purpose computer or a special purpose computer, as it only has a limited set of duties to perform. The main purpose of the computer 3 is to alter the edge readings into a form which permits of additive superposition in a manner to be described hereinafter, a suitable

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computation to effect the alteration of the edge readings being the convolution technique described and claimed in the Complete Specification of British Patent Specification No. 1,471,531.

In most cases, patients to be examined by means of this apparatus will have already been subjected to a preliminary examination by a physician and thus a preliminary diagnosis will be available to indicate the form of malady from which the patient is suffering. In the light of such a preliminary diagnosis, the radiographer utilising the apparatus is able to determine the particular substance within the body, such as fat, water or blood, which is most likely to reveal symptoms of the diagnosed malady, and he will wish to concentrate mainly upon the substance. The "zero" for the computation is selected in accordance with the absorption suffered by the X-radiation on traversing the substance of particular interest, and in practice it is best for this zero to be set a little above the black level on an output display monitor 10, as in this way various substances which exhibit absorptions close to that of the substance of particular interest are easily discernable on the monitor 10.

The "zero" referred to above is selected by means of a keyboard 4, and the selected level is used by the computer 3 as a threshold level for each of the altered edge readings. Thus the computer 3 is arranged to subtract the chosen zero level from each of the altered edge readings, and negative and positive results from the subtraction are applied respectively to digital-to-analogue converters 5 and 6. The converters 5 and 6 feed respective storage tubes 8 and 7 wherein each value is stored as a line of charge deposited under the control of respective input scanning circuits (not shown) upon the charge storage target of one or other the tubes 7 and 8. The input scanning circuits are such that each line scanned thereby is orientated on a storage target in a corresponding manner to the orientation relative to the body of the path from which the respective edge reading was derived.

The position of the line is determined by a scan control unit 9 in response to timing signals from the computer 3. It will be realised that a sweep in a given direction executed by the X-ray machine later gives rise to a raster on the storage tubes in a corresponding direction, the raster being of parallel lines, like those of a normal television raster, which have been rotated to be parallel to the said direction.

In the simplest form of system, deposition of further information upon the targets of the storage tubes is inhibited once

all of the altered edge readings have been deposited thereon. The derivation of the deposited information is then achieved by operating the storage tubes in a "read only" mode.

In an improved arrangement, the accuracy of the displayed image is increased by utilising the final values for each resolveable element of the storage tube targets and the initial edge readings in a process of successive approximations, the process being of the same general nature as that described in British Patent Specification No. 1,283,915. Thus the final values of elements disposed along each beam path are read from the storage tubes and summed to give pseudo edge readings which are then compared with the corresponding true edge readings which, in this arrangement, have to be retained in the store. If there have been no errors in the digital-to-analogue conversion and re-conversion and if the storage tubes impart no errors to the data, then the result of the aforementioned comparison will be an error signal of zero. This will not, however, in general be the case and error signals will be fed back to the storage tubes to up-date the information stored therein, tending to cause the pseudo edge readings to approximate more closely to the true edge readings. The process of successive approximations can continue for as long as an operator wishes to view the monitor 10, thus avoiding the possibility of errors arising due to decay of the information held in the storage tubes.

In the above mode of operation, the forward motion of the spots scanned over the storage tube targets along each line is used to read out information and the return motion along the same path used for deposition of information. However the forward motion of the spots can be used for both reading out and deposition of information if required.

It is not necessary to erase all the charge image on the target of the storage tube in the iteration process. If about half the stored charge is scanned-off in order to obtain the video output, the correction signal can then be added to the residual charge pattern. The advantage of this approach lies in the absence of difficulties associated with storage tube picture "lag" which can slow down the process of successive approximations, and also greater ease of registration of the two scanning lines across the target.

If a scan line can be completed in $50\mu\text{s}$ and the spot can return along the same path in another $50\mu\text{s}$ a scan frequency of 10000hz results, which is quite normal for television rasters. The total time to write in the picture, using the forward going lines

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only, as $160 \times 3 \times 180/10000$ i.e. 8.64 seconds assuming 160 beams per set and 3 sets per degree of angular rotation around the body, for a total rotation angle of 180° .

5 As this process can proceed during the X-ray exposure, very little time elapses after the end of the exposure before the image is complete.

10 As previously mentioned, the forward path along each scan line can be used as output scan to pass the data to the monitor, subtraction of data provided by tube 8 from that simultaneously provided by tube 7 being performed by an analogue circuit (not shown) as the input to the monitor.

15 If the operator chooses a new zero level on the keyboard 4, it takes 8.64 seconds for the apparatus to readjust completely to this new value. For this purpose the system must be switched back into the non-iterative mode using the convoluted data. As soon as the image is complete the system is again put into the iterative mode. In this way, readjustment starts at once and can be

25 seen to be taking place. The system is subject to the errors of analogue addition, which, although not great in this case, are probably greater than if a digital computer had performed the whole calculation. It is, however, a simple matter to add a facility which enables the value at a single point to be calculated accurately using only digital methods.

30 A second keyboard 11 provides analogue voltages in response to knob settings representing a position on the image. An equality detector 12 detects when the scan waveforms produce either the same x value or the same y value, where x and y are the cartesian co-ordinates of the desired point. When either occurs, a pulse is sent to the monitor. This results in the point on the image being marked by electronic "cross wires". When both x and y coincide with the required values, a signal is passed to the

45 adder 13 which takes the digital signal which at that time is being provided by the computer and adds it on to the total. In this way, after 8.64 seconds in this example, an accurate value for the point is found. That is to say, when all contributions to the point have been added to it the sum will be the required value.

50 Using the same general principle within the computer 3, it is possible to calculate the absorption or transmission coefficients of the elements in any particular area more accurately than the capabilities of the storage tubes. Respective analogue to

55 digital converters 14 and 15 can be used to compare the outputs of the storage tubes with the correct value at a particular point, and if they are found to be in error, corrections passed to the tubes via units 5 and 6 respectively. It will be appreciated

that computer 3 contains a store in which these values of absorption (or transmission) coefficients for the elements of the matrix, as accurately computed in digital form are stored. The points used could either be chosen by a computer programme or be manually chosen from the keyboard 11. The connections for this last possibility have not been shown.

It is evident that the television type raster could be made a great deal faster if requires. Data from the computer need only change once per line, i.e. once every $100\mu s$. Even a general purpose digital computer could provide a considerably higher speed if this were required. The monitor could have a bandwidth of 25 mc/s, which means it could go fifteen times faster than in the above example.

In an alternative arrangement, instead of using the return paths along the various lines as the output scan, a separate reading phase may be initiated after all the information has been applied to the targets, wherein the information is derived from the storage tubes 7 and 8 under the influence of output scanning circuits (not shown) which are arranged to scan simultaneously a fixed raster of television format on each of the storage targets. The monitor 10 is then set up to scan with the same waveforms as applied to the output scanning circuits of the storage tubes and the spot brightness is made to represent the difference between the outputs derived from the two storage tubes during the reading period. It will be appreciated, however, that in this case the persistence of the targets is taxed more heavily than in the arrangement previously described, and moreover that the output cannot be thought of as a continuously visible correct representation of the image.

Referring now to Figure 2, there is shown, in block diagrammatic form, an apparatus similar to that described in relation to Figure 1, and wherein similar components are given the same reference numerals as their counterparts in Figure 1. The principal difference between the arrangements of Figures 1 and 2 is that the two storage tubes 7, 8 of Figure 1 have been replaced in Figure 2 by a single tube shown at 16.

The operation of the arrangements of Figures 1 and 2 is similar except that the "zero" level, selected by means of the keyboard 4, is used by the computer 3 as a reference level for each of the altered edge readings. The differences between these readings and the reference level are applied to digital to analogue converter 5 and from there to storage tube 16 where each value is stored as a line of charge on the charge storage target. As before, the position of the line is determined by a scan control unit

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9 in response to timing signals from the computer 3.

A suitable storage tube for use with this example of the invention is shown in Figure 3. The tube, contained in an evacuated envelope 16' employs an electron gun and scanning means, 17 to scan an electron beam 18 over the surface of a charge storage means indicated generally at 19.

The charge storage means, which is shown in more detail in Figure 4 is of the same general nature as that described in our British Patent Specification No. 1,074,811. A target 21, of an insulator such as zinc sulphide, is provided on a conducting layer 22 at the end of envelope 16. The target 21 can conveniently be provided by evaporation onto layer 22. The side of target 21 not in contact with layer 22 is coated with a thin continuous metallic film 23 which may, for example, be evaporated aluminium 10000 Å thick.

In operation, the beam of electrons 18 is arranged to be of constant intensity and is scanned over the target surface while the input signals are applied as time varying voltages between layers 22 and 23 at terminals 24. Alternatively the electron beam may be modulated. The scan control unit 9 arranges the scanning of the tube so that the scanned line is orientated on the storage member 19 in a corresponding manner to the orientation relative to the body of the path from which the respective edge reading was derived.

After all of the altered edge readings have been deposited on the target member the tube is operated in the "read" mode to derive therefrom the required information. To achieve this the voltage between the two conducting layers 22 and 23 is reduced to zero and the target is again scanned with a constant intensity electron beam. The displacement current due to moving charges between the two conductors 22 and 23 then represents the linear sum of the superimposed inputs at any point on the output scan and it is evaluated by the circuit containing target 19. This may comprise a conventional video amplifier which will provide suitable signals to monitor 10. It will be appreciated that the output scan may correspond to the video scan of monitor 10.

Again, the accuracy of the displayed image may be improved by the process of successive approximations described in the aforementioned British Patent No. 1,283,915. In this respect the output scan and the scan of monitor 10 may be indentially arranged in the form of, for example, a television raster being rotated about the centre of the screen. If, the "flyback" time is made equivalent to the "line" period, the "line" may then be used

to read out to the monitor and the "flyback" to write in the iterative correction to that line.

Furthermore, in relation to Figure 2, it should be noted that a set of circulating shift registers may be provided at the output of computer 3 to feed D-A converter 5 and to act as a buffer so that each frame may be repeated more rapidly if required.

WHAT WE CLAIM IS:—

1. Radiological apparatus including means for operating on respective electrical signals, indicative of absorption values for each of a plurality of co-planner paths traversed by penetrating radiation through a body, some of said paths being arranged to intersect, to produce respective altered signals which are susceptible to additive superposition, charge storage tube means having a charge storage target means, input scanning means, associated with said storage tube means, for depositing upon said target means a respective line of charge indicative of each altered signal, the disposition of each such line of charge on said target means being indicative of the disposition, relative to the body, of the path to which the respective altered signal relates, output means for deriving from said target means output signals indicative of the accumulated charge deposited at different locations of said target means, and means for displaying said output signals.

2. Apparatus according to Claim 1 wherein said storage tube means comprises first and second storage tubes, each having a respective charge storage target, and wherein there is provided comparison means for comparing said altered signals with a threshold level and for providing difference signals indicative of said comparison, means for routing positive difference signals to one of said storage tubes and negative difference signals to the other of said tubes, and means for displaying the output signals derived from both of said tubes on a common display device.

3. Apparatus according to Claim 1 wherein said storage tube means comprises a single storage tube having a charge storage target in the form of a planar slab, bearing, on each of its flat surfaces, an electrically conductive layer.

4. Apparatus according to any preceding claim wherein said means for operating on said electrical signals to produce said altered signals comprises means arranged to subject said electrical signals to a convolution process.

5. Apparatus according to any preceding claim including means arranged to receive



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2. Apparatus according to Claim 1 wherein said storage tube means comprises first and second storage tubes, each having a respective charge storage target, and wherein there is provided comparison means for comparing said altered signals with a threshold level and for providing difference signals indicative of said comparison, means for routing positive difference signals to one of said storage tubes and negative difference signals to the other of said tubes, and means for displaying the output signals derived from both of said tubes on a common display device.

3. Apparatus according to Claim 1 wherein said storage tube means comprises a single storage tube having a charge storage target in the form of a planar slab, bearing, on each of its flat surfaces, an electrically conductive layer.

4. Apparatus according to any preceding claim wherein said means for operating on said electrical signals to produce said altered signals comprises means arranged to subject said electrical signals to a convolution process.

5. Apparatus according to any preceding claim including means arranged to receive

said output signals and said electrical signals and to perform a process of successive approximations thereon so as to improve the accuracy of said output signals.

5 6. Apparatus according to Claim 5 wherein said means for performing said process comprises means for:—

10 (a) constructing, from all the output signals derived from a linear region of said target means, an estimate of what the electrical signal relating to the path corresponding to said region ought to be,

(b) comparing said estimate with the

actual electrical signal relating to said path, and

(c) applying a correcting signal, related to any discrepancy between said estimated and actual electrical signals, to each of the output signals used in constructing said estimated signal.

7. Radiological apparatus substantially as herein described with reference to Figure 1 or to Figures 2, 3 and 4 of the accompanying drawings.

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