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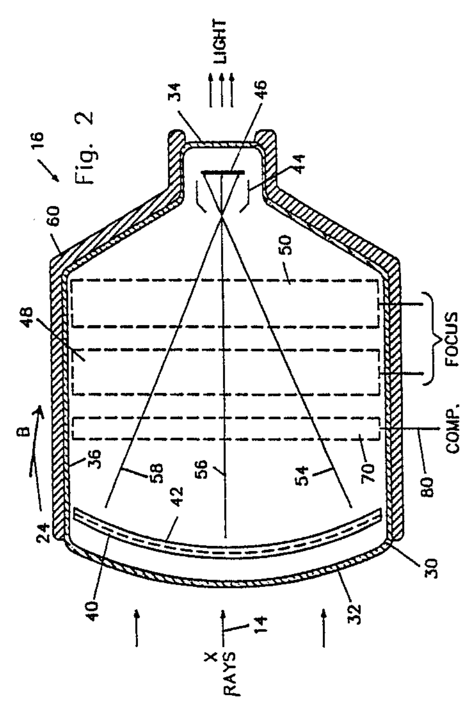
(54) Automatic compensation for image-intensifier tube distortion.

(57) A dynamic compensating system for an image intensifier tube employs a compensating element (80) in the vicinity of image intensifier tube for applying a compensating field to cancel the effect of the earth's magnetic field and, optionally, other perturbing magnetic influences. A source of compensating current is responsive to the cosine of the angle between the tube axis and the perturbing magnetic field vector for varying an amplitude of the compensating current. Means are provided for compensating local perturbation and sources of magnetic field having varying strengths and angles within the range of motion of the image intensifier.



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AUTOMATIC COMPENSATION FOR IMAGE-INTENSIFIER TUBE DISTORTION

BACKGROUND OF THE INVENTION

The present invention relates to imaging devices and, more particularly to techniques for eliminating image tube distortion arising from interaction of moving charged particles with extraneous magnetic fields.

Although the present invention has more general applicability, and should be so viewed, for concreteness, the following description is cast in the environment of a fluoroscopic X-ray imaging system employing an image intensifier.

An X-ray image intensifier employs a large photocathode responsive to impinging X radiation to emit a pattern of electrons which are accelerated toward a smaller anode upon which they impact at high velocity. The impacting electrons generate a corresponding pattern of light representing the output of the image intensifier.

Besides the brightness of gain resulting from the compression of the pattern of light and darkness from the large photocathode to the smaller anode, additional light output results from the energy gained through acceleration of the electrons in their flight from cathode to anode.

Because the electrons are changed particles, they are subject to electrostatic and magnetic fields. The presence of an electrostatic field between cathode and anode produces the desired energy gain. In addition, an electronic lens, built into the imaging tube, produces fields effective for focusing the electrons.

External magnetic fields are preferably excluded or compensated to prevent distortion of the output pattern. Sides of an imaging tube are conventionally shielded with a material of high magnetic permeability such as, for example, Mu metal. Shielding the cathode or anode ends of the imaging tube is infeasible since this interferes with the necessary X-ray input and light output. As a consequence, external magnetic fields in the environment of the equipment are capable of entering the image-intensifier tube and disturbing the desired paths of the electrons. As a result, the output image is distorted. The distortion is proportional to the magnetic field strength of the interfering magnetic field times the sine of the angle between the direction of the magnetic field and the path of the electrons.

In many installations, the principal interfering magnetic field is that of the earth. Although varying in deviation and dip from place to place on the earth's surface, at a particular place, the earth's magnetic field is constant in amplitude and direction. For a stationary image intensifier tube, it is possible to apply a compensating magnetic field having the required amplitude and direction to cancel the effect of the earth's magnetic field. One method may achieve partial or complete cancellation using one or more permanent magnets appropriately placed in the vicinity of the image intensifier tube. A more flexible technique employs a compensating element built into, or applied to, an image intensifier tube and receiving a control voltage capable of generating a compensating field in the tube effective for reducing or eliminating the effects of the earth's magnetic field on the paths of the electrons.

The above compensation techniques are effective for compensating magnetic field effects in a satisfactory image intensifier tube. Modern fluoroscopic systems permit the patient to remain stationary while rotating the X-ray source and image intensifier tube, as necessary, to achieve a desired view of the patient. As the source and tube are rotated, the angle between the earth's magnetic field and the paths of the electrons in the image intensifier tube is not stationary but may assume any arbitrary value. The static compensation techniques of the prior art not only do not work but, in fact, it is possible to achieve angular relationships between compensating field and electron travel wherein the compensating field may add to the distortion rather than reduce it.

A further problem arises from the possible presence of ferromagnetic objects in the vicinity of the fluoroscopic X-ray imaging system. Such ferromagnetic objects may distort the earth's magnetic field so that compensation for the earth's magnetic field, based on the assumption that its magnitude and direction are constant over all possible positions of the fluoroscopic X-ray imaging system, produces substantial error. In one foreseeable situation, more than one fluoroscopic X-ray imaging system may be independently positionable about a patient. Each of the systems may contain ferromagnetic material capable of distorting the magnetic field influencing the other system. Since they are independently positionable, the resulting influences depend on the positional relationships of each of the systems with respect to the earth's magnetic field, and with respect to each other.

Besides producing distortion of the earth's magnetic field from its presence, a second, independently positionable fluoroscopic X-ray imaging system may vary its magnetic influence depending on whether it is turned on or off. The same is true of other equipment in the vicinity of the imaging system, whether or not movable. For example, applying power to any nearby equipment having the ability to produce a magnetic field in the vicinity of the imaging system, may produce a resultant magnetic field varying significantly from that of the earth's magnetic field alone.

OBJECTS AND SUMMARY OF THE INVENTION

It is an object of the invention to provide compensation for magnetic distortion in image intensifier tubes which overcomes the drawbacks of the prior art.

It is a further object of invention to provide dynamic compensation for magnetic distortion in image intensifier tubes capable of accommodating changing relationships between the earth's magnetic field and electron paths.

It is a still further object of the invention to provide dynamic compensation for image intensifier tubes capable of accommodating changing positional relationships of external masses of ferromagnetic material.

It is a still further object of the invention to provide dynamic compensation for image intensifier tubes capable of accommodating changing magnitudes of external magnetic fields.

Briefly stated, the present invention provides a dynamic compensating system for an image intensifier tube employing a compensating element in vicinity of the image intensifier tube for applying a compensating field to cancel the effect of the earth's magnetic field and optionally other perturbing magnetic influences. A source of compensating current is responsive to the cosine of the angle between the tube axis and the perturbing magnetic field vector for varying an amplitude of the compensating current. Means are provided for compensating for local perturbations and sources of magnetic field having varying strengths and angles within the range of motion of the image intensifier.

According to an embodiment of the invention, there is provided apparatus for dynamic compensation of distortion in an image intensifier tube comprising: the tube including an input face and an output face, the input face and output face defining an axis of the tube, a compensating element in the tube, means for applying a compensating signal to the compensating element, and means for varying the compensating signal in relationship to an angle between a perturbing magnetic field and the axis.

The above, and other objects, features and advantages of the present invention will become apparent from the following description read in conjunction with the accompanying drawings, in which like reference numerals designate the same elements.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a highly schematic perspective view of an X-ray fluoroscopic imaging system to which the present invention is applicable.

Fig. 2 is a cross section of an image intensifier tube.

Fig. 3 is a simplified cross section of an image intensifier tube in which the directions of magnetic and velocity vectors are identified for supporting the description of the sources of image distortion.

Fig. 4 is a view of an output fluorescent screen of Figs. 2 and 3 in the absence of distortion.

Fig. 5 is a view corresponding to Fig. 4 showing distortion of a single bright line across the output fluorescent screen.

Fig. 6 is a block diagram of a compensation current generator according to an embodiment of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to Fig. 1, there is shown, generally at 10, a highly schematic representation of an X-ray fluoroscopic imaging system. An X-ray source 12 directs a beam of X rays represented by a tube center line 14 toward an image intensifier tube 16. A patient 18, or other object, may be supported by conventional means in a position intercepting the beam of X rays in its travel from X-ray source 12 to image intensifier tube 16. Any desired angular relationship may be obtained between center line 14 and patient 18 using conventional rotating support apparatus (not shown), as indicated by dashed circles 20 and 22.

An earth's magnetic field vector B 24, illustrated in conventional vector notation, has a magnitude varying slightly from place to place on the earth's surface. An angle between earth's magnetic field vector B 24 and a horizontal plane varies greatly over the earth's surface. Both magnitude and direction of earth's magnetic field vector B 24 are influenced by local perturbing objects such as, for example, a mass of ferromagnetic material 26 in the vicinity of X-ray fluoroscopic imaging system 10. Mass of ferromagnetic material 26 may be capable of distorting earth's magnetic field vector B 24 over a short range, whereby distortion of the output image varies with the distance between image intensifier tube 16 and mass of ferromagnetic material 26, with the angle between center line 14 and an axis 28 of mass of ferromagnetic material 26, and with the angle between earth's magnetic field vector B 24 and axis 28. In addition, mass of ferromagnetic material 26 may contain elements (not shown) varying in magnetic field depending on whether such elements are turned on or off.

Referring now to Fig. 2, image intensifier tube 16 includes an envelope 30 having an input face 32, an output face 34 and a wall 36 fully enclosing internal components. A scintillation layer 40 within input face 32 includes a phosphor effective for producing a pattern of light corresponding to a pattern of incident X rays. A photocathode layer 42, closely coupled to scintillation layer 40, produces a pattern of electrons corresponding to a pattern of light generated by scintillation layer 40. Photocathode layer 42 is conventionally maintained at a negative reference voltage such as, for example, a ground potential. A focus electrode 44 near output face 34 is maintained at a positive potential of, for example, about 30 kilovolts, for accelerating electrons liberated from photocathode layer 42 toward an output fluorescent screen 46.

One or more additional focus electrodes 48 and 50, together with external conventional control circuits, form an electronic lens for directing electrons emitted from photocathode layer 42 along controlled paths, indicated by paths 54, 56 and 58, whereby an output image is formed on output fluorescent screen 46 corresponding to the pattern of electrons emitted by photocathode layer 42. Such pattern of electrons being, in turn, related to the pattern of X rays impinging on scintillation layer 40, thus produces an output image on output fluorescent screen 46 representing a minified image of an attenuation pattern to which the X rays are exposed. The acceleration applied to the electrons by the accelerating field of focus electrode 44 increases their energy, whereby a greater number of photons of light are emitted by output fluorescent screen 46 than are generated by impingement of the X rays on scintillation layer 40. In this manner, the image is brightened or intensified. Output fluorescent screen 46 and output face 34 are transparent to permit viewing, or other use, of the intensified image external to image intensifier tube 16.

A magnetic shielding layer 60 is disposed on wall 36 to prevent distortion of the output image by earth's magnetic field vector B 24. It is not feasible to extend magnetic shielding layer 60 to cover input face 32 and output face 34 since this would interfere with the required entry of X rays and the exit of the output image. Thus, for some angular relationships between center line 14 and earth's magnetic field vector B 24, the paths of electrons travelling along paths 54, 56 and 58 may be perturbed by the entry of earth's magnetic field vector B 24 through the unshielded openings at input face 32 and 34.

Referring now to Figs. 3, a worst-case situation is shown in which earth's magnetic field vector B 24 is aligned with center line 14. In this orientation, earth's magnetic field vector B 24 has greatest access to unshielded input face 32 and output face 34. The amount by which an electron path is disturbed by earth's magnetic field vector B 24 is proportional to the magnitude of earth's magnetic field vector B 24 times the sine of the angle between them. The angle between earth's magnetic field vector B 24 and path 56 being zero, the disturbance of path 56 is also zero. An electron velocity vector 62 along path 54 or 58 makes an angle <u>a</u> with respect to the angle of earth's magnetic field vector B 24. As a consequence, paths 54 and 58 are perturbed by earth's magnetic field vector B 24, whereby an output image formed on output fluorescent screen 46 is distorted.

Referring now also to Figs. 4 and 5, assuming that the X-ray pattern consists of a single horizontal line in the absence of distortion, the output image also consists of a straight line 64. In the presence of the relationship shown in Fig. 3, central path 56 remains unperturbed since the angle between it and earth's magnetic field vector B 24 is zero. Paths 54 and 58 are at angles <u>a</u> and <u>-a</u> with respect to the angle of earth's magnetic field vector B 24 and thus the sine of these angle is not zero. As a consequence, straight line 64 is distorted in opposite directions on opposed sides of a center 68 into a S-shaped curve 66 as shown in Fig. 5. It will be noted that the shape of S-shaped curve 66 does not follow the above directive that portions of straight line 64 further from a center 68 should experience increasing distortion. The fields produced by focus electrode 48 and 50 (Fig. 3) near wall 36 tends to overcome the perturbation of electrons on paths terminating nearest the edges of output fluorescent screen 46.

From the foregoing description it should be clear that the influence of earth's magnetic field vector B 24 on the paths of electrons in image intensifier tube 16 depends on the angle between earth's magnetic field vector B 24 and center line 14. When these angles are at right angles to each other, image intensifier tube 16 is substantially completely shielded from earth's magnetic field vector B 24 by the intervening magnetic shielding layer 60 (Fig. 2). When these angles are equal, the influence of earth's magnetic field vector B 24 is at its maximum. For present purposes, it is sufficient to assume that the magnitude of the perturbing influence is proportional to the cosine of the angle between earth's magnetic field vector B 24 and center line 14.

A compensating coil 70 (Fig. 2) receives a compensating current having an amplitude effective for compensating for the influence of earth's magnetic field vector B 24 on paths 54 and 58 (as well as intermediate paths not illustrated) and thus for eliminating distortion in the output image. The compensating current has a maximum amplitude CC0 sufficient to compensate for the illustrated situation where the angle between earth's magnetic field vector B 24 and center line 14 is zero (the cosine of zero = 1)

At other angles, the compensating current is defined by:

$$CC = CC0\,(\cos \underline{a})$$

Where $\underline{a}$ = the angle between earth's magnetic field vector B 24 and center line 14 of image intensifier tube 16.

Although compensating coil 70 is illustrated within envelope 30, in alternative embodiments, compensating coil 70 may be disposed external to envelope 30 in the vicinity of input face 32.

Referring now to Fig. 6, a compensation current generator 72 includes a conventional angle-measurement device 74 for measuring an angle $\underline{a}$ described by center line 14 (Fig. 2) with respect to any suitable coordinate system. The measured angle $\underline{a}$ is applied to an earth compensator 76 which also receives information about the amplitude and angle of earth's magnetic field vector B 24. Earth compensator 76 generates a signal proportional to the cosine of the angle between earth's magnetic field vector B 24 and center line 14 for application to an adder 78. If only the influence of earth's magnetic field vector B 24 is being compensated, the output of earth compensator 76 may bypass adder 78 and be applied on a line 79 directly to compensating coil 70.

Compensation current generator 72 also contains a compensator 80 to compensate for one or more other perturbing magnetic fields which may have different amplitudes and directions than earth's magnetic field vector B 24 such as, for example, the influence of perturbing magnetic field O 82 (Fig. 1) acting along axis 28. Unlike earth's magnetic field vector B 24, other magnetic field O 82 may vary in both amplitude and angle from place to place within the range of movement of image intensifier tube 16. In addition, the magnitude, angle or even the existence, of perturbing magnetic field O 82 may depend on external factors such as, for example, whether external equipment is turned on, or the mode of operation of such external equipment. Thus, additional parameters of perturbing magnetic field O 82 may be required for application to compensator 80 on a line 84. The source of such additional data may be empirical from continuing measurement, or one-time measurement yielding stored results which are then called upon for providing required values as needed. In some cases, the functions of earth compensator 76 and compensator 80 may be performed from stored values given a measured value of angle $\underline{a}$. The stored value may be in the form of one or more equations whose value is determined from an existing value of angle $\underline{a}$. Alternatively, a lookup table (not shown) of values of compensating current for application on line 79 may be related to values of $\underline{a}$. Upon measurement of a value of $\underline{a}$, access is made to the lookup table to determine the corresponding value of the compensating current.

Either equations or lookup table may accommodate variations in perturbing magnetic field O 82, either due to short-range effects or to differences between an external equipment being on or off. The constants and variables in the equations or the values in the lookup table relating to perturbing magnetic field O 82 may be measured one time and stored for continuous subsequent use.

Having described preferred embodiments of the invention with reference to the accompanying drawings, it is to be understood that the invention is not limited to those precise embodiments, and that various changes and modifications may be effected therein by one skilled in the art without departing from the scope or spirit or the invention as defined in the appended claims.

Claims

1. Apparatus for dynamic compensation of distortion in an image intensifier tube comprising:

said tube including an input face and an output face;

said input face and said output face defining an axis of said tube;

a compensating element in said tube;

means for applying a compensating signal to said compensating element; and

means for varying said compensating signal in relationship to an angle between a perturbing magnetic field and said axis.

2. Apparatus according to claim 1 wherein said relationship includes a cosine of said angle.

3. Apparatus according to claim 1 wherein said perturbing magnetic field includes a magnetic field of the earth.

4. Apparatus according to claim 3 wherein said perturbing magnetic field includes at least one additional magnetic field, said at least one additional magnetic field having a variability in at least one of a magnitude and an angle over a range of positions of said image intensifier tube.

5. Apparatus according to claim 4 wherein said means for applying and said means for varying include a set of equations relating an angle of said axis to said compensating signal.

6. Apparatus according to claim 4 wherein said means for applying and said means for varying include a lookup table relating an angle of said axis to said compensating signal.

7. Apparatus according to claim 3 wherein said means for applying and said means for varying include a set of equations relating an angle of said axis to said compensating signal.

8. Apparatus according to claim 3 wherein said means for applying and said means for varying include a lookup table relating an angle of said axis to said compensating signal.

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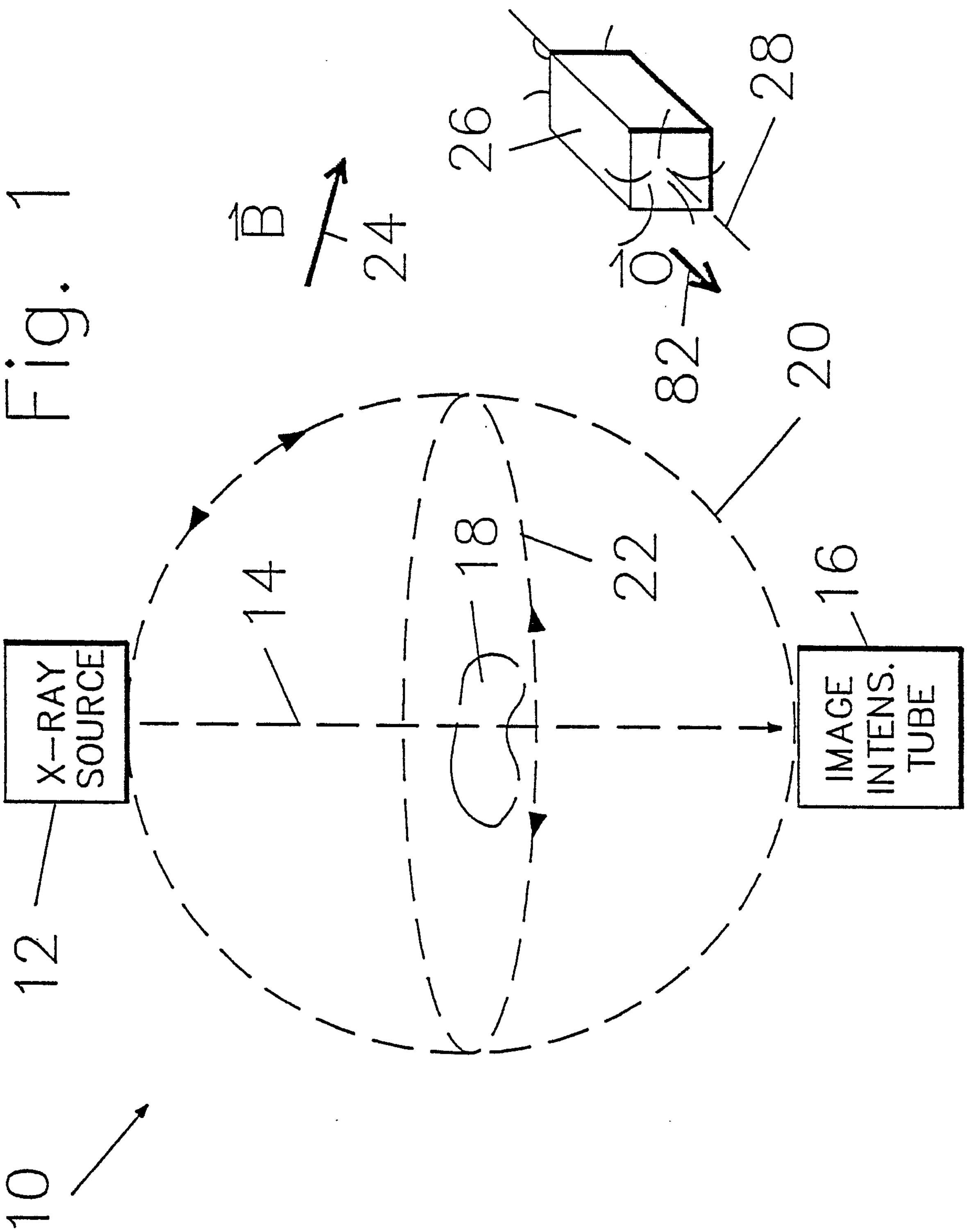

Fig. 1

15XZ-2861

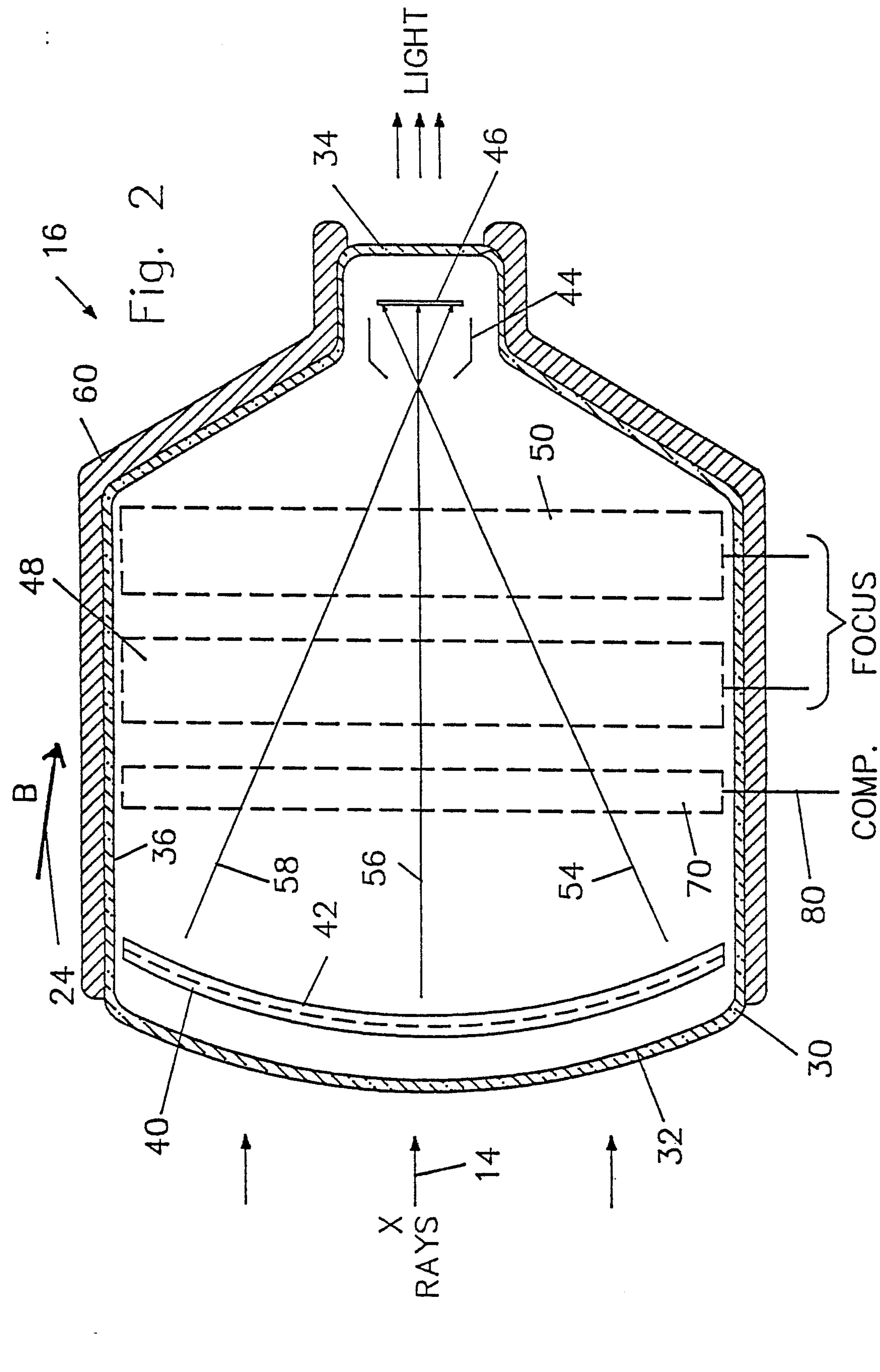

Fig. 2

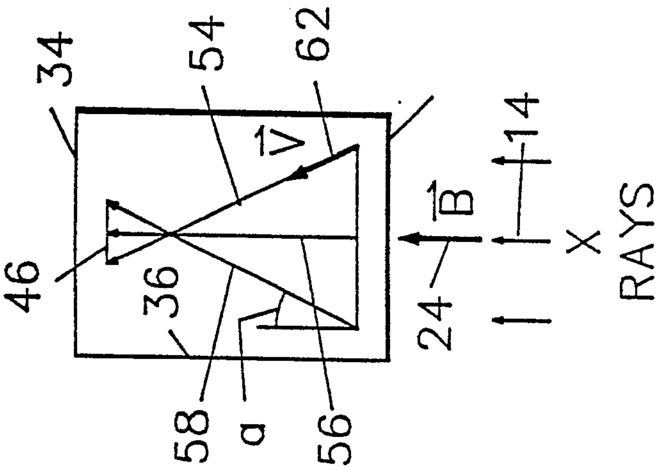

Fig. 3

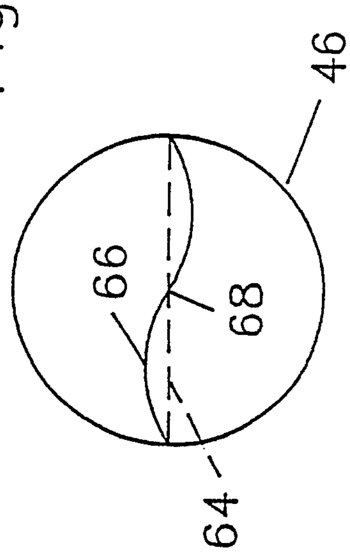

Fig. 5

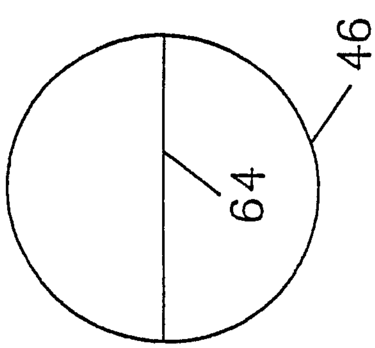

Fig. 4

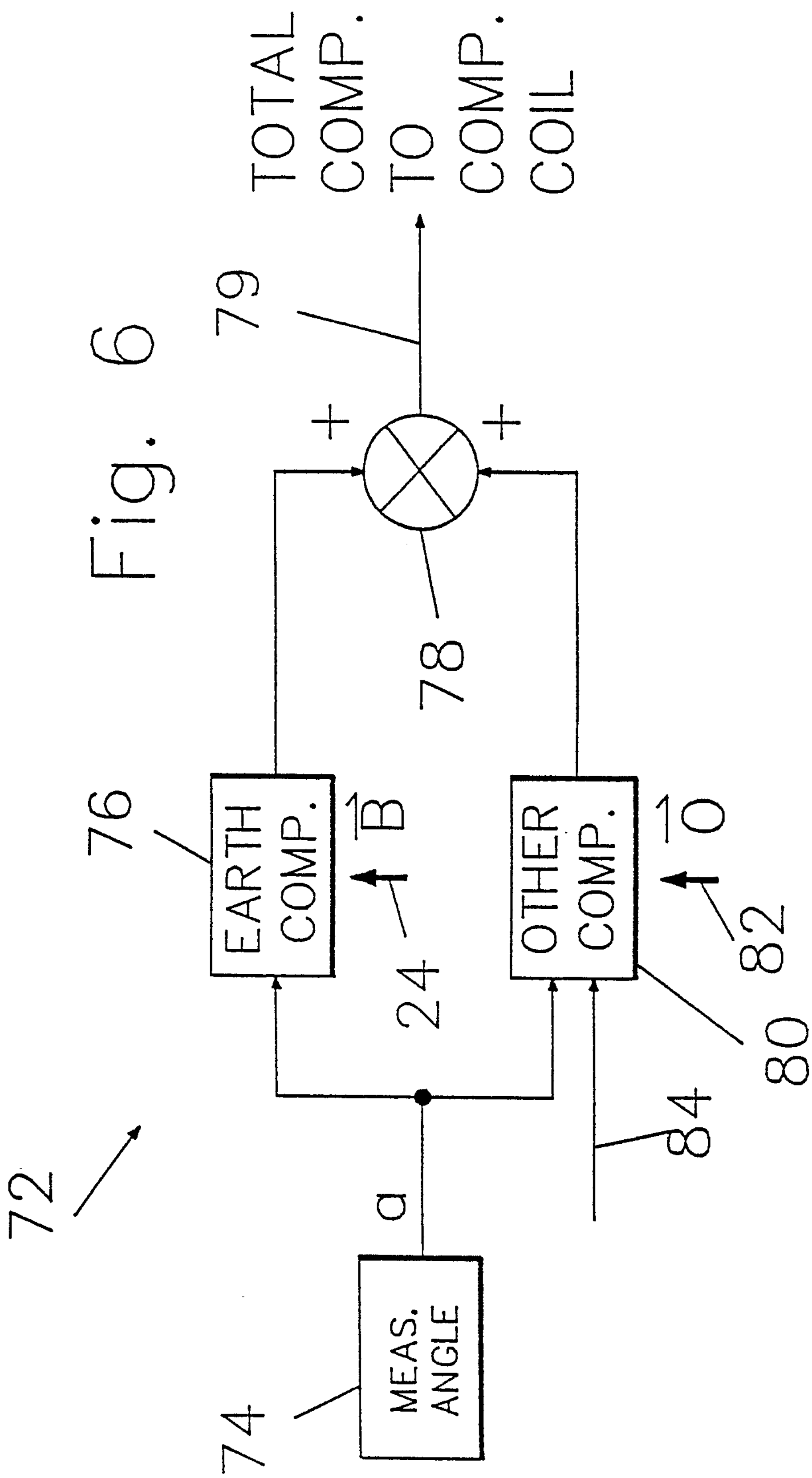
TOTAL COMP. TO COMP. COIL
79
+
+
78
76
EARTH COMP.
B
24
OTHER COMP.
O
82
80
84
a
72
MEAS. ANGLE
74

Fig. 6

European Patent Office

EUROPEAN SEARCH REPORT

Application number

EP 87114051.3

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
A	US - A - 4 523 091 (PERSYK) * Totality * --	1	H 01 J 29/00 G 12 B 17/02 H 01 J 31/50
A	GB - A - 1 574 226 (HITACHI) * Fig. 1,2; claims * --	1	
A	DE - A1 - 2 811 373 (PHILIPS) * Fig.; page 5, line 19 - page 6, line 12; claims 1-7 * --	1	
A	PATENT ABSTRACTS OF JAPAN, E section, vol. 4, no. 157, November 4, 1980 THE PATENT OFFICE JAPANESE GOVERNMENT page 128 E 32 * Kokai-no. 55-108 147 (TOKYO SHIBAURA DENKI) * ----	1	**TECHNICAL FIELDS SEARCHED (Int. Cl.4)** H 01 J 29/00 H 01 J 31/00 G 12 B 17/00 H 05 K 9/00

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
VIENNA	23-12-1987	BRUNNER

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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