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(54) METHOD AND APPARATUS FOR THE EXAMINATION OF AN OBJECT WITHIN AN OPTICALLY OPAQUE BODY

(71) I, PALLE RASMUS JENSEN, a Danish Subject, of Forhabningsholms Alle 30, 1904 Copenhagen V, Denmark, 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 relates to a method and apparatus for the examination of an object within an optically opaque body.

The invention relates in particular to an ultrasonic scanning technique base on an impulse-echo principle. This technique is generally performed in one of two possible manners.

The first is the use of so called B-scanning, which normally involves the scanning of a sectional plane through the object and the recording of the positions of reflecting structures in the section plane. The result is that after a few minutes of scanning it is possible to draw up a two-dimensional picture on a storage-oscilloscope, showing the intersections of the reflecting structures with the sectional plane.

The second is the use of so called dynamic scanning, which involves a rapid scanning of a limited area permitting utilization of the short time memory of the eye for the formation of a picture.

B-scanning by way of a storage-oscilloscope represents the most widely used procedure, but it is not particularly acceptable, as it takes a long time to draw up a satisfactory picture. It is accordingly necessary to form the entire picture before it is possible to see whether it is satisfactory, and then to erase it entirely to adjust the amplifications etc. before the next picture is registered. In the meantime, however, the conditions to be examined may have changed.

This may for instance be the case, if we are dealing with a foetus which is moving. If we examine parts of the human body we have moreover no clear impression of the relation of the sectional picture to the body, as picture and body are normally placed remote from each other. Dynamic scanning is a more recent method, which in certain aspects offers improvements in comparison with the B-scanning. Due to rapid, automatically repeated scanning it is easier to make adjustments to obtain a better picture, as it is possible to detect alterations instantly. Further, the problem of alteration of the conditions of the object being examined is eliminated, as it is possible to ascertain such alterations directly during the scanning.

In spite of these improvements in the manner of producing the scanning pictures, two problems still remain unsolved:

1. Only a picture of the section of the body being examined is obtained which renders difficult the formation of a picture of the entire spatial form and extent of a given structure.
2. No direct information of the position of the examined body is obtained. Alterations of the scanning angle and position bring about a change of the picture, but due to the appearance of the picture on a stationary screen, no information of the position of a depicted structure is obtained.

It is an object of the present invention to obviate or mitigate these two disadvantages, and the method is characterized in that by means of an arrangement of one or more mirrors information is shown as imaginary luminous points placed preferably in exactly the position in an object, where a reflecting structure is found.

In this way the latter drawback has been overcome. The said method can be realized in many different ways by means of one or several mirrors, and it has proved possible by way of several of the possible embodi-

ments to overcome also the former drawback.

The invention relates also to an apparatus for the performance of the method, said apparatus being provided with an ultrasonic or radar transmitter to emit impulses along a first line and to receive the reflected echos along the same line, and to indicate the reflections as luminous points along a second line. The apparatus is characterized by having between the two lines, reflecting media for the formation of the imaginary picture. By use of such media it is possible in a simple manner to form the desired picture, although the picture may also be formed for instance by way of optical and electronic devices.

According to the present invention there is provided a method for facilitating the examination of an object within an optically opaque body through the use of an impulse-echo technique that includes transmitting a sequence of energy impulses into the body along a line from a source, receiving echoes from the object located within the body along said line in response to each impulse, and displaying the received echoes as luminous points in a linear array the spacing of each luminous point from one end of the array being proportional to the distance from said source of the corresponding echo-producing point on the object, wherein the improvement comprises:

locating a reflecting surface at a reference plane between an observation point and the body such that the reflecting surface faces the observation point and intersects a line between the observation point and the object in the body;

positioning the source at a predetermined location with respect to the reference plane;

operatively coupling the linear array to the source in a predetermined relation thereto for movement, relative to the reference plane, in synchronism with movement of the source, relative to said body; and

providing a reflective path from the linear array to the observation point via the reflective surface such that a virtual image of each luminous point of the array is provided by the reflective surface at an apparent location, relative to the observation point, that is coincident with the actual location of the corresponding echo-producing point on the object in the body.

Further, according to the present invention there is provided apparatus for facilitating the examination of an object within an optically opaque body, the apparatus including means for repetitively transmitting impulses of energy along a first line directed toward the object in the body and receiving echoes along the first line from the object and means for displaying said echoes as a linear array of luminous points, the points being spaced on a second line at a distance from one end of the array proportional to the distance of the corresponding echo-producing points from the transmitter, wherein the improvement comprises:

a flat mirror;

means for positioning the mirror to face a predetermined observation point and to intersect a line between the observation point and the object to be examined, the mirror defining a reference plane;

means for operatively coupling the transmitter/receiver combination to the mirror at a predetermined location relative thereto;

means for operatively coupling the linear array to the mirror at a predetermined location relative thereto; and

a reflective path between the linear array of luminous points and the observation point via said mirror for projecting a virtual image of the linear array to the observation point, such that the apparent location of each luminous point of said reflected virtual image coincides with the actual location, relative to the observation point, of the corresponding echo-producing point of the object in the body.

Embodiments of the present invention will now be described by way of example with reference to the accompanying drawings in which:—

Fig. 1 is an elevational view of one embodiment of apparatus according to the present invention;

Fig. 2 is an end view of a second embodiment of apparatus according to the invention;

Fig. 3 is an end view of a third embodiment;

Fig. 4 is a detail view of the mirror of a fourth embodiment;

Fig. 5 is a detail view of the mirror of a fifth embodiment;

Fig. 6 is a detail view of the mirrors of a sixth embodiment;

Fig. 7 is a detail view of the mirrors of a seventh embodiment;

Fig. 8 is a detail view of the mirrors of an eighth embodiment;

Fig. 9 is an end view of the embodiment shown in Fig. 8; and

Fig. 10 is a detail view of mirrors of a ninth embodiment.

Referring to the drawings, Fig. 1 shows a human body 1, viewed from one side, having an inner organ, which is to be examined by means of ultrasonics. A support 3 supports a stereo camera 4, which may be a film camera or a television camera, and a connecting rod 5 mounted longitudinally and movable in a clamp 6 of the support 3. On the connecting rod 5 is mounted a mirror 7, the reflecting surface of which is turned upwards as seen in Fig. 1. At

the end of the rod 5 a pivotally mounted holder 8 for a number of lamps or so called light-emitting diodes 9 is mounted. The holder 8 is designed to swing in a plane perpendicular to the plane of the mirror 7, and which may pass through the connecting rod 5. On the opposite side of the plane of the mirror 7 there is suspended in a similar manner a pivotable ultrasonic transmitter and receiver 10 for the transmission and reception of ultrasonic pulses along a line 11, lying symetrically with the row of lamps 9 about the plane of the mirror 7. The transmitter 10 and the holder 8 are each mounted on intermeshing gears or toothed rims 12 and 13. The transmitter 10 and the row of lamps 9 are moreover connected mutually by means of known electronic means (not shown) in such a manner that the number of echoes along the line 11 is reproduced along the row of lamps 9. Thus a non-inverted mirror-image of the positions of the echo-producing points will be seen by the camera 4. A support 14 pivotable about an axis perpendicular to the plane of the mirror 7 is located on the end of the rod 5 remote from the clamp 6.

The apparatus operates in the following way: When the rod 5 with the mounted parts is moved forwards and backwards or sideways, there will be formed in the mirror 7, seen from the stationary position of the camera 4, reflections from the inner organ 2 precisely from points which are echo-producing. This will also be the case, if the scanning takes place by way of swinging of the holder 8 and the transmitter 10 towards each other or apart from each other and also about the support 14. By reproducing all the echoes during a three-dimensional scanning on, for instance, the same photographic plate of a stereo-camera, that is leaving the shutter of the camera open during the entire scanning process, it will be possible to produce a three-dimensional picture of the echo-producing structures in the inner organ. The only condition is that the inner organ 2 and the camera 4 remain in a mutually fixed position during scanning.

Instead of a photographic camera a television camera may advantageously be used with a pictorial memory and a viewer. In this way it is possible during the scanning process to guide the camera in such a manner that the desired pictures are produced. It is moreover possible at any time to erase the received signals and start afresh.

Another method of determining where and how the pictures are to be taken is to study the picture with the human eye simultaneously with the rapid scanning movements.

Fig. 2 shows schematically another embodiment of an apparatus according to the invention. A holder 14 for a number of lamps 15 is coupled pivotally to a mirror 16 and to an ultrasonic transmitter and receiver 17, which is mounted on a segment shaped plate 18. A motor (not shown) is provided to cause the plate 18 with the transmitter 17 to oscillate as shown by the arrows A and B, the mirror 16 simultaneously being subjected to a similar movement as shown by the arrows C and D, but with an angular deflection half as great. In this manner scanning of a body 19 can be performed within the angle determined by the movement of the transmitter 17. The latter embodiment is distinguished by a simple construction, as it is possible to hold the apparatus manually in the holder 14, while the remaining parts are moving. The lamps 15 are thus stationary, while in the mirror is reflected a correctly situated picture provided the oscillating movement is of a frequency equal to at least 16 oscillations per second.

This apparatus shown in Fig. 3 is constructed to perform a synchronously oscillating movement of a holder 20 for a row of lamps 21 and a transmitter 22, as shown by the arrows E and F, G and H, I and J, a mirror 23 being fixed relative to the moving parts. The synchronous movement is produced by mounting the holder 20 and the transmitter 22 on a respective one of a pair of intermeshing toothed segments 24 and 25. By this construction the centre of rotation 26 comes close to the contact point 27 required for ultrasonic examination of a deformable body 28, for instance, the body of an animal. Thus good contact is achieved. The holder 20 with the lamps 21 lighting at different times will produce a laterally reversed picture when viewed directly. If on the other hand the picture is seen in the mirror the result will be a non-inverted correctly orientated picture.

Fig. 4 shows a transducer 40 bearing against a body 41 containing an echo-producing structure 42. The first line 43 along which the impulses are emitted is colinear with the second line 44, along which are placed indicator lamps 45. Perpendicular to the said lines 43, 44 is placed a mirror 46 with an upward-turned reflecting face. The indicator lamps are now mutually situated in such a manner that an echo from a given point will produce an imaginary luminous spot at that place, when seen in the mirror as indicated by the shown sight lines.

Fig. 5 shows a transducer 50 bearing against a body 51 containing an echo-producing structure 52. The first line 53, along which the impulses are emitted crosses the second line 54, along which the indicator lamps 55 are placed. A mirror 56 is placed

in the plane of symmetry to the two lines. The distance from the mirror 56 is moreover fixed at a certain distance from a firm point 59. If this distance is small the examined part of the body 51 will be covered by the mirror most of the time.

Fig. 6 shows schematically a transducer 60 bearing against a body 61 containing an echo-producing structure 62. The first line 63, along which the impulses are emitted, forms an angle $v + \frac{1}{2} v = 1\frac{1}{2} v$ to a plane mirror 66 with a downward-turned reflecting face. The second line 64, along which the indicator lamps 65 are placed, is situated in a plane perpendicular on the plane of the mirror 66 containing the first line 63. The second line 64 forms at the same time, an angle $\frac{1}{2} v$ to the plane of the said mirror. Another mirror 67 having an upward-turned reflecting face contains the second line 64. By adapting the indicator lamps in a suitable way it is now possible to attain a radiation pattern as shown, which gives a highly compact construction.

Fig. 7 shows a transducer 70 bearing against a body 71 containing an echo-producing structure 72. The first line 73, along which the impulses are emitted, is colinear with the second line, along which the indicator lamps 75 are situated. Perpendicular to the line 73 are placed mirrors 76 and 77 with their reflecting surfaces facing each other.

By adapting the indicator lamps and the mirrors in a suitable way it is possible to attain a radiation pattern as shown, and a compact construction will be the result.

Figs. 8 and 9 should be considered together. An ultrasonic transducer 80 is designed to tip up and down or swing forwards and backwards about an axis 0_1, and an angle v_1, which the longitudinal axis of the transducer 80 forms the longitudinal axis L of the apparatus, will then vary between ± 30 degrees. A mainly triangular first mirror 81 as shown in Fig. 8, and shown as a line in Fig. 9, is made to tip forwards and backwards about an axis 0_2 with the transducer 80, the following requirements, however, being complied with. The axis 0_2 is parallel to the axis 0_1, and the angle v_2, which the mirror 81 forms with a plane perpendicular to the longitudinal axis L must at any time be half as great as the angle v_1. A second mirror 82 situated perpendicular to the longitudinal axis L is situated below the first mirror 81 between the axis 0_1 and 0_2. Finally indicator lamps 83 are situated on the longittudinal axis L in a suitable manner, the following requirements being complied with. The distance L_1 between the axis 0_1 and that end surface of the transducer 80, which is remote from the mirror 82, is equal to the distance L_2 between the axis 0_2 and the indicator lamp corresponding to said end surface of the transducer. Thereafter the other parameters are adjusted to each other in such a manner that the echo-producing structure is depicted as a luminous spot in the form of an imaginary picture of the corresponding light indicator in a point, where the structure is placed. By having the mirror and the transducer swing at a frequency equal to at least 16 oscillations per second it will be possible by looking down into the mirror to have a stationary picture of a section of the body under examination. This embodiment can likewise with advantage be applied in connection with a stationary stereo-camera, as previously described in relation to other embodiment.

Fig. 10 shows an apparatus consisting of a rotatable transducer 100 bearing against a body 106 containing an echo-producing structure 107. The first line 105, along which the impulses are emitted, moves with the transducer 100 about a first axis 0_3. An indicator row 103 is designed to rotate about a second axis 0_4 running parallel to the first axis 0_3, and in relation to the former is situated symmetrically about a first mirror 101 with an upwards turning reflecting face. A second mirror 102 with a downward-turned reflecting face is situated on the second axis 0_4 in such a manner that a mirror image 104 of the indicator row 103 at any time will be situated so that it is symmetrical with regard to the first line 105 about the mirror 101, as it appears from the shown radiation pattern. The second mirror 102 can be stationary relative to the first mirror 101, but it may also be adjustable in relation to the latter. It should be noted, however, that an embodiment could be practicable with both a rotatable indicator row and a rotatable mirror, with the movements of these mechanical elements coupled together in a suitable manner. For instance an indicator row may perform a sinusoidal movement coupled with a mirror made to oscillate in such a manner that the angular velocity of the reflected picture will be numerically constant.

In a modification the reflected images are recorded by a liquid crystal display capable of retaining an image for at least one period of movement of the means to indicate echoes as luminous points.

In a further modification the reflected images are recorded by a stationary television camera coupled with a storage oscilloscope in such a manner that pictorial information can be summed up.

In yet another modification, the apparatus includes a programme unit to control the means for swinging the first line, i.e. the line along which impulses of energy are repetetively transmitted towards the object in the body and echoes are received from

the body, in order to procure an even scaning pattern.

In yet a further modification, the first line is periodically swung at a first frequency and the second line, i.e. the linear array of luminous points is periodically swung at a second frequency which is higher than the first frequency, the second frequency being sufficiently high to retain the impression of all positions of the luminous points of the virtual images reflected to the observation is periodically swung at a first frequency point on the retina of the human eye.

An over-all general embodiment applicable in connection with all other embodiments of the apparatus consisting in a suppor of transmitter-receiver and minor arrangement, is characterised in that the suppor is mounted on a connecting rod mounted longitudinally displaceable in a stationary cardan suspension.

WHAT WE CLAIM IS:—

1. A method for facilitating the examination of an object within an optically opaque body through the use of an impulse-echo technique that includes transmitting a sequence of energy impulses into the body along a line from a source, receiving echoes from the object located within the body along said line in response to each impulse, and displaying the received echoes as luminous points in a linear array, the spacing of each luminous point from one end of the array being proportional to the distance from said source of the corresponding echo-producing point on the object, wherein the improvement comprises:

locating a reflecting surface at a reference plane between an observation point and the body such that the reflecting surface faces the observation point and intersects a line between the observation point and the object in the body.

positioning the source at a predetermined location with respect to the reference plane;

operatively coupling the linear array to the source in a predetermined relation thereto for movement, relative to the reference plane, in synchronism with movement of the source, relative to said body; and

providing a reflective path from the linear array to the observation point via the reflective surface such that a virtual image of each luminous point of the array is provided by the reflective surface at an apparent location, relative to the observation point, that is coincident with the actual location of the corresponding echo-producing point on the object in the body.

2. A method as claimed in claim 1 comprising positioning the source on the side of the reference plane opposite the side having the reflecting surface.

3. A method as claimed in either preceding claim comprising positioning the source at a location offset from the line between the observation point and the object in the body so that the line of transmitted impulses from the source to the object intersects the line between the observation point and the object at an angle.

4. A method as claimed in any preceding claim comprising swinging the source of energy impulse transmission to scan a cross-sectional plane of the object in the body, whereby the positions of the illuminated points of the reflected virtual image of the operatively coupled linear array corresponding to each echo-producing point in the scanned plane provide an image accurately representing the cross-sectional shape of the object in said plane.

5. A method as claimed in any preceding claim comprising moving the line of energy impulse transmission in a direction transverse to the plane of said swinging for scanning a multiplicity of adjacent cross-sectional planes through the object, whereby successive virtual images of the linear array projected from said reflective surface describe an acurate three-dimensional representation of the object.

6. A method as claimed in any preceding claim comprising moving the line of transmitted impulses from said source to scan a cross-sectional plane of the object in the body and recording at the observation point, the position of the illuminated points of the reflected virtual image of the operatively coupled linear array corresponding to each echo-producing point in the scanned plane, thereby providing a recorded image accurately representing the cross-sectional shape of the object in said plane.

7. A method as claimed in any preceding claim comprising moving the line of transmitted impulses from said source to scan at least a portion of the volume of the object in the body and stereo-optically recording, at the observation point, the position of the illuminated points of the reflected virtual image of the operatively coupled linear array corresponding to each echo-producing point in the scanned volume, thereby providing a recorded stereo-optic image accurately representing the three-dimensional shape of the object in said volume.

8. Apparatus for facilitating the examination of an object within an optically opaque body, the apparatus including means for repetitively transmitting impulses of energy along a first line directed toward the object in the body and receiving echoes along the first line from the object and means for displaying said echoes as a linear array of luminous points, the points being spaced on a second line at a distance from one end of the array proportional to the distance of the corresponding echo-producing points

from the transmitter, wherein the improvement comprises:

a flat mirror;

means for positioning the mirror to face a predetermined observation point and to intersect a line between the observation point and the object to be examined, the mirror defining a reference plane;

means for operatively coupling the transmitter/receiver combination to the mirror at a predetermined location relative thereto;

means for operatively coupling the linear array to the mirror at a predetermined location relative thereto; and

a reflective path between the linear array of luminous points and the observation point via said mirror for projecting a virtual image of the linear array to the observation point, such that the apparent location of each luminous point of said reflected virtual image coincides with the actual location, relative to the observation point, of the corresponding echo-producing point of the object in the body.

9. Apparatus as claimed in claim 8 comprising:

means for periodically swinging said first line in a plane with respect to the body for scanning a predetermined sector within the body and

means for periodically swinging said linear array of luminous points synchronously with the movement of said first line so that such luminous points of the reflected virtual image, as viewed from the observation point, always coincides with the actual location of the corresponding echo-producing point in the body.

10. Apparatus as claimed in either claim 8 or claim 9 comprising means positioned at said observation point for recording the reflected images of said linear array of luminous points.

11. Apparatus as claimed in claim 10 wherein said means to record the reflected images comprises a liquid crystal display capable of retaining an image for at least one period of movement of said means to indicate echoes as luminous points.

12. Apparatus as claimed in claim 10 wherein said means for recording the reflected images comprise a camera for filming three-dimensional pictures by way of stereo techniques.

13. Apparatus claimed in claim 10 wherein said means for recording the reflected images comprises a stationary television camera coupled together with a storage oscilloscope in such a manner that pictorial information can be summed up.

14. Apparatus as claimed in claim 13 wherein said camera is adapted for filming of three-dimensional pictures by way of stereo-techniques.

15. Apparatus as claimed in claim 9, or claim 9 and any one of claims 10 to 13, comprising a programmed unit to control said means for swinging said first line in order to procure an even scanning pattern.

16. Apparatus as claimed in claim 9, or claim 9 and any one of claims 10 to 14, wherein said means for swinging said first line and said means for synchronously swinging said linear array of luminous points provide a swinging rate sufficiently high to retain the impression of all the positions of the luminous points for one complete swing on the retina of a human eye location at the observation point; and the impulse repetition frequency is considerably higher than the swinging frequency, whereby there will be a multiplicity of impulses transmitted and sets of echoes received for each complete swing.

17. Apparatus according to claim 16 wherein:

the means for transmitting impulses and receiving echoes along a first line comprises an ultrasonic transducer mounted to pivot about a first axis spaced a predetermined distance from the reference plane on the side opposite said mirror, and including an additional mirror facing the first-mentioned mirror and mounted to pivot about a second axis parallel to the first axis and spaced an equal distance from the reference plane on the same side as said first-mentioned mirror;

means for mounting said means for displaying the echoes as a linear array of luminous points to pivot about said second axis; and

means operatively coupling said display means and said additional mirror so that reflections of the luminous points in the additional mirror present a virtual image symmetrically to the corresponding echo-producing points along the first line with respect to the reference plane.

18. Apparatus as claimed in claim 8 comprising:

means for periodically swinging said first line at a first frequency;

means to store information corresponding to the positions of the echoes;

means for periodically swinging said linear array of luminous points at a second frequency, higher than the first frequency, the second frequency being sufficiently high to retain the impression of all positions of the luminous points of the virtual images reflected to the observation point on the retina of a human eye.

19. Apparatus as claimed in any one of claims 8 to 18 wherein said transmitter/receiver combination and said linear array of luminous points are mounted on a longitudinally displaceable rod mounted in a fixed cardan suspension.

20. Apparatus as claimed in claim 8

wherein said means for transmitting impulses and receiving echoes comprises an ultrasonic transducer, said transducer being mounted for pivotal movement about a first axis;

said means for displaying echoes as a linear array of luminous points along a second line being mounted for pivotal movement about a second axis parallel to said first axis;

the reference plane of said mirror is located equidistant between said first and second axes; and including

means for pivotally moving said transducer about said first axis; and

means for pivotally moving said means for displaying echoes about said second axis in synchronism with the movement of said transducer.

21. Apparatus as claimed in claim 8 wherein said means for transmitting impulses and receiving echoes comprises an ultrasonic transducer, said transducer being mounted to pivot about a first axis; and

an additional mirror is mounted to pivot about a second axis parallel to the first axis;

the apparatus has a longitudinal center line extending perpendicularly between said first and second axes, said means for displaying echoes as a linear array of luminous points being mounted coincident with said center line, the distance from said first axis to the end of the transducer being equal to the distance from the second axis to the luminous point corresponding to said end of the transducer; and including

means to pivotally move said transducer and said additional mirror so that the angle of rotation of said additional mirror is half the angle of rotation of said transducer;

said first-mentioned mirror being mounted in a plane equidistant from said first and second axes; and

said means to display echoes as luminous points producing luminous points a distance apart equal to the distance between the structures producing the echoes.

22. A method as claimed in claim 1 substantially as hereinbefore described with reference to the accompanying drawings.

23. Apparatus as claimed in claim 8, substantially as hereinbefore described with reference to the accompanying drawings.

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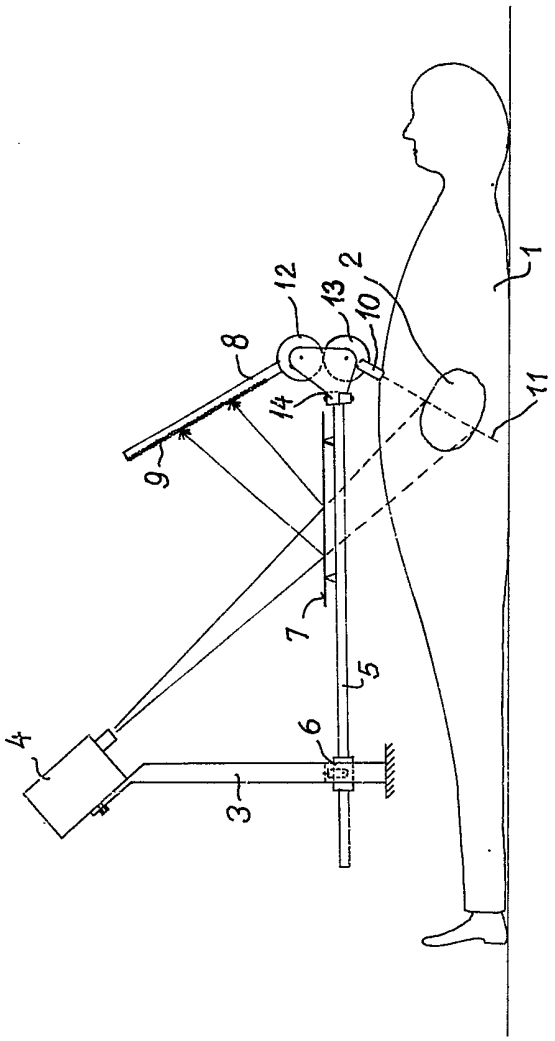


Fig. 1

Fig. 2

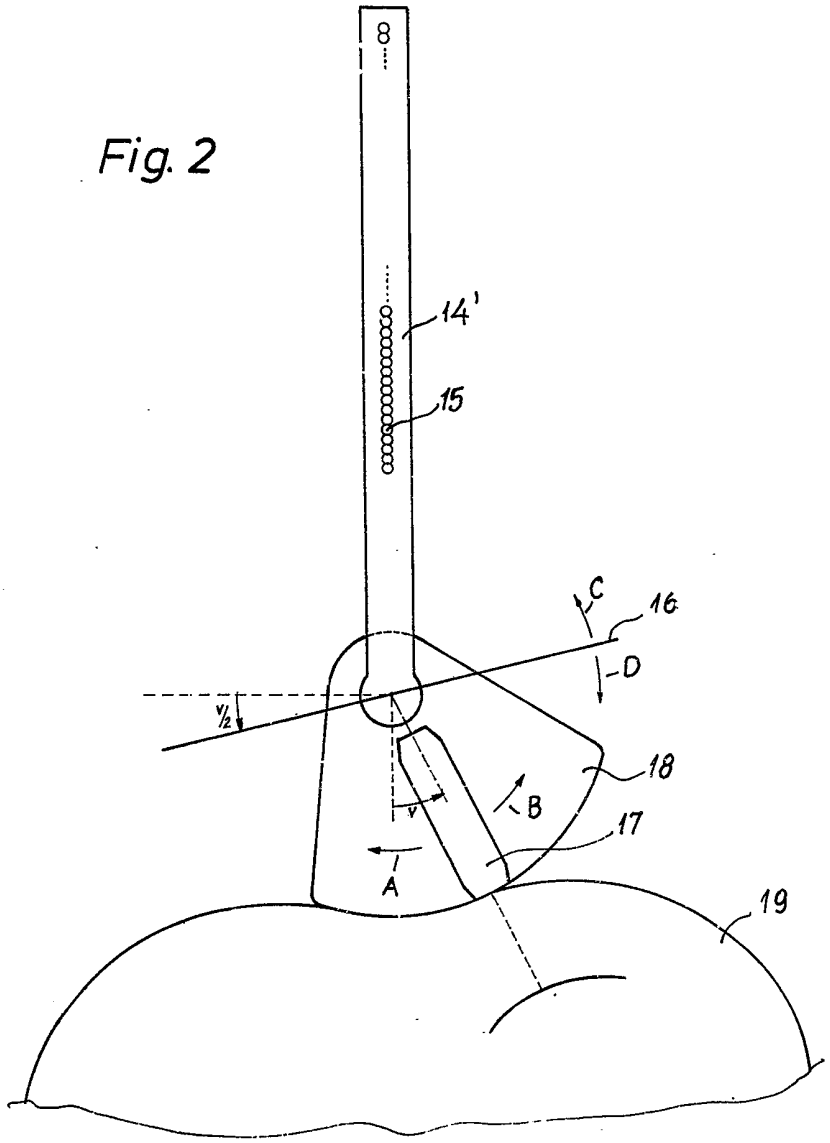


Fig. 3

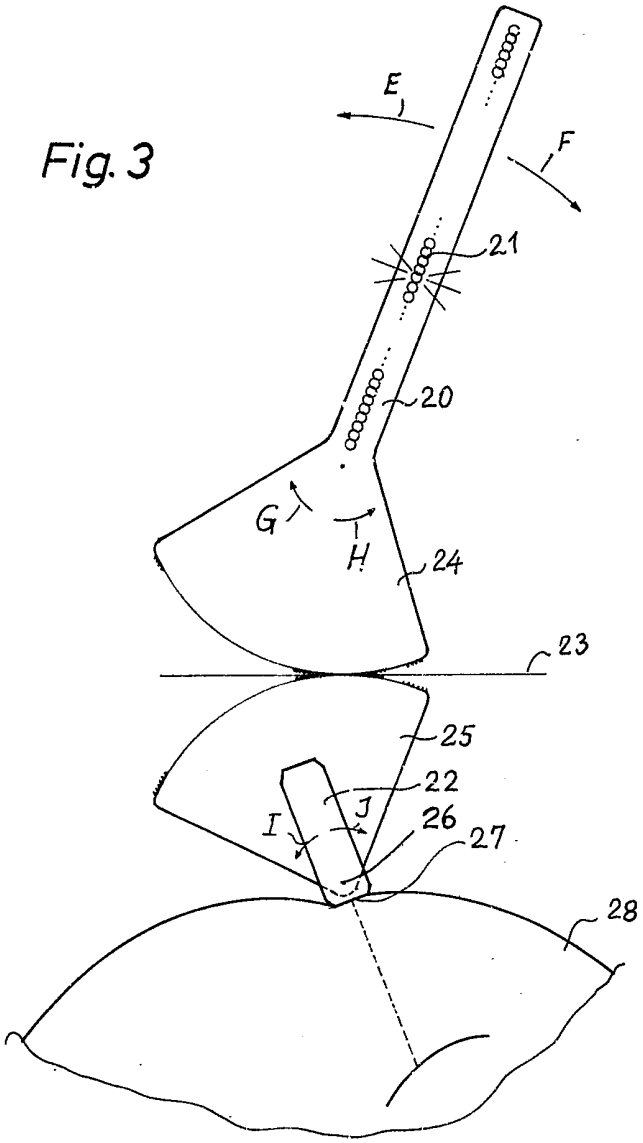


Fig. 4

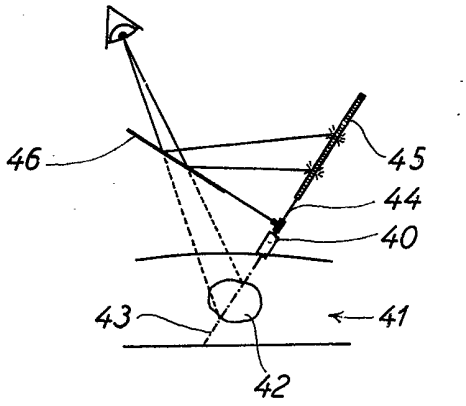


Fig. 5

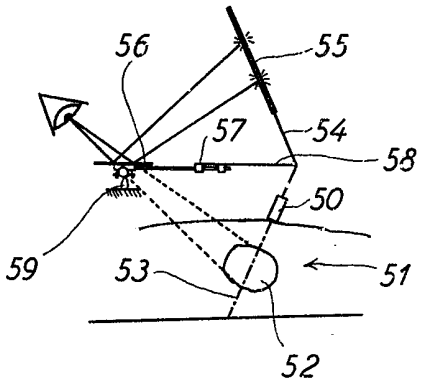


Fig. 6

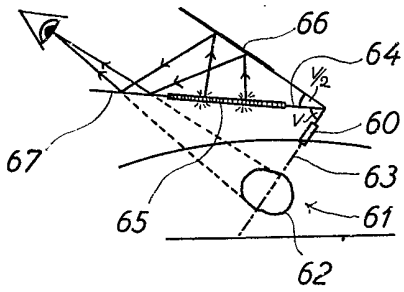


Fig. 7

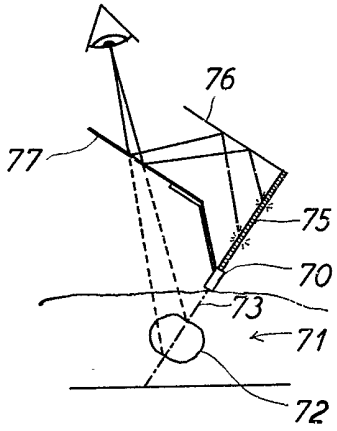


Fig. 8

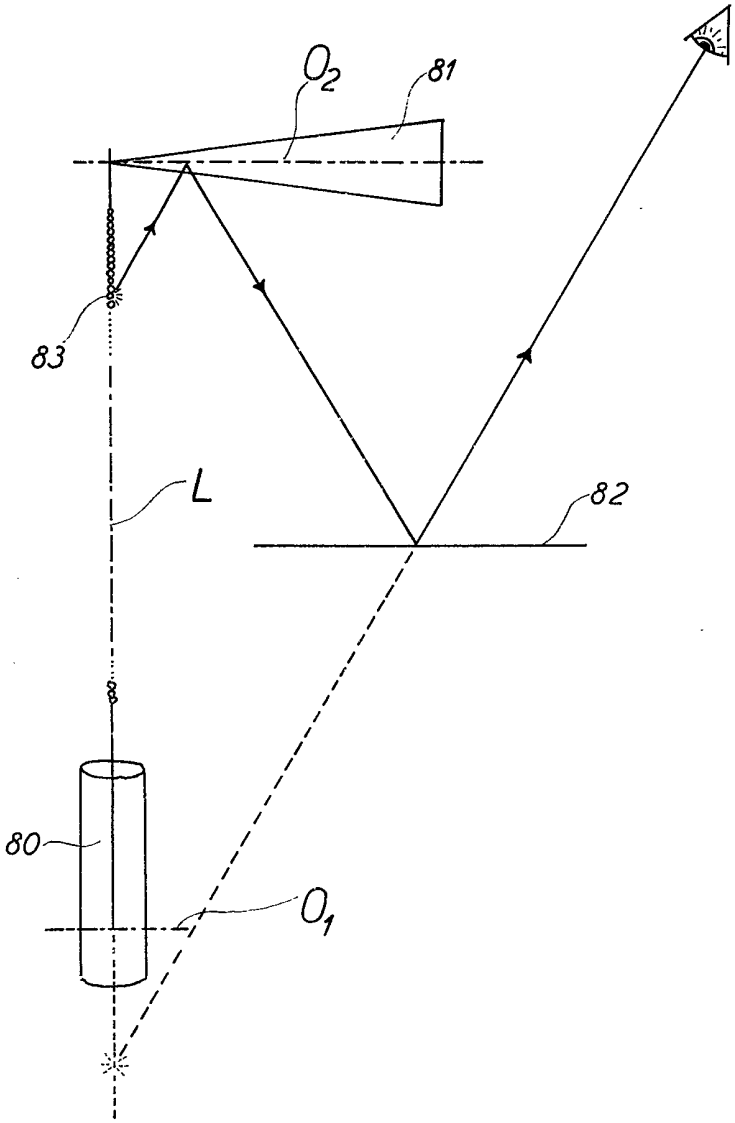
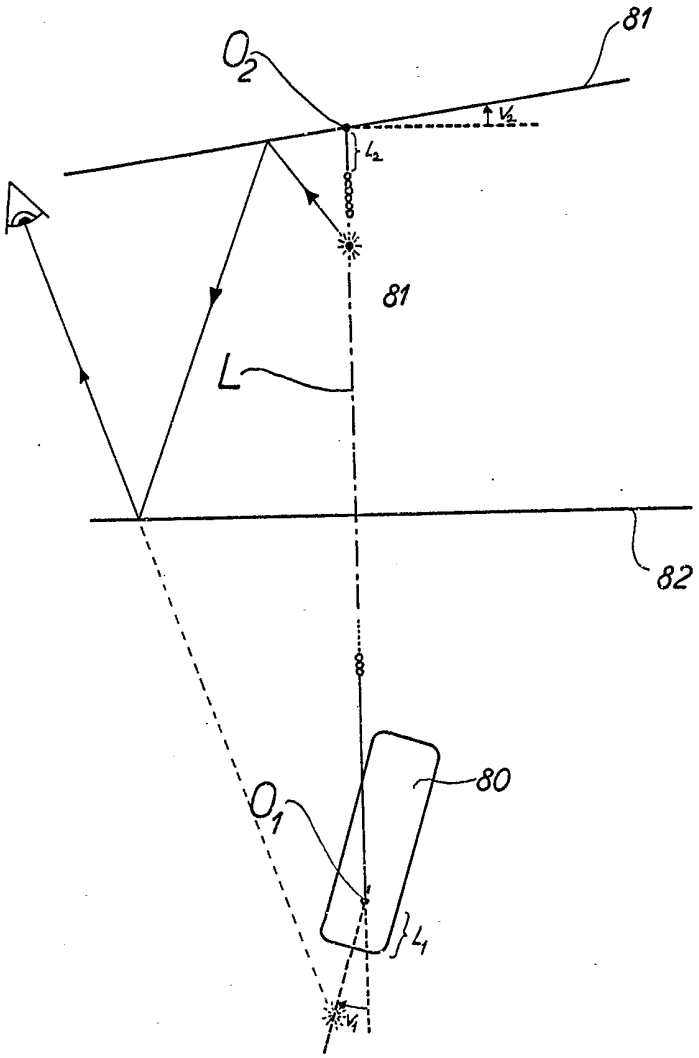


Fig. 9



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8 SHEETS This drawing is a reproduction of the Original on a reduced scale
Sheet 8

Fig. 10

