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## (54) ULTRASONIC CALIBRATION ASSEMBLY

(71) We, WESTINGHOUSE ELECTRIC CORPORATION, of Westinghouse Building, Gateway Center, Pittsburgh, Pennsylvania, United States of America, a corporation organised and existing under the laws of the State of Pennsylvania, 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 relates to ultrasonic calibration assemblies.

Nuclear reactor vessels employed in the commercial generator of electrical power utilize a generally cylindrical metallic container having a base and a top flange welded thereto. The main cylinder portion itself usually comprises a series of lesser cylinders welded to each other. In addition, a plurality of circumferentially spaced nozzles extend through the main cylinder wall and are welded thereto. Thus, numerous welds are necessarily used in fabricating the actor vessel.

The weld areas of the reactor vessel are, of course, inspected prior to its initial use. Such inspection is carried out with all portions of the vessel relatively accessible to an inspection device prior to its encasement in the concrete containment. However, in-service inspection of the reactor vessel welds is not only desirable, but is mandated under governmental regulations.

Under such regulations, it is required that the vessel weld areas be subjected to periodic volumetric examination whereby the structural integrity of the vessel is monitored. Due to the nature of an in-service inspection, the device designed to accomplish the specified weld examinations must be capable of successfully operating in an underwater and radioactive environment under remote control while maintaining a high degree of control over the placement and movement of the inspection sensors.

The use of ultrasonic transducers to inspect metal welds is known. One such system is described in the periodical *Materials Evaluation*, July 1970, Volume 28, No. 7, at pages 162—167. This article describes a transmitter-receiver type ultrasonic inspection system for use in the in-service inspection of nuclear reactor vessels.

In United States Patent No. 3,809,607, a nuclear reactor vessel in-service inspection device is detailed which device is adapted to permit remotely controlled and accurate positioning of a transducer array within a ractor vessel. This device comprises a positioning and support assembly consisting of a central body portion from which a plurality of radially directed support arms extend. The ends of the support arms are extended to and adapted for being seated on a predetermined portion of the reactor vessel to define a positional frame of reference for the inspection device relative to the reactor vessel itself. Repositioning and support assemblies are provided and include integral adjustment means which cooperate to permit the simultaneous variation of the extension of the support arms thereby allowing the inspection device to fit reactor vessels of differing diameters. A central column is connected to the positioning and support assemblies, which central column extends along the longitudinal axis thereof. One or more movable inspection assemblies are connected to the central column and include drive and position indicating means. Three specific inspection subassemblies include a flange scanner, a nozzle scanner and a vessel scanner. Each of these scanners employ multiprobe transmitter-receiver ultrasonic transducers to permit more accurate volumetric plotting of the integrity of the welds used in fabricating the reactor vessel.

Since the development of the above-identified inspection devices, the original inspection code has been amended to call for more reliable and more rigorous inspections. In addition, these prior art devices were unable to accurately measure or reach certain weld areas of the reactor vessel. Still other drawbacks in the prior art inspection devices were the reliability and speed of the actual inspection effort.

One particular problem which was not solved by any of the above-described prior art devices was that of calibrating or referencing a zero start point for the vertical axis of transducer movement within the reactor vessel so that the exact location of the array and derivatively of any weld defect would be known. Another problem not satisfactorily solved by the prior art devices was that of verifying the mounting of the transducers.It was necessary to insure that those transducers which were to be mounted perpendicularly were, in fact, so positioned and that those transducers which were to be mounted at predetermined angles to a transducer array plate were also, in fact, properly positioned. Particularly where the manipulator arm or the transducer array carried thereon bumps into or impacts the vessel it would be necessary to withdraw the inspection apparatus to verify that there had been no change in the alignment of any transducer, a procedure which would result in at least a two shift delay due to decontamination procedures alone. Yet another problem left unsolved by these prior art devices was that of ascertaining the speed per unit of distance in the operating medium of the transducer beam prior to the actual inspection.

It is an object of this invention to provide an improved ultrasonic calibration assembly with a view to overcoming the deficiencies of the prior art.

The invention resides in a calibration assembly for use in association with the ultrasonic transducers of a nuclear reactor vessel inspection apparatus, characterized in that it includes a generally spherical body having a surface for reflecting an ultrasonic beam from one of said transducers, said generally spherical body being disposed at a fixed position, and means for moving said transducer with respect to said generally spherical body until the beam reflection therefrom is the highest amplitude return signal, indicating that said transducer is in radial alignment with said generally spherical body.

The invention will become readily apparent from the following description of exemplary embodiments thereof, when read in conjunction with the accompanying drawings, in which:

Figure 1 is an isometric view of nuclear vessel inspection apparatus including a calibration assembly according to one embodiment of the invention;

Figure 2 is a schematic side view, partly in section, of the calibration assembly shown in Figure 1, as it would be targeted by a transducer in use;

Figure 3 is a top view of the calibration assembly shown in Figure 2;

Figure 4 is an isometric schematic illustration of the manipulator arm and transducer array of the inspection apparatus in use with the calibration assembly of the present invention;

Figure 5 is a schematic view of a calibration assembly, partly in phantom, in accordance with another embodiment of the invention;

Figure 6 is a top plan view of the mounting means and target employed in the calibration assembly shown in Figure 5; and

Figure 7 is a graphical representation of the near and far field effects in a transducer beam superimposed over the target distance shown in Figures 5 and 6.

Referring now to the drawings, Figure 1 illustrates an isometric view of a nuclear reactor vessel inspection apparatus 14. The inspection apparatus 14 is more fully described in U.S. Patent Application No. 781,403, filed on March 25, 1977, and need not, therefore, be similarly described herein. Additional and specific details thereof may be had by reference to that application.

In the operation of the inspection apparatus, it is lowered into and seated within a reactor vessel. The vessel inspection is then carried out by driving a manipulator arm 26, which carries a transducer array 28, along or about nine axes of movement to effect interrogation of the vessel weld integrity.

As previously noted, it is required in order to ensure test authentically, that the starting point of the transducer array, be accurately known since the location of the vessel welds or discovered defects is derivable directly therefrom. Accordingly, at the start of each test and during specified intervals therein, the transducer array 28 is driven into a facing position with a calibration assembly 300, as is shown in Figures 2 and 4. In addition, should the transducer array 28 accidentally bump into any portion of the reactor vessel during the inspection, it is desirable to verify transducer positioning to avoid, if possible having to remove and decontaminate the inspection apparatus 14 in order to ensure that there has been no disturbance of transducer mounting.

As shown in Figures 2 and 3, the calibration assembly 300 includes a generally rectangular plate 301 which, as shall be hereinafter explained, serves as an infinitely large reflecting surface for calibrating the perpendicularly mounted transducers in the array. A stand 304 is mounted at the approximate center of the plate 301 and carries thereon a small ball 302 which, as shall also be explained hereinafter, serves as an infinitely small reflecting surface. Also mounted on the same side of plate 301 are a plurality of upstanding truncated cones, in this embodiment three innumber 306, 308 and 310, which are cut off at angles corresponding to expected angular settings of the transducers as mounted in the array 28. It will be appreciated by those having skill in this art that the shape of plate 301 and the location of stand 304 and of the cones 306, 308 and 310 is a matter of convenience. Further, to enhance the versatility of the calibration assembly 300, the cones 306, 308 and 310 can be fabricated from common stock or standards, such as stand 304, having an appropriately machined angular tip fastened thereto or an adjustable or removable tip which can be set to a desired angle as required. In any case, the various elements of the calibration assembly 300 will be fabricated from material which can readily withstand the hostile inspection environment.

The opposite side of plate 301 carries a clamp assembly 312 which engages the support leg 20A as is shown in Figures 2 and 4. A keyway 314 is cut into the clamp assembly 312 and engages a key 316 formed in the periphery of support leg 20A. The engagement of key 316 and keyway 314 insures that the calibration assembly 300 is properly oriented when mounted on support leg 20A. The calibration assembly 300 is tightly clamped to the support leg 20A by bolts 320 or some other suitable securing element.

Figure 3 shows a top plan view of the ball 302 and the cones 306, 308 and 310. The distances therebetween are known as are the distances therefrom with respect to an arbitrary zero point on the plate 301. The tips of the cones 306, 308 and 310, in the preferred embodiment, are respectively cut at angles of 10°, 19° and 23°, but can be changed or adjusted to accommodate the particular angles at which cretain of the transducers in array 28 are mounted.

In operation, the calibration assembly 300 is clamped to support leg 20A as is shown in Figures 1 and 2. Since the support leg 20A will sit in or on a known vessel location, the point at which the calibration assembly 300 is clamped to, is known in a rough sense. The carriage assembly 82 is then driven up or down the main column 24, along the vertical axis, to a point where the transducer array plate 40 can be brought opposite the calibration assembly, as shown in Figure 4. At that time, the operator will coarsely align one of the perpendicularly mounted transducers in array 28 with the ball 302. For convenience, only one transducer 244 has been shown in Figures 2 and 4.

With the transducer 244 in coarse alignment with the ball 302, it is actuated and thereupon emits an ultrasonic beam 303, as is best shown in Figure 2. The beam reflection from the ball 302 will be the highest amplitude return signal and the operator continues to maneuver the transducer array 28 about by moving the appropriate segments of the manipulator arm 26 until satisfied that the reflection from ball 302 is the highest possible maximum signal received which means that the test transducer 244 and the ball 302 are in horizontal alignment. At this time, the reading of the vertical resolver 102, which indicates the vertical position of the transducer array 28 or carriage assembly 82, is taken and is subsequently offset from future readings to calibrate or fix the future locations of the transducer array 28 with reference to the zero starting point just determined. At the same time, the perpendicularity of the mounting or alignment of transducer 244 can be verified as can be perpendicular alignment of all other transducers in array 28 which are so mounted.

Since the foregoing calibration test takes place with the inspection apparatus 14 in place in the reactor vessel, the calibration assembly 300 can also be used to verify or measure the speed of the transducer ultrasonic beam 303 in the operating medium, in this and other inspection cases, water. When the calibration transducer 244 is actuated, the resulting beam 303 has a slight spread as is shown in Figure 2. The central portion 305 of the beam 303 strikes the ball 302, a relatively small surface, and is reflected therefrom back to transducer 244. The outer portion 307 of the beam 303 strikes plate 301, a relatively large surface for example at point 309 thereon, and is also reflected back to the transducer 244, but by a time delay which is a function of the distance between the ball 302 and the plate 301 and the medium in which the beam 303 travels. Since the height of the strand 304 is known, the water path distances from the transducer 244 to the ball 302 and from the transducer 244 to the plate 301 will also be known. Thus, the operator with the aid of an oscilloscope or other suitable device can calculate the time per unit of distance for the beam 303 in the operating medium. This calibration can be utilized later in the actual inspection to verify distances from the array 28 or any transducer therein to the vessel or any portion thereof.

In addition, after calibrating for and verifying the start position in the vertical axis and the beam speed, the operator can verify the angular mounting of various other transducers in the array employing the angled reflecting surfaces of the cones 306, 308 and 310. To achieve this verification, the array 28 is driven to a point opposite the calibration assembly 300 in a manner similar to that shown in and described with respect to Figure 4. In this instance, another of the transducers (not transducer 244) which has been angularly mounted in array 28 is brought into alignment with one of the cones 306, 308 or 310. That transducer is actuated and will receive a maximum reflected beam only if its angle of mounting corresponds with the angle formed in the tip of the cone at which it is directed. In this manner, the correctness of each of the mountings of the transducers in array 28 can be verified at any point in, before or after the inspection procedure. In the preferred embodiment, the tips of cones 306, 308 and 310 are truncated by machining them to a desired angle. Alternatively, the cones could be fabricated of identical stock or standards having angularly adjustable or removable tips.

In accordance with another embodiment of the invention, there is provided a calibration assembly particularly suitable to verify the position and orientation of transducers used in nuclear reactor vessel inspection apparatus. The calibration assembly includes movable mounting means adapted, within a tank, to removably secure a transducer mounted, in turn, in its normal inspection mounting.

Drive means which engage the movable mounting means are also provided for transporting the transducer in the tank to different positions relative to target means which are also provided. The target means is slidably positioned in the tank at a predetermined distance from the transducer, which distance is selected to avoid the distortion effects in the near field of the transducer response.

The drive means for the tank's mounting means is provided with graduated indicia of travel so that an operator can quickly determine by visual inspection the distance traveled by the mounting means. Alternatively, a scale can be affixed to or cut in the side of the tank to accomplish the same result.

Referring to Fig. 5 which illustrates such a calibration assembly, each transducer, secured in its retaining block 266 is placed in a calibration tank 402 filled with water 403. The test transducer 244 is secured to a mounting assembly 404 which is movably mounted, in turn, within the calibration tank. The mounting assembly 404 generally comprises a rectangular bar 252 and a circular bar 258 and the necessary bolts to secure the retaining block is found on the transducer plate 406 and shown most clearly in Figure 6. The bars 252 and 258 are fixed to plate 406 which is, in turn, secured to the mounting assembly 404 by bolts.

The rear portion of the mounting assembly 404 includes a slide block 410 having a threaded aperture 412 therein. Slide block 410 is engaged by a lead screw 414 which is rotatably clamped to the top and bottom portions of the calibration tank by the blocks 416. The top portion of the lead screw 414 terminates in a handle or crank 418 which, when turned, will raise or lower the mounting assembly 404. Intermediate the handle 418 and the top of lead screw 414 is a collar 420, the top portion of which is graduated into a scale 422. The operator can use the scale 422 to determine the vertical travel of the mounting assembly 404. Alternatively, the side of the tank 402 can be fitted with a linear scale or rule (not shown) for the same purpose.

A target assembly 425 is positioned at the far end of tank 402. The target assembly comprises a base 424 having longitudinal slots 427 cut therein. The base 424 is secured to the tank 402 by bolts 429 and can be moved towards or away from the transducer by loosening the bolts 429 and sliding the base in an appropriate direction as shown in Figure 6. Secured to the base 424 is a support or stand 426, having a generally rectangular cross-section, and secured, in turn, to the support 426 is a ball 428. As shall be hereinafter explained, the support 426 acts as a relatively infinitely large reflecting surface and the ball 420 acts as a relatively infinitely small reflecting surface.

The target assembly 425 is positioned at a predetermined distance from the mounting assembly 404 and the transducer 244 being calibrated. This distance is selected to avoid the distortion 435 found in the "near field" 434 of the transducer beam 432. Therefore, the target assembly 425 is positioned, as shown in Figure 7, at a point B which is in the "far field" 436 of the transducer beam 432. Line A, drawn through the graphical representation of the transducer beam 432 shown in Figure 14 which is superimposed over the beam transmission distance, separates the near and far fields. Point B, the location of the target assembly 425, is selected to be beyond the knee of the beam transmission curve 433 at a segment thereof which is generally linear and free of distortion. This ensures that the calibration procedure will not be affected by the "near field" distortion.

In operation, the calibration apparatus 400 is utilized in the following manner. A transducer 244 to be calibrated is placed in its normal inspection mounting, as described hereinabove, in the calibration mounting assembly 404. The transducer 244 is then driven by turning handle 418 to a point, shown in phantom in Figure 5, where it faces the support 426. When acuated in this position, transducer beam 432 impinges the support 326 in a generally perpendicular manner. The operator, who can track the reflected beam by appropriate equipment (not shown) can reach into the tank 402 and, by loosening the appropriate bolt, nut or screw, adjust the transducer position to achieve a maximum reflection to coarsely verify perpendicularity. After such coarse adjustment has been made, the transducer 244 is moved up to where its beam will directly impinge the surface of ball 428. Since only one point on the ball's curved surface will reflect back a maximum beam, i.e., no scattering due to non-perpendicular impingement, fine positioning of the transducer 244 can now be accomplished by adjusting its position as needed to obtain such maximum reflection. In this manner, any transducer yaw offset can be corrected.

If the transducer 244 is to be mounted at a predetermined angle in the array 28, then its perpendicularity is checked as above, in alignment with the support 426 and the ball 428. The transducer 244 is moved upwardly from a zero point determined by the beam impingement with the ball 428. The mounting angle is designated as $\theta$ in Figure 5. Since the distance from the ball 428 to the transducer 244 at the zero point is known or can be measured the transducer 244 is raised by an amount which corresponds by trigonometric function or relationship to the tangent of the angle $\theta$; that is, the horizontal distance 440 at the zero point, which is known, divided into the vertical distance 422 over which the transducer 244 is moved, which distance is also known. With the transducer raised to its solid line position in Figure 5, adjustment of its position is made with respect to the ball 428 until a maximum reflection of beam 430 is received. At that point, the transducer is correctly oriented at the desired angle and it is secured in its mounting by the operator. The transducer 244 in its normal inspection mounting is then transferred to the array plate 40 and secured thereto as described above.

If necessary, the target assembly 425 can be positionally adjusted to alter the distance 440 by loosening the bolts 429. This capacity is provided to ensure that the target assembly will be in the "far field" of the transducer beam or that slight adjustments can be made in the geometry of the triangle formed by the transducer 244, the target assembly 425 and the zero point (distance 440).

WHAT WE CLAIM IS:—

1. A calibration assembly for use in association with the ultrasonic transducers of a nuclear reactor vessel inspection apparatus, characterized in that it includes a generally spherical body having a surface for reflecting an ultrasonic beam from one of said transducers, said generally spherical body being disposed at a fixed position, and means for moving said transducer with respect to said generally spherical body until the beam reflection therefrom is the highest amplitude return signal, indicating that said transducer is in radial alignment with said generassy spherical body.

2. A calibration assembly according to claim 1, wherein said transducers are mounted in an array, characterized in that said generally spherical body is mounted to a predetermined portion of the inspection apparatus so as to permit calibration of movement of said transducer array with reference to a zero starting point within the reactor vessel.

3. A calibration assembly according to claim 2, characterized in that it includes a generally flat reflecting plate disposed at a predetermined distance from said generally spherical body in such a manner that said generally spherical body will be impinged by the ultrasonic beam prior to its impingement of said generally flat reflecting plate.

4. A calibration assembly according to claim 3, characterized in that it includes at least one additional reflecting surface which is angled with respect to said generally flat reflecting surface.

5. A calibration assembly according to claim 1, characterized in that it comprises a tank capable of holding fluid therein, mounting means, movably mounted in said tank for securing said transducer, and means for moving said mounting means, said generally spherical body being mounted in said tank a predetermined distance from said mounting means, said distance being selected to be greater than the distance required to place said generally spherical body without the "near field" of the transducer beam.

6. A calibration assembly according to claim 5, characterized in that said mounting means includes a slide having a threaded bore and wherein said means for moving includes a lead screw which threadingly engages said bore.

7. A calibration assembly according to claim 6, characterized in that said means for moving additionally comprises a handle for turning said lead screw and a collar having indicia thereon indicative of the distance moved by said mounting means.

RONALD VAN BERLYN.

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Sheet 1

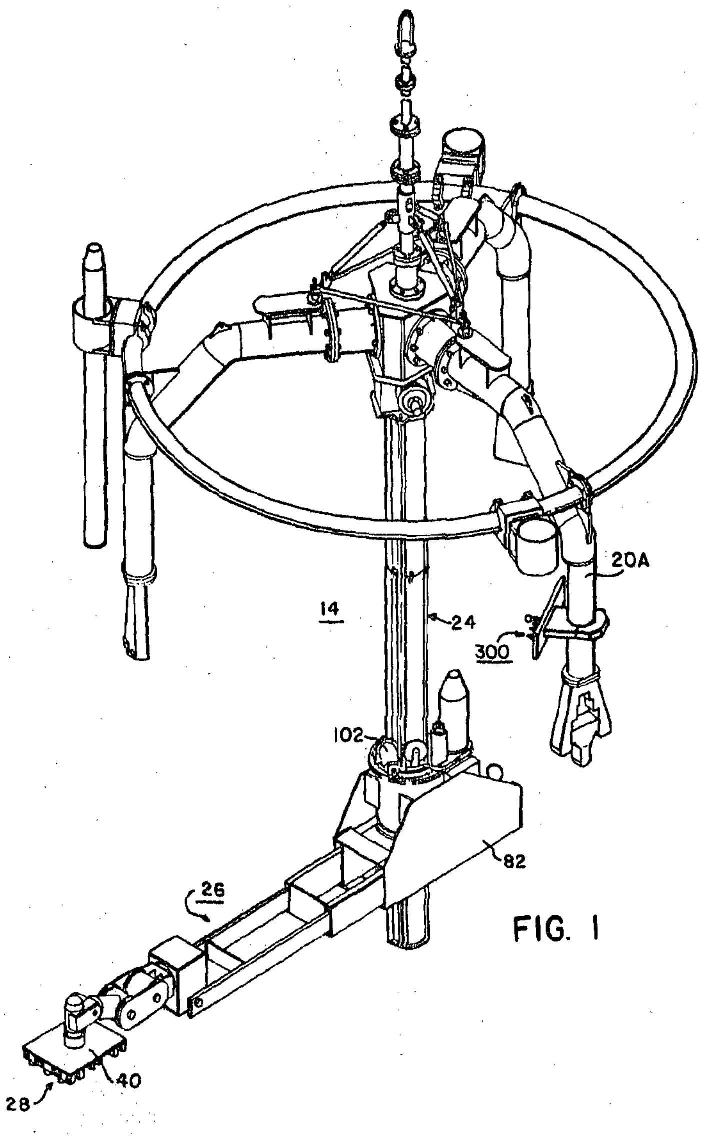


FIG. 1

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Sheet 2

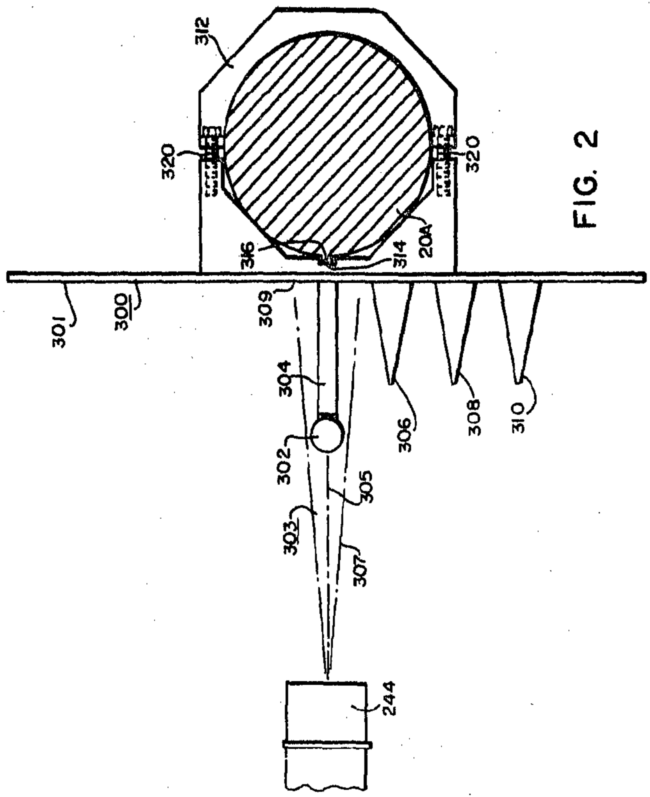

FIG. 2

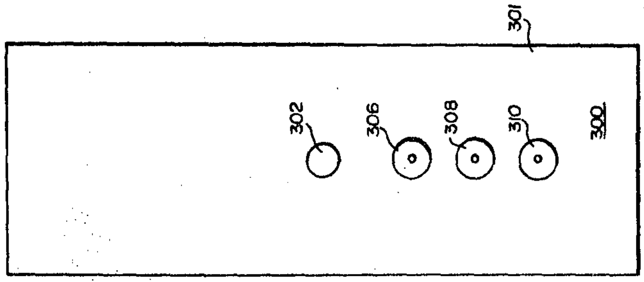

FIG. 3

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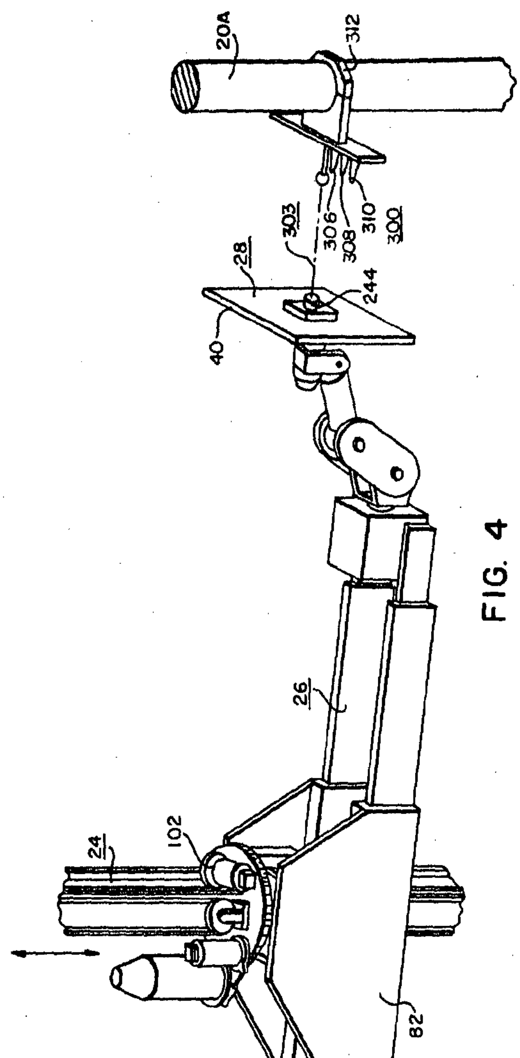


FIG. 4

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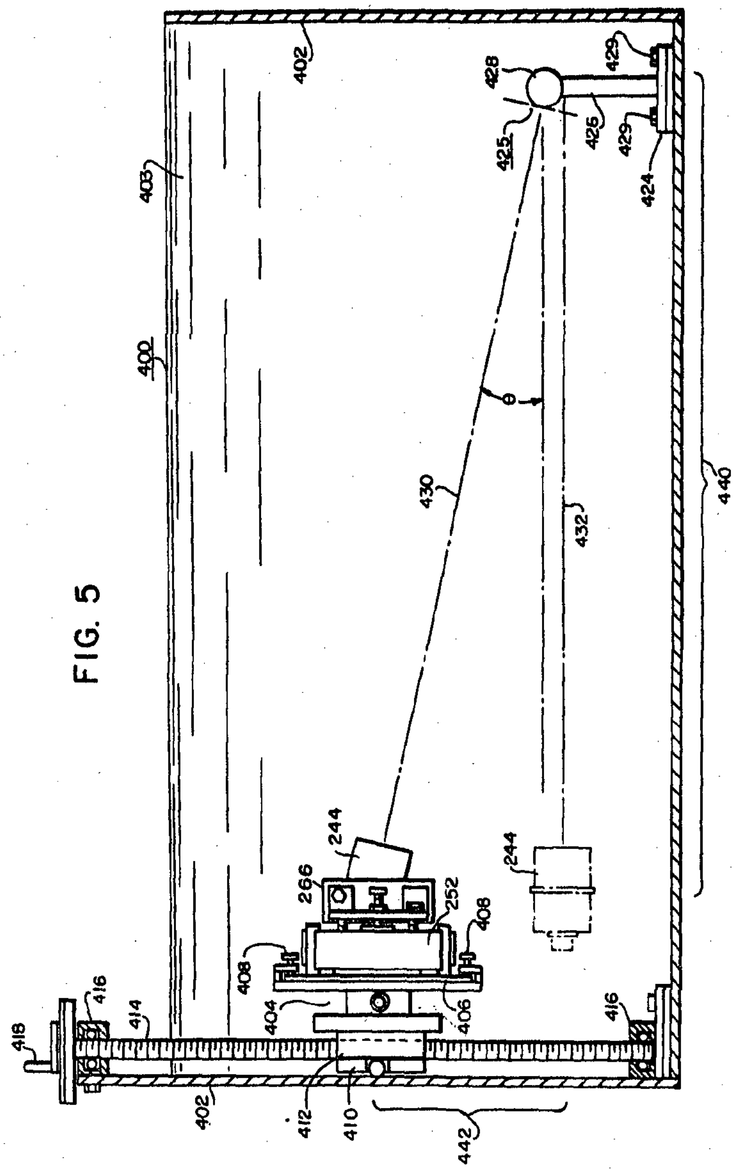


FIG. 5

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Sheet 5

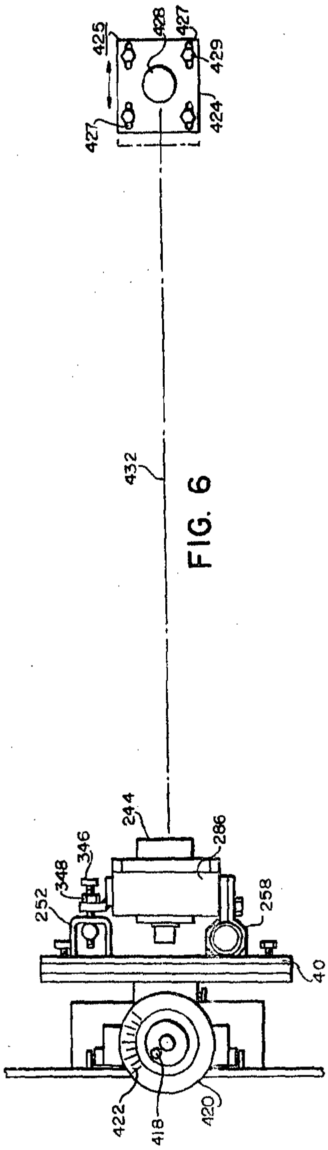


FIG. 6

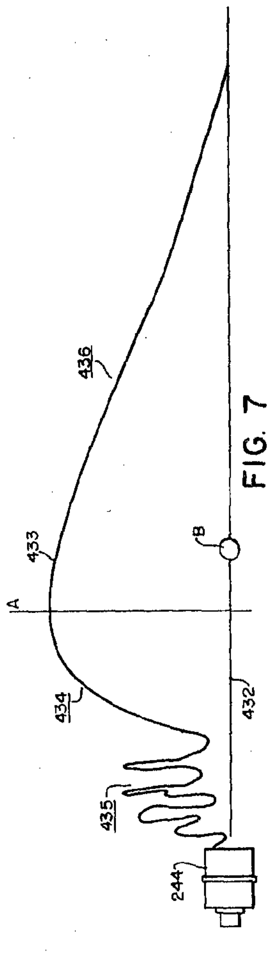


FIG. 7