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(54) MANIPULATOR ARM FOR A NUCLEAR REACTOR VESSEL INSPECTION DEVICE

(71) We, WESTINGHOUSE ELECTRIC CORPORATION of Westinghouse Building, Gateway Center, Pittsburgh, Pennsylvania, United States of America, a company organised and existing under the laws of the Commonwealth 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 an improved manipulator arm for a nuclear reactor vessel inspection device.

Nuclear reactor vessels employed in the commercial generation 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 reactor vessel.

Under governmental 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. The positioning arrangement for the transducers uses a track which is mounted on the interior wall of the reactor vessel.

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 reactor 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.

One particular problem which was not solved by the above-described prior art devices concerns the removal of the inspection device from the reactor vessel should an emergency, such as power failure, occur. This problem is made acute where the inspection device utilizes a relatively long manipulator arm which must be changed from its normal orientation prior to removal to prevent collision thereof with the walls of the reactor vessel.

It is a principal object of this invention to provide an improved manipulator arm for a nuclear reactor vessel inspection device.

The invention resides in a manipulator arm for a nuclear reactor vessel inspection apparatus, said arm being adapted to transport a transducer array to accomplish the examination at any appropriate vessel point, comprising: first segment means adapted to be driven independently through a first plane of motion parallel to a vertical axis, independently through a second plant of motion about the vertical axis and independently in a third plane of motion radially towards and away from the vertical axis; second segment means, cooperably and movably linked to said first segment means adapted to be driven independently in a fourth plane of movement about an axis in said third plane of movement; third segment means, cooperably and movably linked to said second segment means, adapted to be driven independently in a fifth plane of movement that is normal to said fourth plane of movement; fourth segment means, cooperably and movably linked to said third segment means, adapted to be driven independently in a sixth plane of movement that is parallel to said first plane of movement; fifth segment means cooperably and movably linked to said fourth segment means, adapted to be driven independently in a seventh plane of movement; sixth segment means, cooperably and movably linked to said fifth segment means, adapted to be driven independently in an eighth plane of movement; and seventh segment means, cooperably and movably linked to said sixth segment means and to the transducer array, adapted to be driven independently in a ninth plane of movement.

The invention will become more apparent from the following description of an exemplary embodiment thereof when taken in conjunction with the accompanying drawings, in which:

Figure 1 is an isometric view of the inspection apparatus showing the manipulator arm thereof in one of its possible inspection positions in which the transducer array is positioned within a nozzle of the reactor vessel;

Figure 2 is an isometric view of the manipulator arm used in the inspection device shown in Figure 1;

Figure 3 is an end view representation of a telescoping drive assembly used, in part, to position the manipulator arm; and

Figure 4 is an isometric representation of an emergency disconnect apparatus for the manipulator arm of the inspection device.

Referring now to Figure 1, the inspection device as depicted comprises a quick-disconnect lifting assembly 16, a support ring 18, three support legs 20A, 20B and 20C, a main column 24, a manipulator arm 26, a transducer array 28 and an overall control system 30 which includes an assortment of motors, resolvers and cabling. These main elements cooperate to permit inspection of the reactor vessel 10 in accordance with code requirements.

The manipulator arm 26, which is more clearly shown in Figure 2, includes a carriage assembly 82 which rides on the main column 24 in the "U" shaped grooves 80. The carriage assembly 82 is fitted with internally mounted and sealed ball bearings which ride in and are engaged by the "U" grooves 80 and facilitate vertical movements by manipulator arm 26 on the main column 24. When the vertical drive motor (not shown) in the vertical motor assembly 72 is actuated, it rotates the drive pulleys 74, causing such vertical movement of the manipulator arm.

An axis motion or rotation of the manipulator arm 26 about the main column 24 is shown in Figure 2. As illustrated therein, actuation of the A axis motor 118 drives the carriage rotary gears 122 and 124 causing the entire manipulator arm to swing about the main column 24. The position of manipulator arm 26 in the A axis is verified by a signal which is generated by the rotary resolver 120. It should be noted with respect to all of the drive motors described herein, whether shown or not, that a resolver or position determining sensor is coupled thereto to provide a signal which is then employed to indicate the position of manipulator arm 26 or any portion thereof, in or about the particular axis of movement associated with the motor being described.

Y axis movement, which is also indicated in Figure 2, is achieved by driving a set of telescoping arms 126 and 128, which are movable mounted within the carriage channels 130, toward and away from the carriage assembly 82. As is more clearly illustrated in the end view shown in Figure 3, the Y axis motor 132 is coupled by its shaft 134 to a drive gear 136. When the Y axis motor 132 is actuated, it causes drive gear 136 to be rotated, driving a rack 138 engaged thereby, which rack is bolted to the telescoping arm 126. This causes arm 126 to be driven towards or away from the carriage assembly 82, depending on the direction of rotation of the Y axis motor 132. When the outer telescoping arm 126 is moved, it carries with it an idler gear 140 which is meshingly engaged between rack 142, which is attached to the inner telescoping arm 128, and rack 144 which is coupled to the carriage channel 130. For purposes of clarity, the illustration in Figure 3 depicts only one half of the telescoping arrangement of the Y axis drive, but it will be understood that the Y axis motor 132 causes, through the action of another drive gear (not shown), both sets of telescoping arms 126 and 128 to be driven in a desired direction along the Y axis. Movement of the manipulator arm 26 along the Y axis is required, in particular, to position the transducer array 28 within any one of the reactor vessel nozzles 38 for inspection thereof, as is shown in Figure 1.

B axis motion is obtained by actuating the B axis motor (not shown) which is mounted within the B axis drive housing 160 and connected to mounting bracket 178. As is more clearly illustrated in Figure 4, the B axis drive housing 160 is secured in the following manner. A mounting bracket 162 is bolted to each of the inner telescoping arms 128. Attached to the upper end portion of bracket 162 is an apertured dog ear 164. Attached to the upper portion of the B axis drive housing 160 is a movable linkage assembly 166 which is actuated by a locked-over-center lever 168. The linkage assembly 166 terminates in a dog 170 which engages the aperture in dog ear 164 when lever 168 is moved to its locked position 172 and holds the B axis drive housing in a normal position with respect to the telescoping arm 128. The bottom portion of the B axis drive housing is movably secured by engagement with a hinge pin 174.

As noted above, the transducer array 28 and manipulator arm 26 can be withdrawn from a vessel nozzle 38 in an emergency situation. However, it may not yet be safe to lift the inspection apparatus 14 from the vessel 10 since the forward portion of the manipulator arm may strike the reactor vessel 10. Accordingly, after the manipulator arm 26 has been manually retracted, the hook is again lowered and engages the linkage lever 168. As the hook and lever 168 are pulled upwardly, the linkage assembly 166 extracts the dog 170 from engagement with the dog ear 164, allowing the B axis drive housing to rotate about hinge pin 174 as is shown in phantom in Figure 4. With the B axis drive housing in its final position 176, the entire inspection apparatus 14 can be withdrawn from the vessel 10 without any fear of striking the vessel walls.

Further movement of the transducer array 28 is possible along or about five additional axes of movement. In addition to movement of the manipulator arm 26, and derivatively movement of the transducer array 28, along or about the A, B, Y and Z axis, movement can be effected about the C, D, E, F and G axes. The B axis motor shaft is connected to a mounting bracket 178 and, when driven, rotates bracket 178 and all elements connected forwardly thereof about the B axis. Two additional mounting brackets 180 and 182 are secured to the B axis motor bracket 178, as is shown in Figure 2. The C axis motor housing 184 is coupled between and secured to the brackets 180 and 182 with the C axis motor shaft 186 extending through and being drivingly engaged by the brackets 180 and 182. When actuated, the C axis motor drives its shaft 186 and the brackets 180 and 182, as well as all of the manipulator elements connected forwardly thereof, about the shaft 186. Motion in the D axis is achieved in a similar manner. The D axis motor housing 188 is also coupled between and secured to the brackets 180 and 182 with the D axis motor shaft 190 extending through and being drivingly engaged by the brackets 180 and 182. When the D axis motor is actuated to drive its shaft 190, motor shaft 190 and all of the manipulator arm elements connected forwardly thereof are rotated in the D axis. The E axis motor housing 192 is connected to the C axis motor housing 188 with the E axis motor shaft (not shown) being connected to mounting bracket 194. When actuated, the E axis motor shaft drives bracket 194 about the E axis, as well as all of the manipulator arm elements connected forwardly thereof. The F axis motor housing 196 is secured by mounting bracket 194 and by mounting brackets 198. The shaft 200 of the F axis motor (not shown) extends through and drivingly engages the mounting bracket 198. When actuated, the F axis motor drives its shaft 200 and the remainder of the manipulator arm elements connected forwardly thereof through F axis motion. The G axis motor housing 202 is secured to the end of mounting bracket 198. The G axis motor shaft 204 extends outwardly of housing 202 and is clamped into the transducer plate collar 206 which, in turn, is clamped to the transducer array plate 40. When actuated, the G axis motor drives its shaft 204 and the transducer array plate about the G axis. Thus, the transducer array 28, with reference to any point in the reactor vessel 10, can be driven in nine planes of movement or about nine axes of rotation. This highly mobile and segmented articulating drive train can be employed to accurately position the transducer array 28 at any point within the reactor vessel 10.

WHAT WE CLAIM IS:-

1. A manipulator arm for a nuclear reactor vessel inspection apparatus, said arm being adapted to transport a transducer array to accomplish the examination at any appropriate vessel point, comprising: first segment means adapted to be driven independently through a first plane of motion parallel to a vertical axis, independently through a second plane of motion about the vertical axis and independently in a third plane of motion radially towards and away from the vertical axis; second segment means, cooperably and movably linked to said first segment means adapted to be dri-

ven independently in a fourth plane of movement about an axis in said third plane of movement; third segment means, cooperably and movably linked to said second segment means, adapted to be driven independently in a fifth plane of movement that is normal to said fourth plane of movement; fourth segment means, cooperably and movably linked to said third segment means, adapted to be driven independently in a sixth plane of movement that is parallel to said first plane of movement; fifth segment means cooperably and movably linked to said fourth segment means, adapted to be driven independently in a seventh plane of movement; sixth segment means, cooperably and movably linked to said fifth segment means, adapted to be driven independently in an eighth plane of movement; and seventh segment means, cooperably and movably linked to said sixth segment means and to the transducer array, adapted to be driven independently in a ninth plane of movement.

2. A manipulator arm according to claim 1 wherein said third and fourth segment means are drivably engaged by bracket means for permitting either of said third and fourth segment means to be driven in their respective planes of movement while simultaneously driving said bracket means with respect thereto.

3. A manipulator arm according to claim 1 or 2 wherein said ninth plane of movement is selected to be normal to the vertical axis of the transducer array.

4. A manipulator arm according to claim 1, 2 or 3 wherein said eighth plane of movement is selected to be about an axis parallel to the horizontal axis of the transducer array.

5. A manipulator arm according to claim 3 wherein said eighth plane of movement is selected to be about an axis parallel to the horizontal axis of the transducer array.

6. A manipulator arm according to any of the preceding claims, comprising means for changing the normal orientation of the manipulator arm to a shorter one which permits the safe removal of the inspection device from the reactor vessel.

7. A manipulator arm according to claim 6 wherein said means for changing the normal orientation comprises a motor housing; first bracket means for connecting said motor housing intermediately in the manipulator arm to a first segment thereof; second bracket means for connecting said motor housing to a second segment of the manipulator arm; an apertured flange and a dog engaged therewith for removably coupling said motor housing to a first portion of said second bracket means as part of the normal orientation of the manipulator arm and for pivotally coupling said motor housing to a second portion of said second bracket means, said apertured flange and said dog at said first portion restraining pivotal movement at said second portion until disengaged; and a normally accessible lever and means coupling said lever to said dog, said lever being normally locked over the center of said dog, said lever having a first position wherein said dog and said flange are engaged and a second position wherein said lever pulls the dog out of said engagement with said flange for disengaging said motor housing from said first portion of said second bracket means to permit, when actuated, pivotal movement of said motor housing about said second portion to change the normal orientation of the manipulator arm to the short one.

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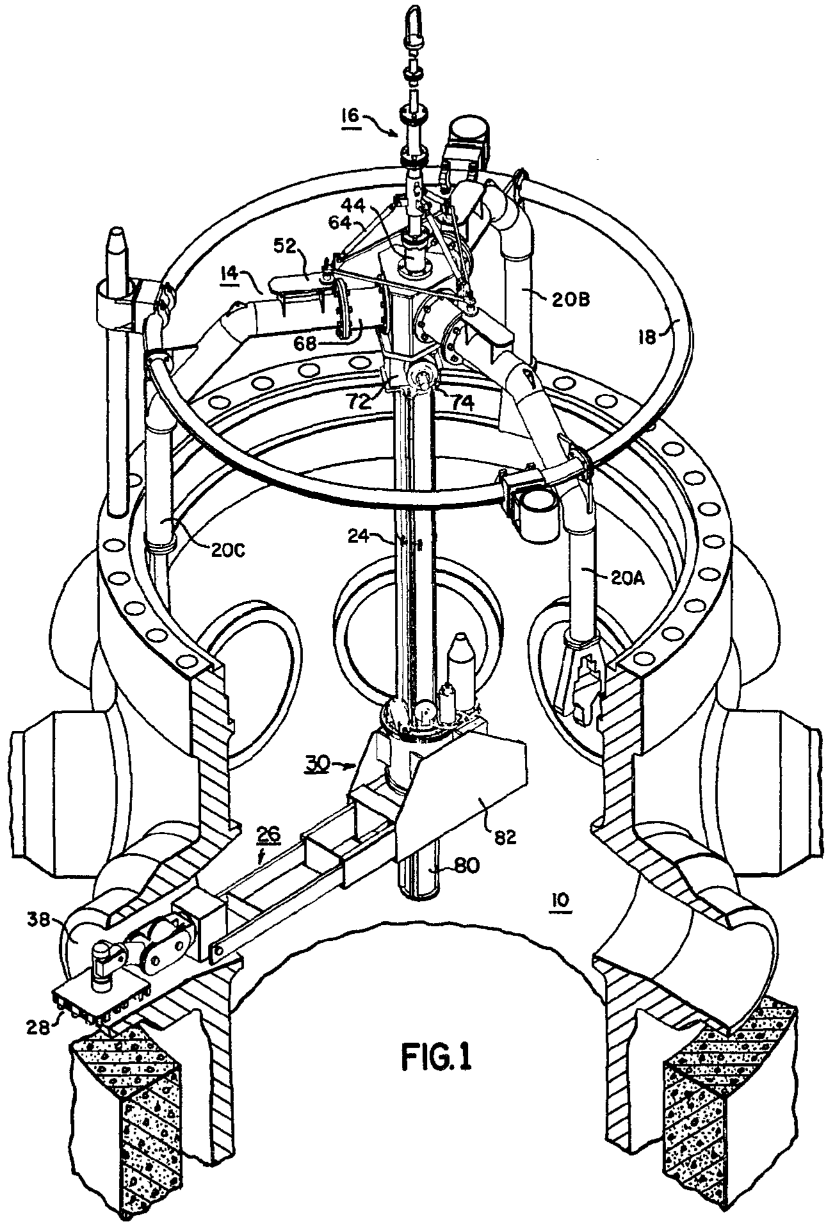
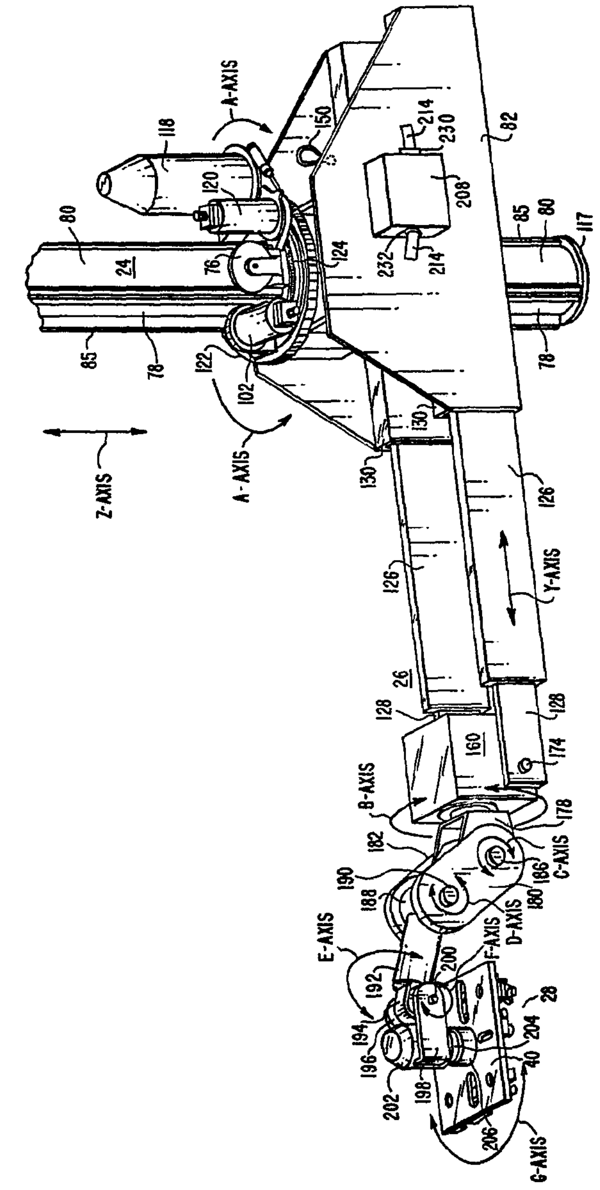


FIG. 1



Z-AXIS
A-AXIS
A-AXIS
Y-AXIS
B-AXIS
C-AXIS
D-AXIS
E-AXIS
F-AXIS
G-AXIS

FIG. 2

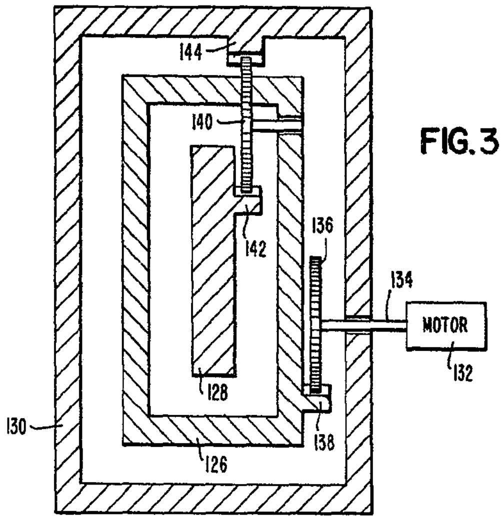


FIG. 3

1573593 COMPLETE SPECIFICATION

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

Sheet 4

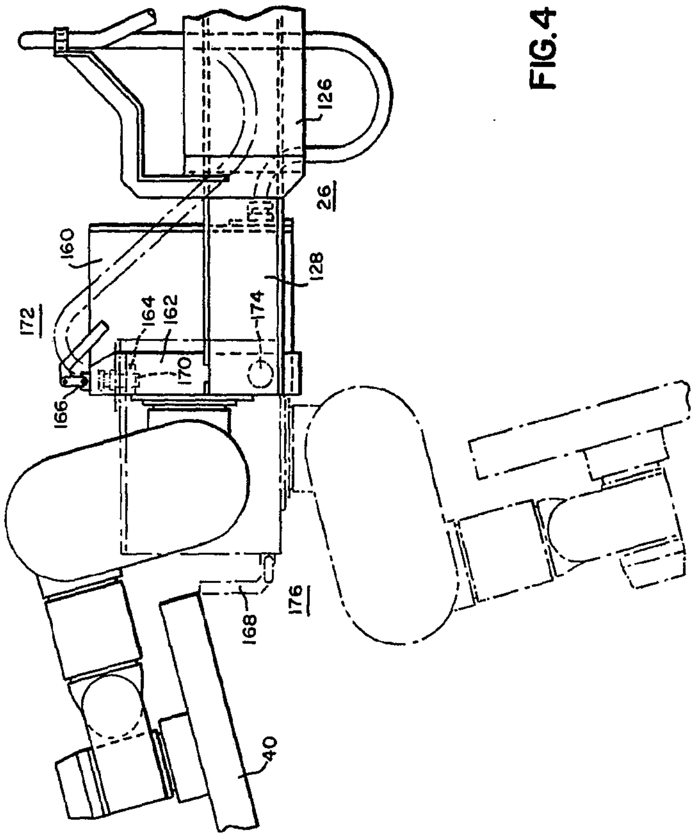


FIG.4