PATENT SPECIFICATION (11) 1599699

1599699

(21) Application No. 12286/80 (22) Filed 31 May 1978 (19)

(62) Divided out of No. 1599698

(44) Complete Specification published 7 Oct. 1981

(51) INT. CL.³ B25J 3/00

(52) Index at acceptance

B8H 300 304 404 560 DV

(72) Inventors LESTER WALTER HAAKER
and DEMETRIUS GEORGE JELATIS

(54) COUNTERWEIGHT SYSTEM FOR MASTER-SLAVE MANIPULATOR

(71) We, CENTRAL RESEARCH LABORATORIES, INC., a coporation organised and existing under the laws of the State of Minnesota, United States of America, of Route 2, Red Wing, Minnesota 55066, 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 remote control master-slave manipulators of the type by which an operator on one side of a protective barrier wall engages a handle in movements which are reproduced in a tong or other tool on the opposite side of the barrier wall. The role of such manipulators in the nuclear industry has changed from relatively simple laboratory instruments to work-horses of the industry. Emphasis has shifted from simple remote handling capability to considerations for overall manipulator performance including decontamination and maintenance considerations, higher manipulator handling capacities, reliability considerations, and overall operating efficiency. The present invention is directed to a manipulator which satisfies the demands imposed by this new role and at the same time includes considerations for exchangeability with existing manipulator systems allowing retrofitting of existing facilities with the manipulator according to the present invention.

In the past thirty years or so, master-slave manipulators have evolved from simple mechanical devices capable of basic movements and functions to highly sophisticated systems of greatly enhanced capability of efficiency. Early improvements included "Y" motion indexing to extend the forward reach of the manipulator and to facilitate installation, lateral rotation or side canting of the slave arm relative to the master arm, and "Z" motion extension by which the length of the slave arm is increased relative to the master arm. Systems have been developed for translation of linear motions into rotary motions for transfer through rotary seals in order to insure safe separation of the operator's environment and that of the work area. Specific improvements have been made in handles, wrist joints, tong mechanisms, and the like.

According to the invention there is provided a remote control master-slave manipulator for performing work on the opposite side of a barrier wall, said manipulator comprising a rotatable horizontal support adapted to extend through said barrier wall, a longitudinally extensible master arm pivotally connected to one end of said horizontal support and rotatable therewith and a longitudinally extensible slave arm pivotally connected to the opposite end of said horizontal support and rotatable therewith, means within said horizontal support for translating linear motion to rotary motion for transfer through the barrier wall and retranslating to linear motion, said manipulator characterized by:

A) said horizontal support comprising a rotatable through tube, a master transfer assembly secured to the through tube at one end and a slave transfer assembly secured to the throught tube at the opposite end,

B) said master transfer assembly comprising:

1) a generally cylindrical housing abutting the through tube at one end,

2) pivot means supporting the master arm at the opposite open end,

3) a rotary Y motion element journaled for limited rotational movement within said housing,

4) link means coupling said rotary element to the master arm for transmission of Y motion,

5) a longitudinally Y motion shaft journaled for rotation within said housing, and movable responsive to rotation of said rotary

element, and

C) dual counterweight means on said master transfer assembly operable in opposite directions responsive to rotation of said Y-motion shaft.

The manipulator according to the present invention is illustrated in the accompanying drawings in which like numerals refer to corresponding parts and in which:

Figure 1 is an elevation, partly in section and partly broken away, showing the manipulator mounted in a protective barrier wall;

Figure 2 is a front elevation, from the operator's point of view, of the master arm subassembly of the manipulator shown partly in section and partly broken away;

Figure 3 is a similar right side elevation of the master arm subassembly;

Figure 4 is a left hand elevation of the master transfer and rotary counterweight assembly of the manipulator;

Figure 5 is a plan view, partly in horizontal section on the line 5—5 of Figure 4 and in the direction of the arrows, of the master transfer and rotary counterweight assembly;

Figure 6 is a front elevation (operator's view) of the master transfer and rotary counterweight assembly;

Figure 7 is a similar section on the line 7—7 of Figure 5;

Figure 8 is a fragmentary section on the line 8—8 of Figure 7 showing the gear train for operating the rotary counterweights;

Figure 9 is an end elevation from the wall side of the master transfer and counterweight assembly;

Figure 10 is a fragmentary side elevation showing the slave end of the seal tube assembly which extends through the barrier wall;

Figure 11 is a horizontal section through the seal tube on the longitudinal axis thereof;

Figure 12 is a vertical section through the seal tube on the line 12—12 of Figure 13 and in the direction of the arrows;

Figure 13 is an end elevation of the slave arm end of the seal tube assembly;

Figure 14 is an end elevation of the master arm end of the seal tube assembly;

Figure 15 is a horizontal section through the slave transfer assembly on the line 15—15 of Figure 18 and in the direction of the arrows;

Figure 16 is a vertical section through the slave transfer assembly on the longitudinal axis thereof;

Figure 17 is an enlarged fragmentary section showing details of the mechanism for transfer of Y motion from the seal tube;

Figure 18 is an end elevation (operator's view) of the slave transfer assembly;

Figure 19 is a section on the line 19—19 of Figure 15 and in the direction of the arrows;

Figures 20 and 20A are a left side elevation of the slave arm assembly (from the operator's point of view), shown partly in section and partly broken away;

Figure 21 is a rear (cell side) elevation of the slave pivot assembly;

Figure 22 is a left hand elevation thereof; and

Figure 23 is a top view thereof.

The complete manipulator, of which the present invention is a part, and its mode of operation, are fully illustrated and described in application No. 25607/78 (Serial No. 1599698), of which this application is a division. Only those parts of the manipulator which are directly related to the Y-motion counterweight system are identified and described in detail herein. However, because the manipulator includes associated systems for performing other motions and functions, both independently and simultaneously with the Y motion counterweight system, other parts are necessarily shown in the drawings.

Throughout this application the manipulator is described and illustrated in terms of a single horizontal support with a single master arm and a single slave arm. It is to be understood, however, that in virtually all instances the manipulators are employed in laterally spaced pairs so that the operator, by the use of two master control arms, is able to manipulate two slave arms in order to reproduce the action of a pair of hands in the remote area on the opposite side of the barrier wall. Although illustrated and described with reference to a sealed manipulator, sealing is not an essential feature of the invention.

General Arrangement of Parts (Figure 1):

Referring now to the drawings, and particularly to Figure 1, the remote control master-slave manipulator according to the present invention comprises generally a master arm assembly, indicated generally at 10, connected through a master transfer assembly, indicated generally at 11, to a horizontal seal tube assembly, indicated generally at 12. The seal tube assembly 12 functions, along with master and slave transfer assemblies, as a horizontal support for the master and slave arms and extends through a generally vertical barrier or shielding wall 13, being mounted therein in a horizontal tube 14 secured so as to be structurally integral with the wall. A slave arm assembly, indicated generally at 15, is pivotally connected to a slave transfer assembly, indicated generally at 16, which in turn is connected to the seal tube assembly 12 on the opposite side of the barrier wall. Wall 13 is provided with a window 17 of approximately the same thickness as the wall.

A handle 18 is secured to the wrist joint 19 at the lower end of the master arm assembly.

A tong 20, or other working tool, is secured to the wrist joint 21 at the lower end of the slave arm. In normal non-operating position, the master arm 10 and the slave arm 15 are balanced to hang generally vertically. The master arm assembly 10 with its transfer assembly 11, the slave arm assembly 15 with its transfer assembly 16, and the seal tube assembly 12, are all completely separable units. These units are standardized and are interchangeable with different corresponding units in the event of failure or contamination or one or two of these units making up the manipulator, without the necessity of replacing all of the manipulator units. Connections are made through rotary mechanical couplings at the interface between adjacent units.

As indicated in Figure 1, the slave arm 15 may be indexed forwardly or backwardly (in Y motion) relative to the master arm. The extended length of the slave arm (Z motion) can be indexed relative to the master arm. Also, as in Patent Specification No. 876,736, the slave arm may be indexed laterally (X motion) to the right or left relative to the master arm.

The Master Arm (Figures 1—3):

The master arm assembly includes a relatively stationary part or trunk tube comprising a pair of spaced apart parallel tubular guides 22 supported in an intermediate pivot frame 24 and secured at their respective ends in a top bracket 25 and bottom bracket 26. This relatively stationary part of the master arm is pivotally connected at 27 to the master transfer assembly 11 forming part of the horizontal support for the manipulator. The master arm also includes a relatively movable part comprising a boom tube 28 which is longitudinally reciprocable relative to the stationary part of the arm. The lower end of the movable boom tube carries a wrist joint which may be the type illustrated and described in Patent Specification No. 1,236,006.

Master Transfer Assembly (Figures 1 and 4—9):

The master transfer assembly, indicated generally at 11, comprises part of the horizontal tubular support of the manipulator. The transfer assembly comprises an outer housing 60, adapted to be fixed to and rotate with the seal tube assembly 12, and an inner housing 62 suitably journaled so as to be rotatable relative to the outer housing 60. Inner housing 62 carries a pair of spaced apart arms 64 and 66, the ends of which carry a pair of studs 68 and 70 on which the master arm assembly 10 is pivotally supported on pivot axis 27.

Pivotal movement of the master arm assembly toward and away from the wall (Y motion) is transmitted through a link, indicated generally at 128, pivotally connected at one end at 129 to the master arm pivot frame 24 and pivotally connected at the other end at 130 to an arm 131 coupled to a shaft 132 journaled for rotation within master transfer housing 60. Link 128 is preferably in the form of a screw actuator driven by electric motor 133. The link is flexibly coupled to compensate for lateral rotation. At the same time, it forms a rigid connection for transmission of movement of the master arm about its pivot 27 to cause corresponding pivotal movement of the slave arm. By actuation of motor 133, the effective length of the link can be increased or shortened to index the slave arm relative to the master arm.

Shaft 132 is coupled to a rocker arm 134 which carries a bevel gear 135 which meshes with a further bevel gear 136 to rotate shaft 137 which terminates in coupling 138 for transmission of Y motion to the seal tube.

The slave arm in Y motion is counterbalanced by a pair of oppositely movable counterweights 140 and 141 located on the master arm side of the wall. The counterweights are carried by arms 142 and 143, respectively, which in turn are mounted for movement with rings 144 and 145, respectively, in face-to-face abutment and journaled for rotation about master transfer housing 60. As best seen in Figures 7 and 8, rings 144 and 145 are adapted to be rotated in opposite directions in response to rotation of Y motion shaft 137 in order to move arms 142 and 143 and their counterweights 140 and 141 in opposite directions. A pinion gear 148 is mounted on Y motion shaft 137 for rotation therewith. Gear 148 meshes with gear 149 rotatable on stub shaft 150, which in turn meshes with gear 151 rotatable on stub shaft 152. Gear 151 in turn meshes with ring gear 146 to rotate counterweight ring 144. Counterweight ring 145 is rotated in the opposite direction by virtue of gear 148 also meshing with gear 153 rotatable on stub shaft 154 and meshing with ring gear 147.

When the slave arm 15 is perpendicular to the horizontal axis of the manipulator through tube 12, the counterweight arms 142 and 143 are aligned and diametrically opposite arm 15 and the total mass moment of the counterweight system is adjusted to balance the slave arm. As the slave arm is displaced in Y motion, the counterweight arms are displaced in opposite directions in X motion through angles equal to the Y motion displacement angle. Thus, by having a pair of equal weights 140 and 141 of suitable mass on arms 142 and 143, the balance is maintained at all times. Normally, manipulators are used in parallel pairs closely spaced within the reach of the operator and quite often simultaneously indexed in Y motion to reach a work object. As counterweight 140 of

a right manipulator is moved in one direction, the same counterweight of the adjacent left manipulator is moved in the same direction. In doing so, the path of left counterweight 140 may overlap the path of right counterweight 141 moving in the opposite direction. However, because of the method of mounting of the counterweights on opposite sides of the displaced counterweight arms, the counterweights are free to move relative to each other without interference.

The motion transfer coupling 138 for Y motion protrudes from master transfer assembly end plate 164. A pair of locating and orientation pins 165 and 166 also project from end plate 164 to assist in connection of the master transfer assembly to the seal tube assembly.

Seal Tube Assembly (Figures 1 and 10—14):

The horizontal seal tube assembly or through tube 12 is adapted to extend through the barrier wall mounted in horizontal tube 174. Tube 174 is sealed in the tube 14 in the wall opening by compression seal rings 170 pressure applied to compression ring 171 by screws 172 to cause the rings to expand radially outwardly and tightly engage the surface of the opening in sealing relationship. Tube 174A is journaled within tube 174 so as to be freely rotatable therein.

Tube 174A is sealed in tube 174 by means of an annular rotary shaft seal 173 which may be, for example, of the type shown and described in Patent Specification No. 1,226,690 or equivalent shaft sealing means, such as the so-called "Ferro-Fluidic" type.

The end plate 164 of the master transfer assembly is adapted to fit in face-to-face abutment with a mirror image end plate 175 of the seal tube (Figure 14). Orientation pins 165 and 166 of the master transfer assembly engage sockets 176 and 177, respectively, in the seal tube end plate. The two end plates are secured together as by bolts or equivalent fastening means. Y motion master transfer coupling 138 engages seal tube coupling 183.

Coupling 183 is splined to be rotatable with a horizontal shaft 189 which extends through the length of the seal tube and terminates in a further coupling 195 in the seal tube end plate 196 at the slave end. Coupling 183 is spring loaded and provided with ratchet lock means for engaging similar lock means in seal tube face plate 175 so that upon assembly and disassembly of the seal tube and master transfer assembly, the seal tube coupling and shaft retain their proper orientation. When the master transfer end plate is connected to the seal tube end plate, the master transfer couplings project sufficiently far that upon engagement with the corresponding seal tube couplings, the coupling 183 on shaft 189 is forced toward the slave arm sufficiently far to release the locking means and permit rotation of the shaft.

Shaft 189 is provided with appropriate seals to prevent transmission of contaminating substances from the slave cell to the operator's area. Preferably these are Ferro-Fluidic seals. Before terminating in coupling 195 in end plate 196, shaft 189 extends through an intermediate end plate 197 at the slave cell end of the seal tube. End plate 196 is movable relative to the intermediate end plate 197 to facilitate coupling of the slave transfer assembly 16 to the seal tube.

Slave Transfer Assembly (Figures 1 and 15—19):

The slave transfer assembly 16 is enclosed within a rigid tubular housing rigidly connected to and rotatable with the seal tube assembly 12. The slave transfer housing is provided with a pair of projecting ears 235 and 236 engageable, respectively, with the notched seats 227 of projecting arms 225 and 226 of the seal tube assembly. When the slave transfer assembly is seated between arms 225 and 226 of the seal tube, then movable end wall 196 of the seal tube is retracted to expose the coupling 195. At the same time, as arms 225 and 226 are retracted with the end wall, the entire slave transfer assembly is pulled into contact with the seal tube such that corresponding couplings are engaged for continued transfer of the various functional rotary motions. Thus, Y motion coupling 195 engages coupling 245. Locating pins 228 and 229 engage sockets 247 and 248 in the slave transfer assembly to insure proper engagement of the various couplings.

Coupling 245 is connected for rotation of horizontal shaft 255. As in the case of the seal tube coupling, slave transfer coupling 245 is splined to be rotatable with shaft 255 and longitudinally movable with respect to that shaft. The coupling is spring loaded and provided with ratchet lock means for maintaining the proper orientation of the coupling and shaft. When the slave transfer assembly is coupled to the seal tube assembly, the coupling is forced inwardly against spring pressure and the ratchet lock is released and the transfer shaft is properly oriented with the corresponding seal tube shaft.

Shaft 255 terminates in a bevel gear 265. Y motion bevel gear 265 meshes with bevel gear 275 coupled to rotate a rocker arm 277 which is journaled on transverse shaft 278 in the slave transfer housing. A pair of tie rods 279 and 280 are pivotally connected at 281 and 282, respectively, to the rocker arm 277 for pivotal movement of the slave arm about pivot axis 283. The slave arm is supported on a pair of pivot stub shafts 284 and 285 supported, respectively, in arms 286 and 287 extending from the slave transfer housing.

Slave Arm Assembly (Figures 1, 20 and 20A):

The slave arm assembly 15 is supported in arms 286 and 287 of the slave transfer assembly 16 for pivotal movement about pivot axis 283. Pivot bushings 298 and 299 (slave pivot assembly Figures 21—23) engage pivot stub shafts 284 and 285, respectively, of the slave transfer assembly. Tie rod 279 is pivotally connected at 300 and tie rod 280 is pivotally connected at 301 to the slave pivot housing 302. It will be seen that as the rocker arm 277 in the transfer assembly is rotated, the tie rods are moved in opposite directions to rotate the slave arm on the pivot axis 283 in response to corresponding movement of the master arm or by action of the Y indexing mechanism.

The slave arm is comprised of a plurality of telescoping tubular segments, a trunk tube 305, an intermediate tube 306 of lesser diameter, and a boom tube 307 of still lesser diameter. A wrist joint 21 corresponding to the master arm wrist joint 19 is mounted in the bottommost end of the boom tube 307.

Attention is hereby directed to the claims od our copending Application No. 25607/78 (Serial No. 1599698) and our copending Divisional Application No. 12287/80 (Serial No. 1599700).

WHAT WE CLAIM IS:—

1. A remote control master-slave manipulator for performing work on the opposite side of a barrier wall, said manipulator comprising a rotatable horizontal support adapted to extend through said barrier wall, a longitudinally extensible master arm pivotally connected to one end of said horizontal support and rotatable therewith and a longitudinally extensible slave arm pivotally connected to the opposite end of said horizontal support and rotatable therewith, means within said horizontal support for translating linear motion to rotary motion for transfer through the barrier wall and retranslating to linear motion, said manipulator characterized by:

A) said horizontal support comprising a rotatable through tube, a master transfer assembly secured to the through tube at one end and a slave transfer assembly secured to the through tube at the opposite end,

B) said master transfer assembly comprising:

1) a generally cylindrical housing abutting the through tube at one end,

2) pivot means supporting the master arm at the opposite open end,

3) a rotary Y motion element journaled for limited rotational movement within said housing,

4) link means coupling said rotary element to the master arm for tranmission of Y motion,

5) a longitudinal Y motion shaft journaled for rotation within said housing, and movable responsive to rotation of said rotary element, and

C) dual counterweight means on said master transfer assembly operable in opposite directions responsive to rotation of said Y-motion shaft.

2. A manipulator according to Claim 1 wherein said counterweight means comprises:

A) a pair of concentric rings journaled for rotation about said master transfer housing adjacent the through tube end thereof,

B) an annular ring gear within each of said rings,

C) a radial arm extending outwardly from each of said rings and a weight on each of said arms,

D) gear means interconnecting said Y motion shaft and ring gears for rotation of the ring gears in opposite directions.

3. A manipulator according to Claim 1 wherein said counterweight means comprises:

A) a pair of concentric rings journaled for rotation about said master transfer housing adjacent the through tube end thereof,

B) an annular ring gear within each of said rings,

C) a radial arm extending outwardly from each of said rings and a weight on each of said arms,

D) a first pinion gear on said Y motion shaft,

E) a second gear engaged with said first gear and with one of said ring gears to rotate one of the weights in one direction, and

F) a third and fourth gear engaged with each other, said third gear engaged with said first gear and said fourth gear engaged with the other of said ring gears to rotate the other of said weights in the opposite direction.

4. A manipulator according to Claim 2 wherein the weight on one of said radial arms is displaced forwardly of that arm and the weight on the other of said arms is displaced rearwardly of that other arm.

5. A manipulator according to Claim 1 wherein:

A) a gear is mounted on said rotary element,

B) a further gear is mounted on said Y motion shaft, and

C) said gears are in engagement for rotation of said shaft responsive to movement of the rotary element.

6. A manipulator according to Claim 5 wherein:

A) said rotary member is a rocker arm journaled for pivotal movement about a transverse axis, and

B) said engaging gears on said rotary element and longitudinal Y motion shaft are bevel gears.

7. A manipulator according to Claim 1

wherein said link means is a screw actuator driven by an electric motor.

For the Applicants:
FRANK B. DEHN & CO.,
Chartered Patent Agents,
Imperial House,
15—19 Kingsway,
London WC2B 6UZ.

Printed for Her Majesty's Stationery Office by Burgess & Son (Abingdon) Ltd.—1981. Published at The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

1599699 COMPLETE SPECIFICATION

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

Sheet 1

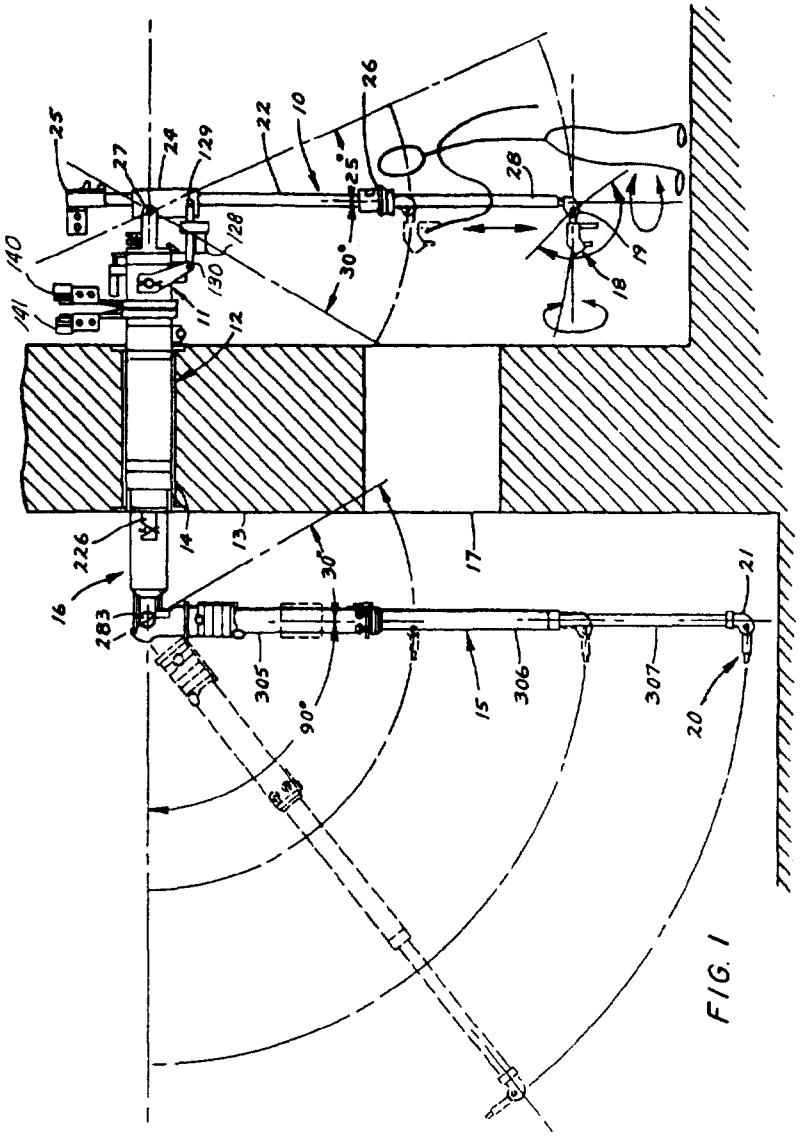


FIG. 1

1599699 COMPLETE SPECIFICATION
15 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheet 2

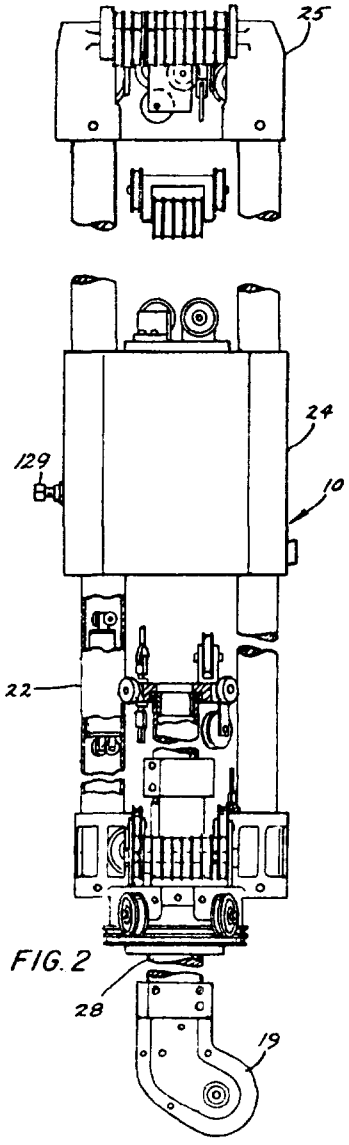


FIG. 2

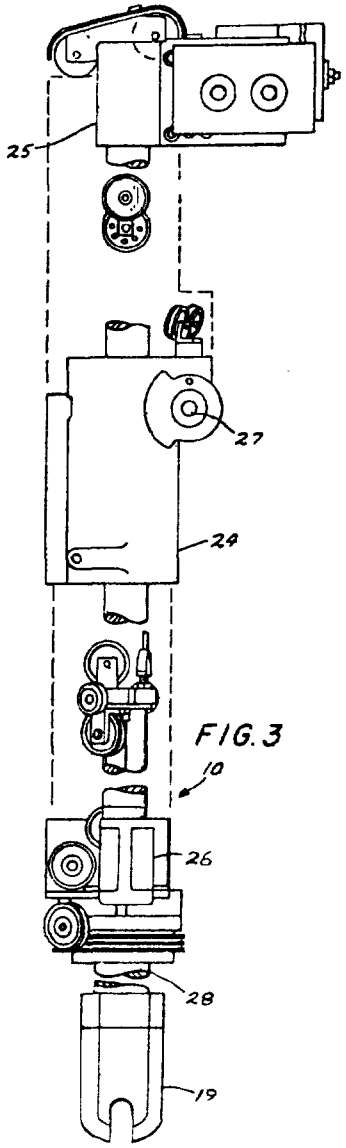
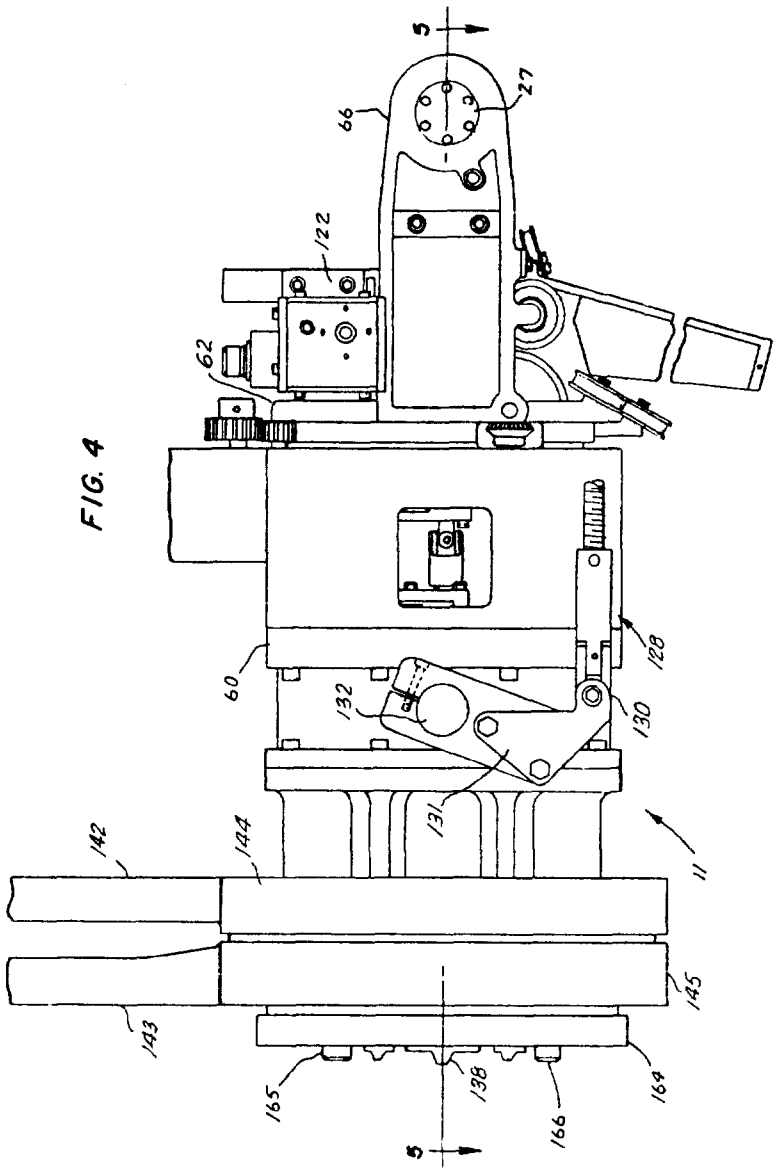


FIG. 3

1599699 COMPLETE SPECIFICATION
15 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheet 3

FIG. 4



1599699 COMPLETE SPECIFICATION
15 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheet 4

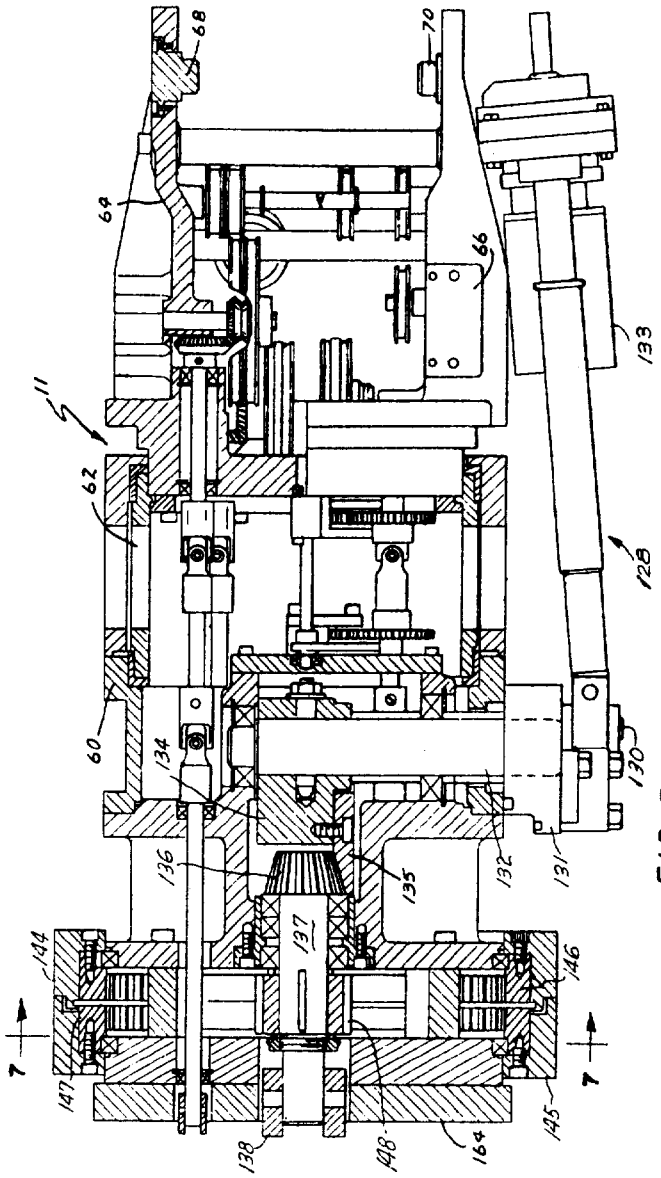


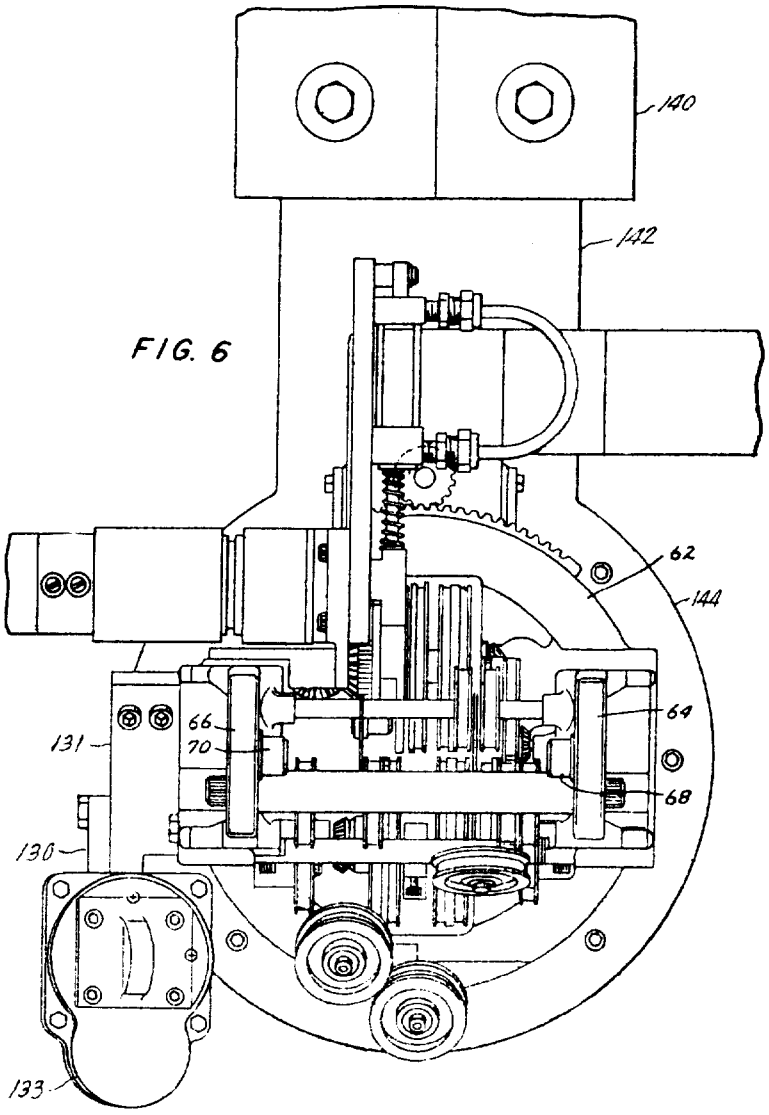
FIG. 5

1599699 COMPLETE SPECIFICATION

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

Sheet 5

FIG. 6



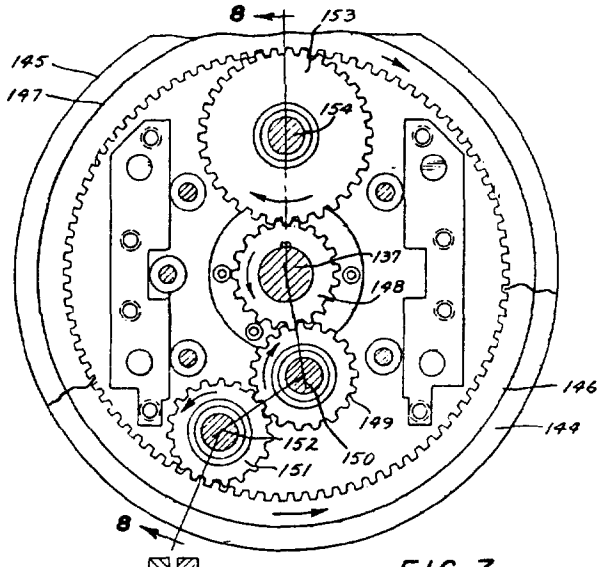

8
153
145
147
154
137
148
146
149
144
152
150
151
8

FIG. 7

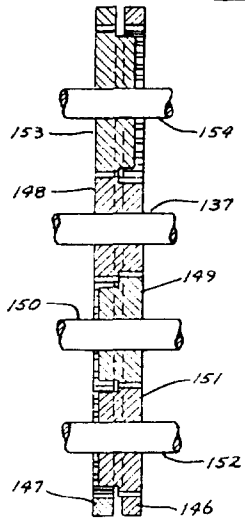

153
154
148
137
149
150
151
152
147
146

FIG. 8

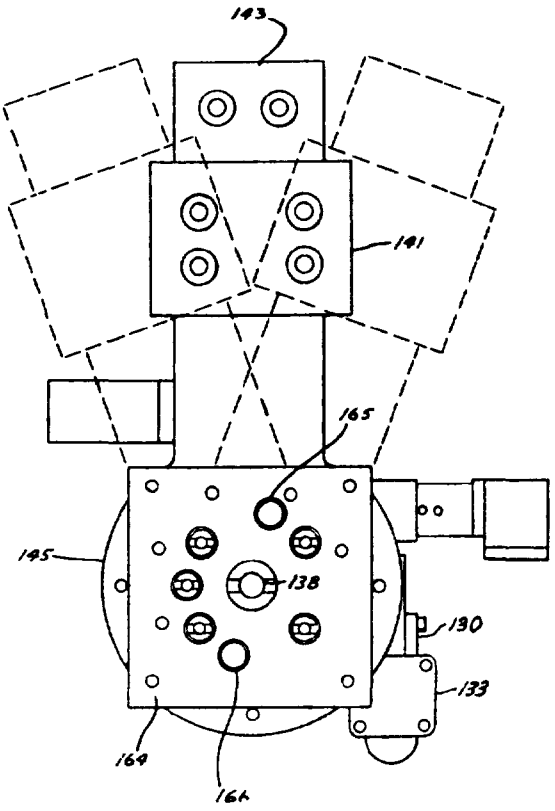


FIG. 9

1599699 COMPLETE SPECIFICATION
15 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheet 8

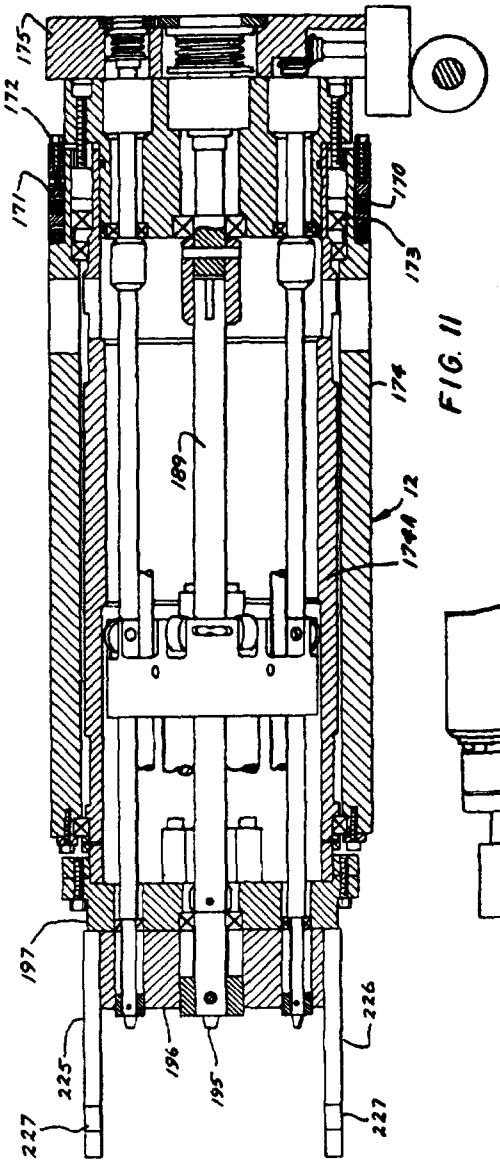
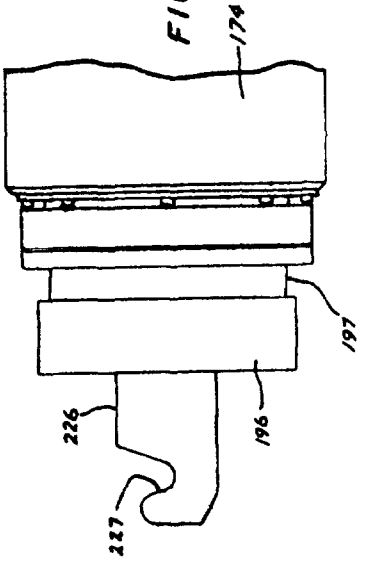


FIG. 11

FIG. 10



1599699 COMPLETE SPECIFICATION

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

Sheet 9

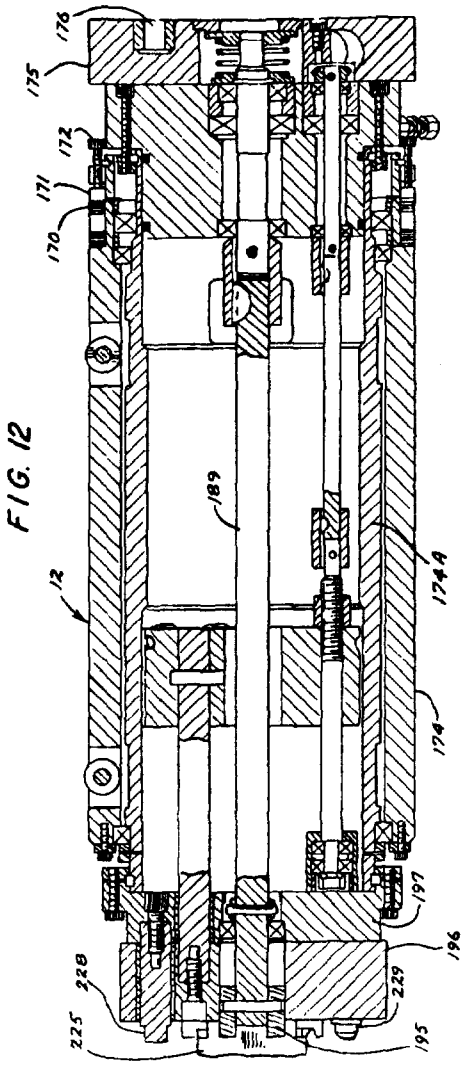


FIG. 12

1599699 COMPLETE SPECIFICATION
15 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheet 10

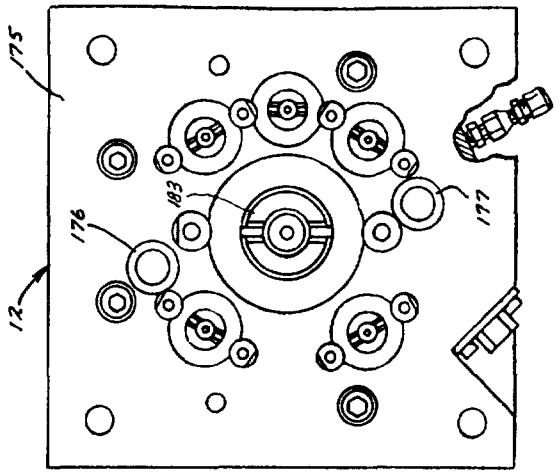


FIG. 14

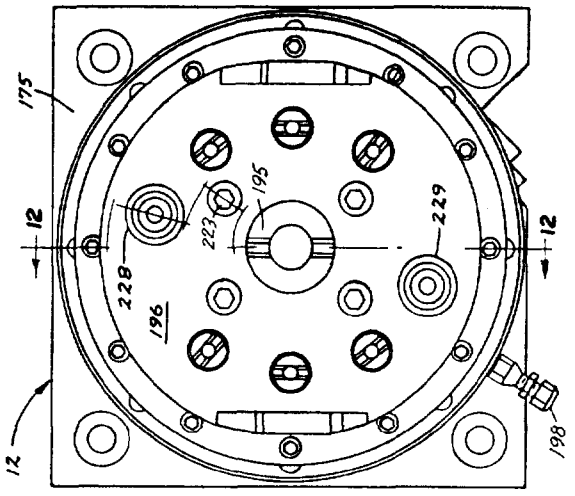


FIG. 13

1599699 COMPLETE SPECIFICATION
15 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheet 11

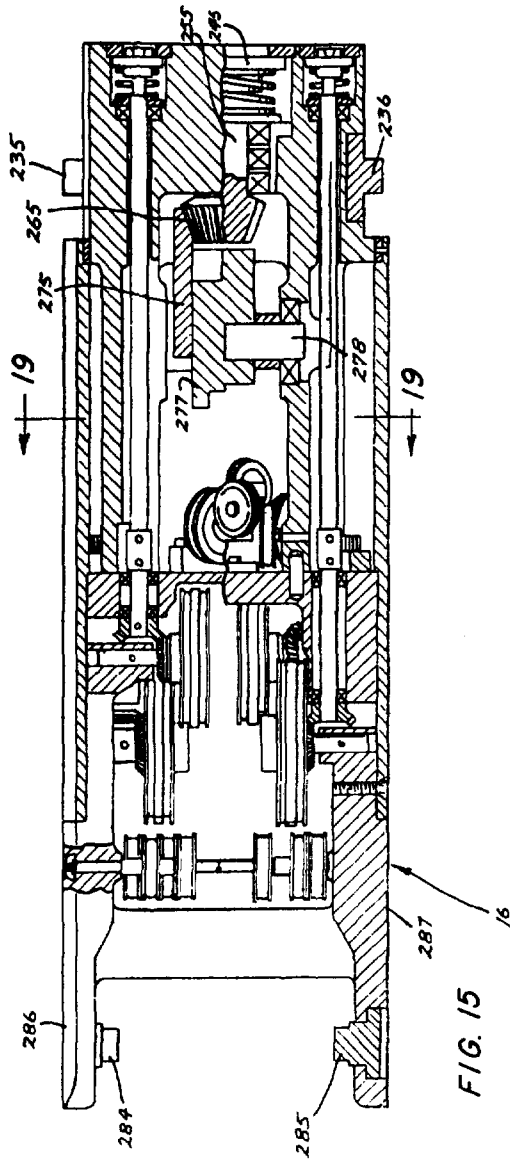


FIG. 15

1599699 COMPLETE SPECIFICATION
15 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheet 12

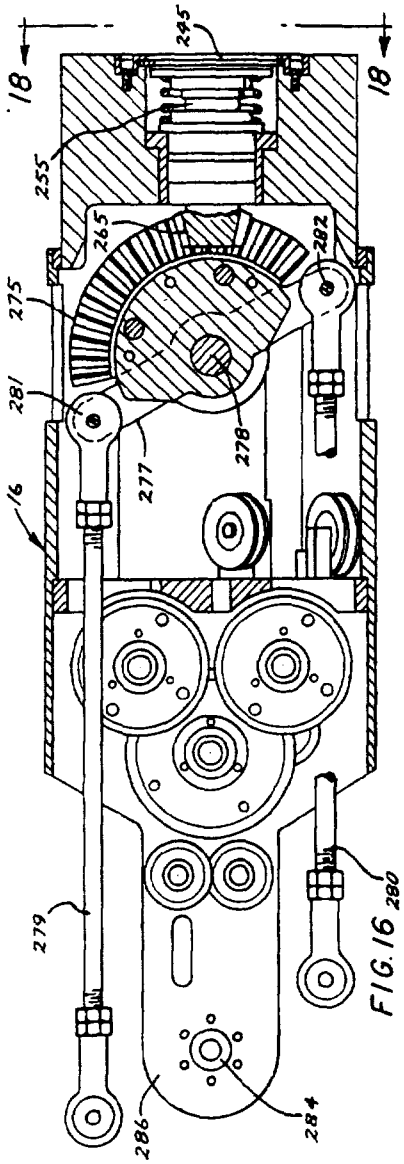


FIG. 16

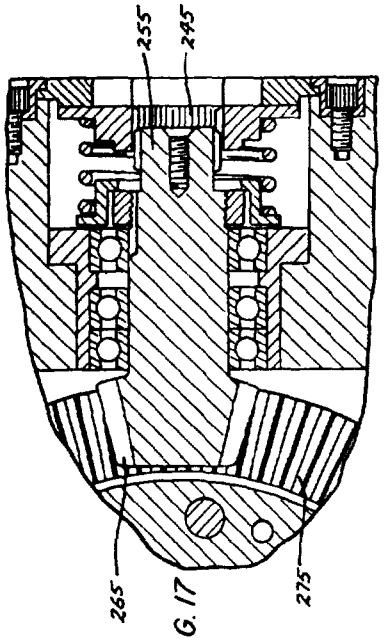


FIG. 17

1599699 COMPLETE SPECIFICATION
15 SHEETS This drawing is a reproduction of the Original on a reduced scale
Sheet 13

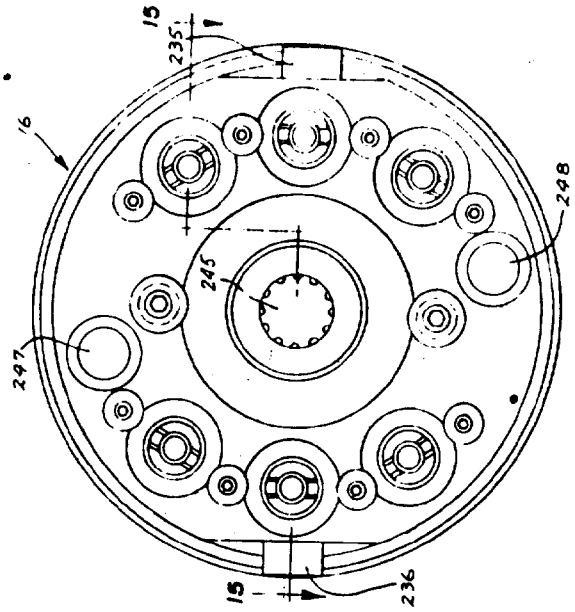


FIG 18

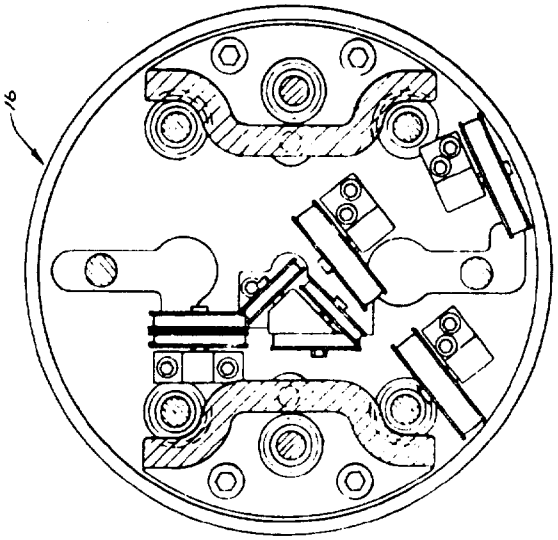


FIG 19

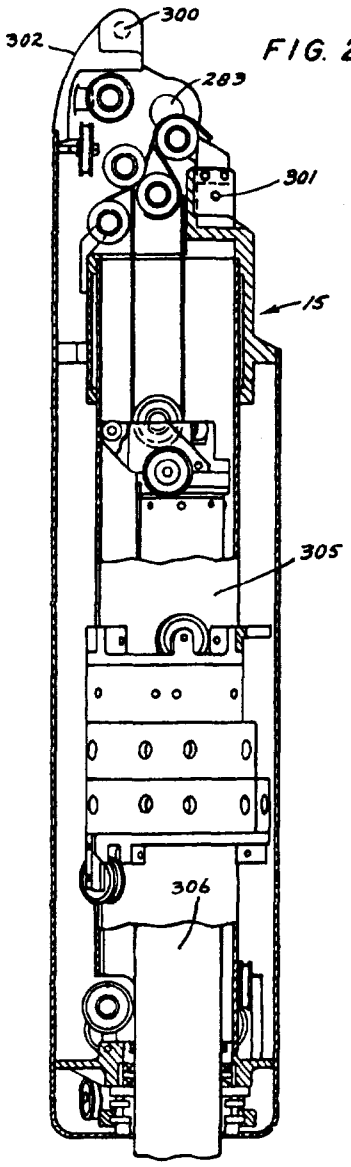


FIG. 20

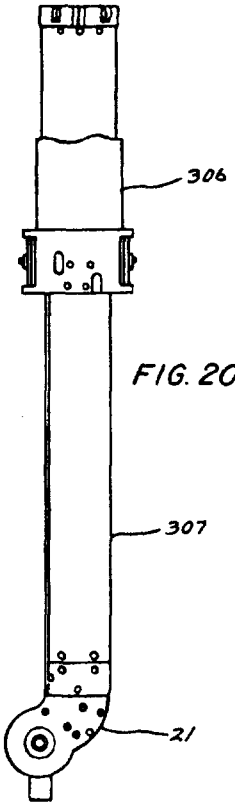


FIG. 20A

1599699 COMPLETE SPECIFICATION
15 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheet 15

FIG. 23

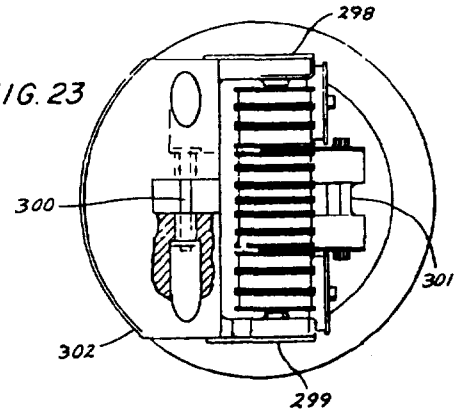


FIG. 21

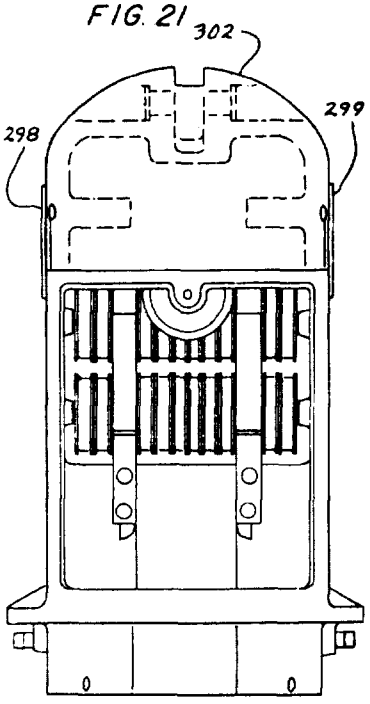


FIG. 22