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(54) Annular foreign object search and retrieval apparatus.

(57) An apparatus (10) is for foreign object search and retrieval in annular space (12) around a tube bundle (14) of a nuclear power steam generator (16). A lance drive (18) through which a stiff, nonbuckling lance (20) extends has a nose piece (22) extending into handhole (24) of the steam generator (16). The lance drive (18) is mounted in front of the handhole (24) by a support rail (26) to which the lance drive (18) is mounted. A lance guide (28) is connected between rear (30) of the lance drive (18) and a lance takeup drum (32). The lance drive (18) has external nosepiece (22) serving as a guide for the stiff, nonbuckling lance (20) as it exits from the lance drive (18). The nosepiece (22) has a series of roller bearings (36) through which the stiff, nonbuckling lance (20) passes to curve it into the annular space (12). The stiff, nonbuckling lance (20) consists of a plurality of substantially vertically extending, one piece hosebar supports (38) strung on supporting cables (40) in a manner similar to beads on a string. Each of the hosebar supports (38) has a convex front surface (42) and a concave rear surface (44). The convex front surface (42) fits into the concave rear surface (44) of the next adjacent hosebar support (38). With the surfaces (42) and (44) engaging in this manner, the stiff, nonbuckling lance (20) has a substantially increased vertical stiffness, so that it can extend for substantial distances from the nosepiece (22) into the annular space (12) without lateral support.

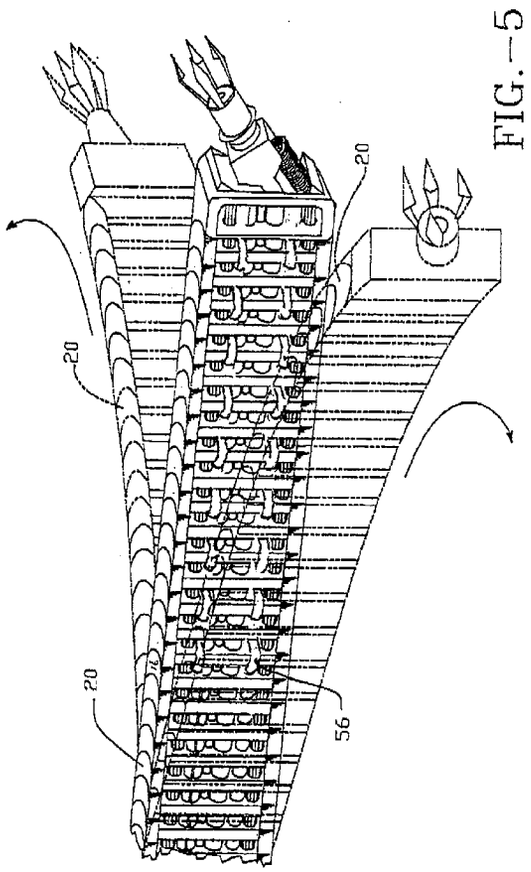

FIG. -5

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BACKGROUND OF THE INVENTION

1. Field of the Invention:

The present invention relates generally to a robotic system that is useful in nuclear power plants and other structures with a difficult to access geometry. More particularly, it relates to such a system which is capable of locating and removing foreign objects that have been accidentally introduced into such structures with a difficult to access geometry, such as in the annular space surrounding tube bundles of a nuclear power plant's steam generators.

2. Description of the Prior Art:

Nuclear power generation equipment consists of two major parts, the reactor and the steam generator. The steam generator includes a heat exchanger, which, in simple terms, consists of a bundle of thin wall tubes, which are tightly spaced and arranged in a matrix-like fashion. The spacing between the tubes is less than 0.5 inches, and the tube height extends to many feet. Hot reactor coolant is pumped through the tubes, which in turn heats water under pressure above the boiling point to several hundred degrees, thus generating steam.

During reactor shut down for refueling or any other reason, repair and maintenance technicians enter various areas, one of which is the steam generator housing. During such entry, accidental dropping of such items as welding rods, washers, screws and the like is possible. Such items can cause damage to the thin wall tubes if they are not retrieved. Repairing, replacing or plugging such damaged tubes is very expensive, both in terms of the labor involved and required reactor shut down. To date, it has been difficult to retrieve such items, due to the physical constraints of the steam generator geometry and the presence of radiation.

When a lance is introduced into the tube bundle, the lance is laterally supported by the tube bundle, and it can therefore be extended into the tube bundle substantially further than it could be extended without falling over in the absence of such lateral support. Such lateral support is not provided in the annular space surrounding the tube bundle. A lance intended for introduction into the annular space therefore requires substantially more structural integrity while retaining flexibility to move within the confines of the annular space than a lance that is intended for introduction into the tube bundle.

U.S. Patent 4,638,667, issued January 27, 1987 to Zimmer et al. discloses a remote probe positioning apparatus including a flexible tape which has an optical fiber cable running the length of the tape and a retractor tool at a distal end of the tape. However, no details are given on the construction and operation of the retractor tool. Further development is therefore required in order to provide a system for removing foreign objects which will meet the needs of nuclear power plant steam generator geometry and similar difficult to access geometries, especially for use in the annular space around the tube bundle in the steam generator geometry.

SUMMARY OF THE INVENTION

Accordingly, it is an object of this invention to provide a system for finding and retrieving foreign objects in a difficult to access geometry, such as the annulus of a nuclear power plant steam generator.

It is a further object of the invention to provide a flexible lance for accessing a difficult to access geometry which has sufficient flexibility to negotiate into the difficult to access geometry, but sufficient structural integrity so that it can be extended for substantial distances into the difficult to access geometry without lateral support.

The attainment of these and related objects may be achieved through use of the novel annular foreign object search and retrieval apparatus herein disclosed. An annular foreign object search and retrieval apparatus in accordance with this invention has a stiff, non-buckling lance for accessing an assembly having a difficult to access geometry. The lance comprises a stiff, non-buckling member having a distal end. An optical cable extends lengthwise along and within the stiff, non-buckling member for illuminating a portion of the difficult to access geometry. A video cable also extends lengthwise along and within the stiff, non-buckling member. A video camera is connected to the video cable at the distal end of the stiff, non-buckling member for forming an image of a scene visible from the distal end of the stiff, non-buckling member for transmission by the video cable. A retractor tool is mounted at the distal end of the stiff, non-buckling member. At least one actuating cable for the retractor tool extends lengthwise along and is free to move within the stiff, non-buckling member. The stiff, non-bucking member is configured to be driven into the difficult to access geometry. A rigid guide extends lengthwise of the stiff, non-buckling member. The stiff, non-buckling member is movably mounted along the rigid guide. The rigid guide has an end positioned to turn the stiff, non-buckling member in a predetermined angle with respect to an extending direction of the stiff, non-buckling member as the stiff, non-buckling member passes from the rigid guide through the end. A drive means drives the stiff, non-buckling member through the rigid guide. The stiff, non-buckling member comprises separate segments strung on at least one flexible cable which runs the length of the stiff, non-buckling member. The stiff, non-buckling member has sufficient flexiblility to curve laterally in the difficult to access geometry and sufficient stiffness

to extend suspended in cantilever fashion when extended in the difficult to access geometry without substantial lateral support.

The attainment of the foregoing and related objects, advantages and features of the invention should be more readily apparent to those skilled in the art, after review of the following more detailed description of the invention, taken together with the drawings, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a perspective view, partly in cross-section of a portion of an annular foreign object search and retrieval apparatus in accordance with the invention.

Figure 2 is an enlarged side view of the area 2 in Figure 1.

Figure 3 is an enlarged perspective view of a front portion of a flexible lance of the apparatus.

Figure 4 is an enlarged perspective view similar to that of Figure 3, but with a portion of the flexible lance in a different position.

Figure 5 is a perspective view, partially in phantom, showing positioning of the flexible lance of Figures 3-4.

Figure 6 is a perspective view of a portion of the flexible lance of Figures 3-5.

Figure 7 is a plan view showing details of a portion of the apparatus of Figure 1.

Figure 8 is a perspective view of a control panel for the apparatus of Figure 1.

DETAILED DESCRIPTION OF THE INVENTION

Turning now to the drawings, more particularly to Figure 1, there is shown an apparatus 10 for foreign object search and retrieval in annular space 12 around a tube bundle 14 of a nuclear power steam generator 16. A lance drive 18 through which a stiff, nonbuckling lance 20 extends has a nose piece 22 extending into handhole 24 of the steam generator 16. The lance drive 18 is mounted in front of the handhole 24 by a support rail 26 to which the lance drive 18 is mounted. A lance guide 28 is connected between rear 30 of the lance drive 18 and a lance takeup drum 32. The lance takeup drum 32 is mounted on one side of the lance drive 18, with counterweights 33 for the takeup drum on the other side of the lance drive 18. The lance drive 18 is as described in United States patents nos. 5 065 703 and 5 036 871.

In place of an internal guide member in the lance drive as described in those applications, the lance drive 18 has the external nosepiece 22 serving as a guide for the stiff, nonbuckling lance 20 as it exits from the lance drive 18. As is shown more clearly in Figure 2, the nosepiece 22 has a series of roller bearings 36 through which the stiff, nonbuckling lance 20 passes to curve it into the annular space 12. The lance drive 18 provides two degrees of motion for the stiff, nonbuckling lance 20, i.e., forward and backward translation by means of a sprocket drive 21 right behind the nosepiece 22, and rotation about the handhole 24 centerline, by rotation of the lance drive 18 with an enclosed gear drive (not shown).

Details of the stiff, nonbuckling lance 20 are shown in Figures 3 -6. As in the case of the flexible lance shown in United States Patent No. 5 036 871, the stiff, non-buckling lance 20 consists of a plurality of substantially vertically extending, one piece hosebar supports 38 strung on supporting cables 40 in a manner similar to beads on a string. As is best shown in Figure 6, each of the hosebar supports 38 has a convex front surface 42 and a concave rear surface 44. The convex front surface 42 of the hosebar supports 38 fits into the concave rear surface 44 of the next adjacent hosebar support 38. With the surfaces 42 and 44 engaging in this manner, the stiff, nonbuckling lance 20 has a substantially increased vertical stiffness, so that it can extend for substantial distances from the nosepiece 22 into the annular space 12 without lateral support. The interlocking feature of the hosebars 38 allows them to support the bending and twisting loads when the lance 20 is extended 100 inches.

In addition to the support cables 40, a positioning cable 46 (Figure 4) for qripper 48 extends through the hosebar supports 38 and is attached to base 49 of the gripper 48. Pulling on the positioning cable 46 moves the gripper 48 from the position shown in Figure 4 to the position shown in Figure 3. Springs 50 (Figure 3) oppose the upward motion of the gripper 48, so that the position shown in Figure 4 represents the normal position of the gripper 48 when force on the positioning cable 46 is released. An actuating cable 52 for the gripper 48 also extends through the hosebar supports and is attached to qripper fingers 54, in the same manner as in United States Patent No. 5 036 871. The gripper fingers 54 are spring loaded in their closed position. Pulling on the actuating cable 52 opens the fingers 54, and subsequently releasing the actuating cable 52 allows the fingers to close on an object to be grasped for removal from the annular space 12.

Steering cables 56 for the stiff, nonbuckling lance 20 are provided on either side of the stiff, nonbuckling lance, and are interwoven among the first 18 hosebars 38, i.e., pass alternatively in front of a portion of a hosebar and behind the portion on an adjacent hosebar, on the distal end of the stiff, nonbuckling lance, as best shown in Figure 4.

Pulling on the steering cables 56 will move the distal end to the left and right, as indicated in Figure 5.

In the stiff, nonbuckling lance 20, the hosebars 38 are made of different materials than in United States Patent No. 5 036 871 in which rigid nylon plastic was used for the hosebars. The hosebars 38 are made of

aluminum and stainless steel. Aluminum hosebars 38 are used for the first 48 inches of the stiff, nonbuckling lance 20 from the distal end, and for the last 42 inches, for both weight and cost reasons. The remaining portion of the stiff, nonbuckling lance 20, to give a total length extended from the nosepiece 22 of 165 inches, is formed from stainless steel hosebars 38 for added strength. The aluminum and stainless steel construction provides the torsional stiffness to support the loads when the lance 20 is fully extended.

To allow visual inspection of the annular space 12, a Welch Allyn Videoprobe minature video camera and light source 60 is mounted in block 62 at the distal end of the stiff, nonbuckling lance 20. Light for the light source and electrical signals to and from the video camera are transmitted by a fiber optic and electrical cable 64, which incorporates separate fiber optic and electrical cables.

Details of actuator package 70 inside the takeup drum 32 for the stiff, nonbuckling lance 20 are shown in Figure 7. The control of the lance sweep and end effector tilt and grapple is performed by linear actuators 72 and potentiometers 74 in take up reel 75. There are four linear actuators 72, two of which are shown and two potentiometers 74 used to actuate and control the lance and end effector motion. The stiff, nonbuckling lance is coiled around the take up reel 75 when it is not extended into the annular space 12.

Figure 8 shows a control panel 80 for the apparatus 10. The control panel includes a knob 82 connected to a rotary shaft encoder for controlling sweep of the lance 20 distal end from left to right by pulling on one of the steering cables 56, as determined by rotation of the knob 82. A pair of joysticks 84 and 86 respectively control tilting of the gripper 48 upward and downward and opening and closing of the fingers 54, by pulling on, respectively, positioning cable 46 and actuating cable 52.

In use, the lance 20 supports the gripper 48 above the floor 49 (called the tube sheet) of the annular space 12. The gripper 48 effectively hovers above the tube sheet as the lance drive 18 pushes and pulls the lance around the annulus 12. The gripper 48 has three degrees of freedom, i.e., side to side sweep of the lance 20 end, up and down tilt of the gripper 48, and opening and closing of the fingers 54.

It should now be readily apparent that an annular foreign object search and retrieval apparatus capable of achieving the stated objects of the invention has been provided. The system will find and retrieve foreign objects in a difficult to access geometry, such as the annular space surrounding the in bundle area of a nuclear power plant steam generator. The lance for accessing a difficult to access geometry of this system has sufficient flexibility to negotiate into the difficult to access geometry, but sufficient structural integrity so that it can be extended for substantial distances into the difficult to access geometry without lateral support.

It should further be apparent to those skilled in the art that various changes in form and details of the invention as shown and described may be made. It is intended that such changes be included within the spirit and scope of the claims appended hereto.

Claims

1. A system comprising, in combination, a stiff, nonbuckling lance for accessing an assembly having a difficult to access geometry, which comprises a stiff, non-buckling member having a distal end, an optical cable extending lengthwise along and within said stiff, non-buckling member for illuminating a portion of the difficult to access geometry, a video cable, a video camera connected to said video cable at the distal end of said stiff, nonbuckling member for forming an image of a scene visible from the distal end of said stiff, non-buckling member for transmission by said video cable, a retractor tool mounted at the distal end of said stiff, non-buckling member, and at least one actuating cable for said retractor tool extending lengthwise along and within said stiff, non-buckling member, said stiff, non-buckling member being configured to be driven into the difficult to access geometry, a rigid guide extending lengthwise of said stiff, non-buckling member, said stiff, non-buckling member being movably mounted along said rigid guide, said rigid guide having an end positioned to turn said stiff, non-buckling member in a predetermined angle with respect to an extending direction of said stiff, non-buckling member as said stiff, non-buckling member passes from said rigid guide through said end, a drive means for driving said stiff, non-buckling member through said rigid guide, said stiff, non-buckling member comprising separate segments strung on at least one flexible cable which runs the length of the stiff, non-buckling member, said stiff, non-buckling member having sufficient flexiblility to curve laterally in the difficult to access geometry and sufficient stiffness to extend suspended in cantilever fashion when extended in the difficult to access geometry without substantial lateral support.

2. The system of Claim 1 in which said retractor tool comprises a multi-prong retriever and said at least one actuating cable for said retractor tool comprises a tool operating wire connected to said retractor tool to open and close the multi-prong retriever.

3. The system of Claim 2 additionally comprising a positioning cable for said retractor tool extending

lengthwise along and within said stiff, non-buckling member and connected to said retractor tool to change position of said retractor tool on the distal end of said stiff, non-buckling member.

4. The system of Claim 3 additionally comprising at least one steering cable for said stiff, non-buckling lance extending lengthwise along said stiff, non-buckling member to change position of said stiff, non-buckling lance.

5. The system of Claim 4 in which said at least one steering cable comprises a pair of steering cables for moving said stiff, non-buckling member to the left and the right proximate to the distal end of said stiff, non-buckling member.

6. The system of Claim 5 in which said pair of steering cables is interwoven among said separate segments proximate to the distal end of said stiff, non-buckling member.

7. The system of Claim 1 in which said separate segments have front and rear surfaces that interlock with the rear and front surfaces of adjacent separate segments.

8. A foreign object search and retrieval apparatus for use in an assembly having a difficult to access geometry, which comprises a stiff, non-buckling member having a distal end, said stiff, non-buckling member comprising a plurality of separate segments strung on at least a pair of flexible cables, said segments extending transversely between said pair of flexible cables, said segments being parallel to one another, an optical cable extending lengthwise along and within said stiff, non-buckling member, a video cable, a video camera connected to said video cable at the distal end of said stiff, non-buckling member for forming an image of a scene visible from the distal end of said stiff, non-buckling member for transmission by said video cable, a retractor tool mounted at the distal end of said stiff, non-buckling member, and at least one actuating cable for said retractor tool extending lengthwise along and within said stiff, non-buckling member, said stiff, non-buckling member being configured to be driven into the difficult to access geometry, said stiff, non-buckling member having sufficient flexiblility to curve laterally in the difficult to access geometry and sufficient stiffness to extend suspended in cantilever fashion when extended in the difficult to access geometry without substantial lateral support.

9. A system comprising, in combination, a stiff, non-buckling member for accessing an annular space in a closed vessel, said stiff, non-buckling member having a distal end, and a rigid guide for moving said stiff, non-buckling means in the annular space, said stiff, non-buckling member for accessing comprising a plurality of separate, integrally formed hosebar supports, each comprising a pair of separate, longitudinally extending shapes engaging the separate shapes of adjacent hosebar supports and together defining stiff, non-buckling, longitudinally extending strips and a bar joining said pair of shapes, said bar having at least one correspondingly positioned aperture with respect to apertures in bars of the adjacent hosebar supports, a pair of flexible support members, each extending lengthwise through corresponding ones of each pair of the engaging separate, longitudinally extending shapes, an optical cable extending lengthwise along and within said stiff, non-buckling member for illuminating a portion of the difficult to access geometry, a video cable, a video camera connected to said video cable at the distal end of said stiff, non-buckling member for forming an image of a scene visible from the distal end of said stiff, non-buckling member for transmission by-said video cable, a retractor tool mounted at the distal end of said stiff, non-buckling member, and at least one actuating cable for said retractor tool extending lengthwise along and within said stiff, non-buckling member, said stiff, non-buckling member having sufficient flexibility to curve laterally in the difficult to access geometry and sufficient stiffness to extend suspended in cantilever fashion when extended in the difficult to access geometry without substantial lateral support.

10. A system comprising, in combination, a stiff, non-buckling lance for accessing an assembly having a difficult to access geometry, which comprises a stiff, non-buckling member having a distal end, said stiff, non-bucking member being configured to be driven into the difficult to access geometry, a rigid guide extending lengthwise of said stiff, non-buckling member, said stiff, non-buckling member being movably mounted along said rigid guide, said rigid guide having an end positioned to turn said stiff, non-buckling member in a predetermined angle with respect to an extending direction of said stiff, non-buckling member as said stiff, non-buckling member passes from said rigid guide through said end, a drive means for driving said stiff, non-buckling member through said rigid guide, said stiff, non-buckling member comprising separate serpents strung on at least one flexible cable which runs the length of the stiff, non-buckling member, said stiff, non-buckling member having sufficient flexibility to curve laterally in the difficult to access geometry and sufficient stiff-

ness to extend suspended in cantilever fashion when extended in the difficult to access geometry without substantial lateral support.

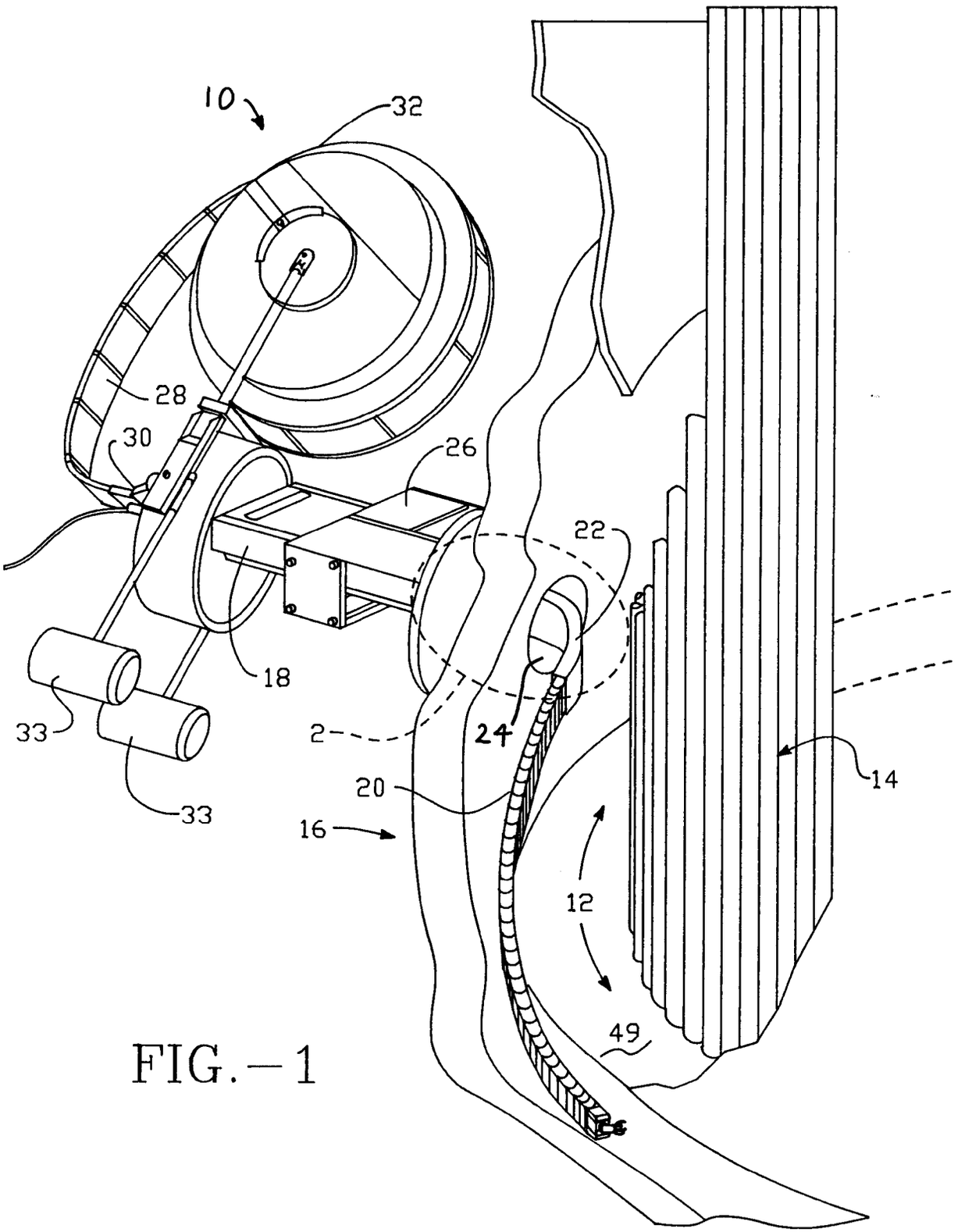

FIG.—1

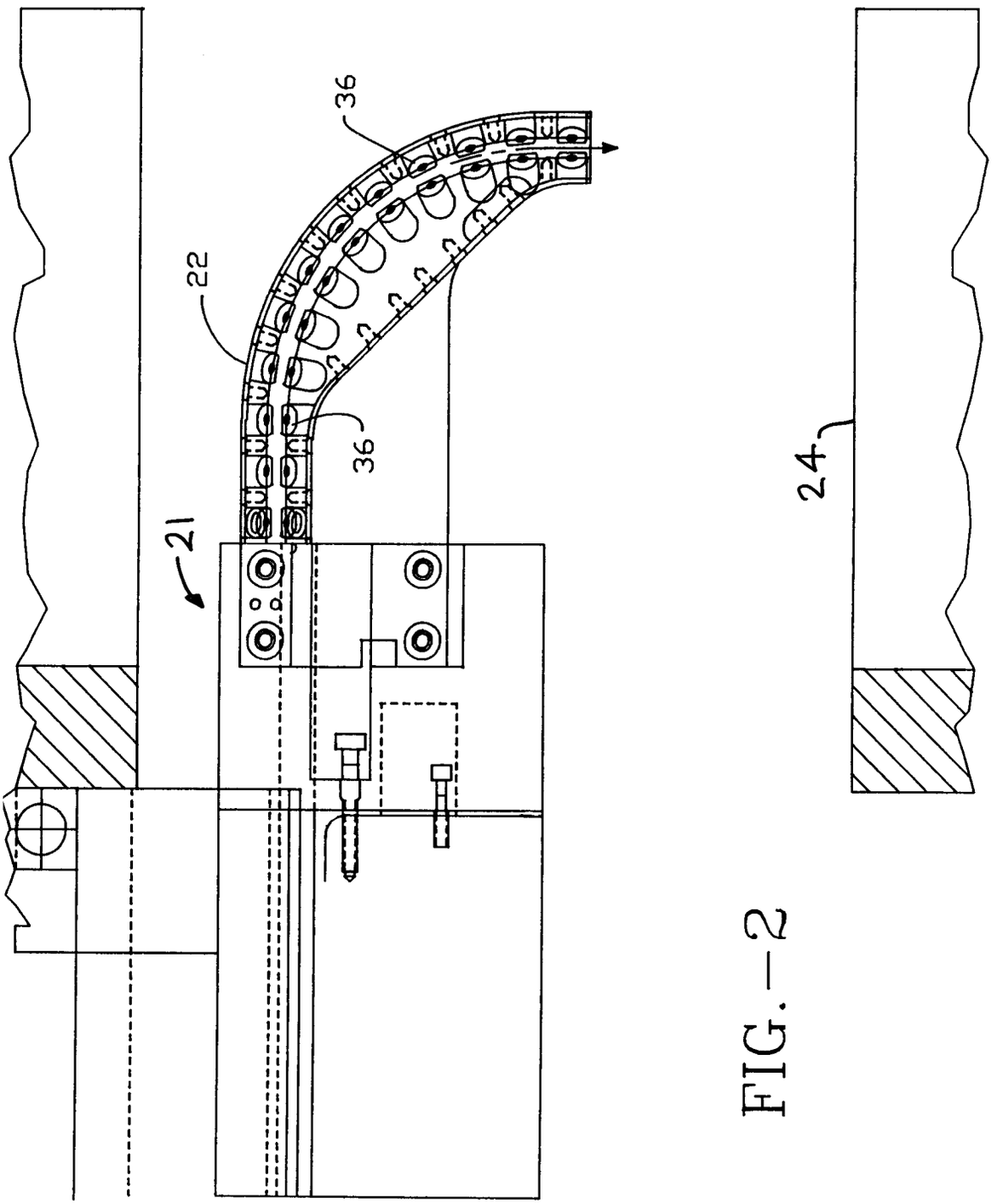

FIG.-2

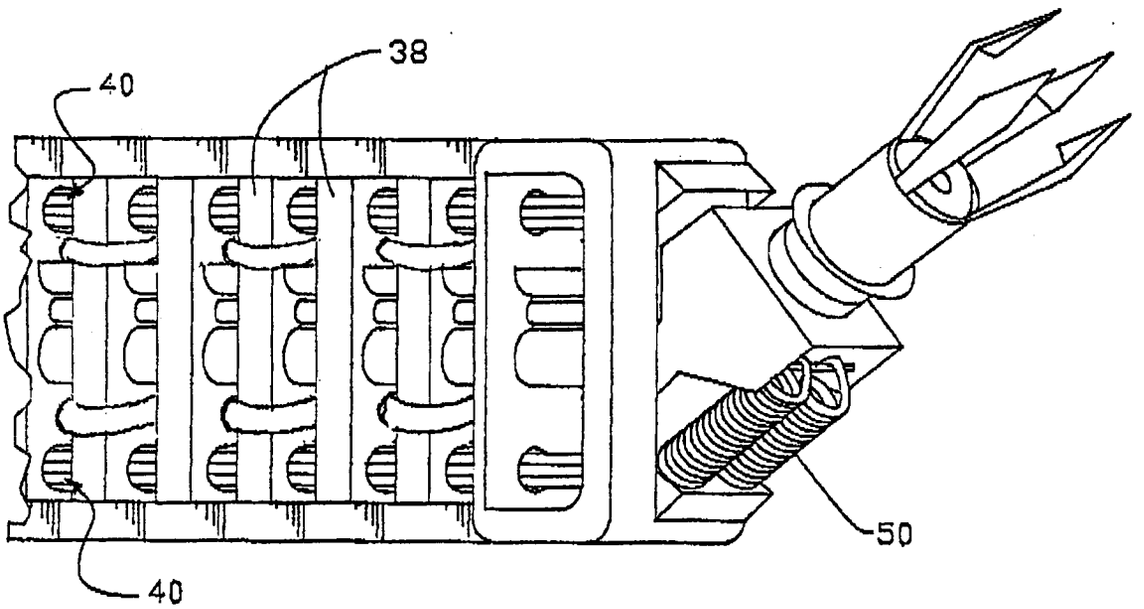

FIG.—3

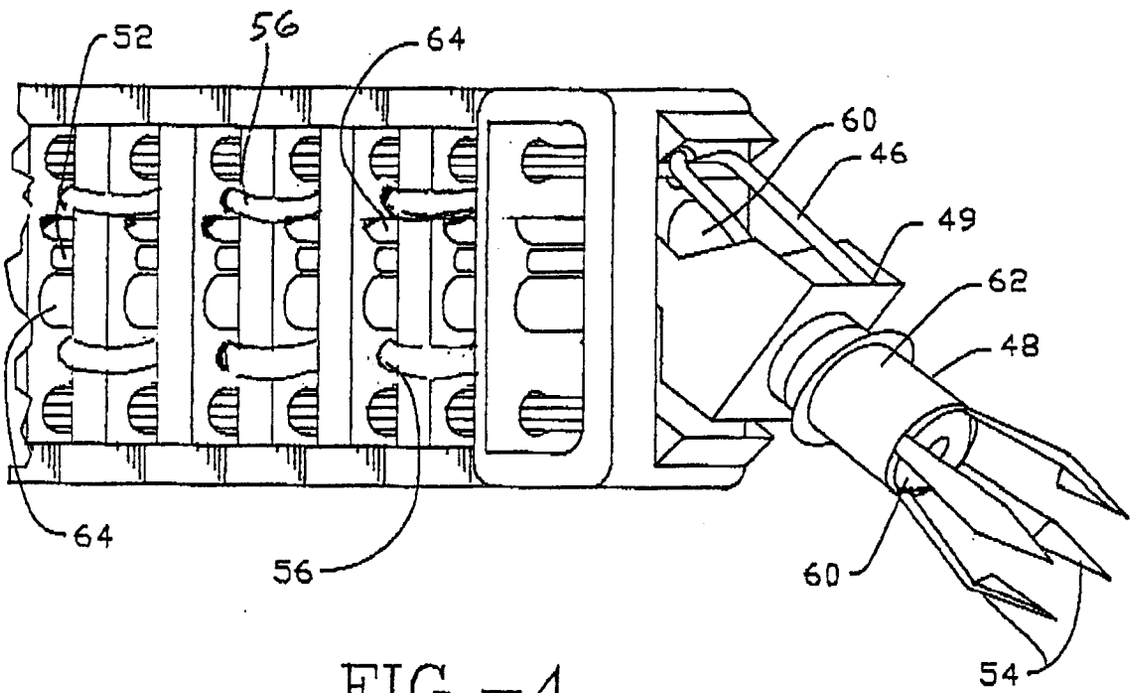

FIG.—4

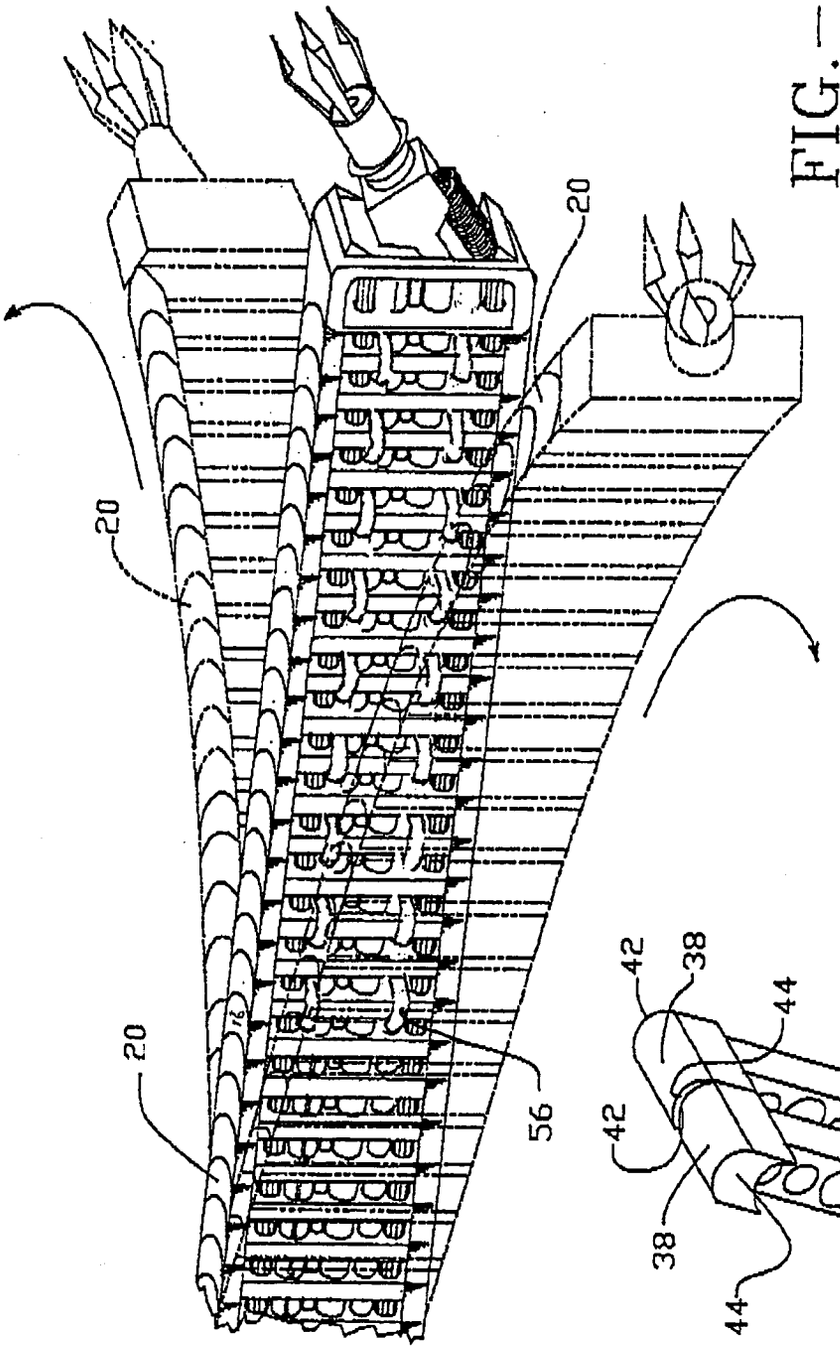

FIG.—5

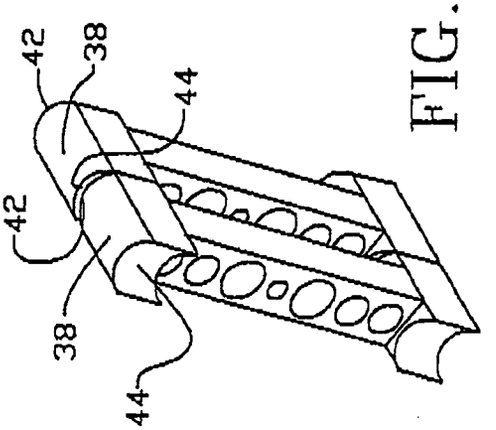

FIG.—6

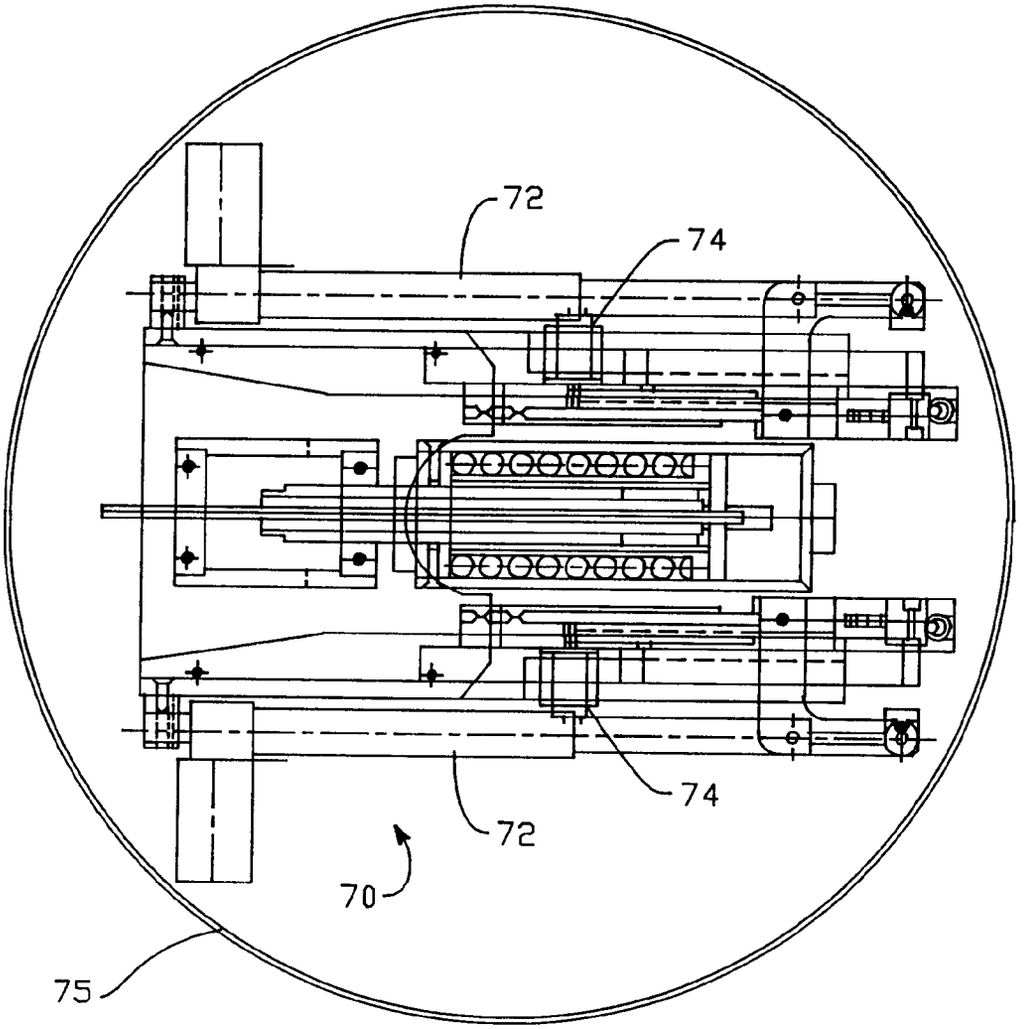

FIG.—7

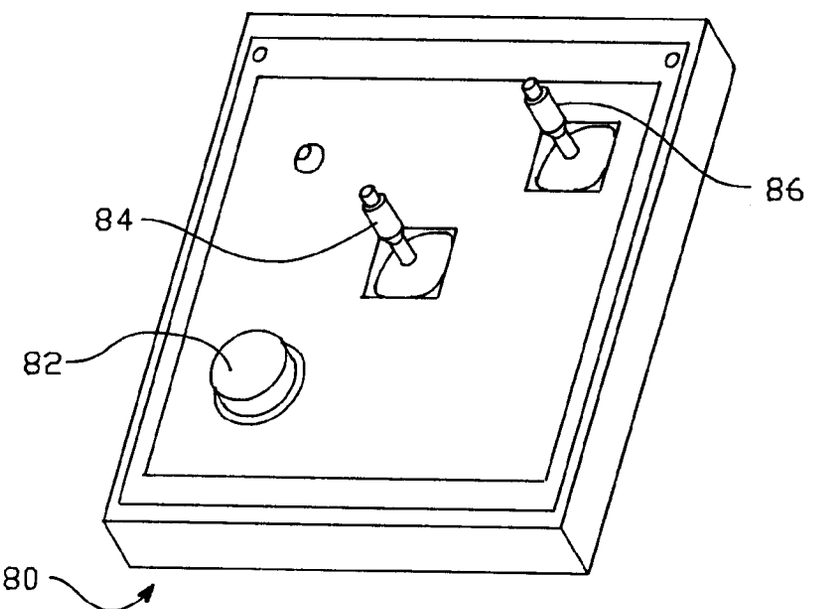

FIG.—8

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 92 30 3994

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	WO-A-8 807 156 (ELECTRIC POWER RESEARCH INSTITUTE) * page 7, line 13 - page 8, line 3; figures * & US-A-5 065 703 (LEE)	1,8,9,10	F22B37/00 B25J18/06
A,P,D	---		
A	WO-A-9 009 850 (ELECTRIC POWER RESEARCH INSTITUTE) * page 4, line 5 - page 5, line 10; figures * & US-A-5 036 871 (RUGGIERI)	1,8,9,10	
P,D,A	---		
A	US-A-4 393 728 (LARSON) * column 3, line 9 - line 42; figures *	1,8,9,10	
A	---		
	US-A-4 575 185 (WENTZELL)		

TECHNICAL FIELDS SEARCHED (Int. Cl.5)
F22B B25J

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	20 AUGUST 1992	VAN GHEEL J.U.M.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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