NASA CASE NO. GSC 13,161-1

PRINT FIG. 1

NOTICE

The invention disclosed in this document resulted from research in aeronautical and space activities performed under programs of the National Aeronautics and Space Administration. The invention is owned by NASA and is, therefore, available for licensing in accordance with the NASA Patent Licensing Regulation (14 Code of Federal Regulations 1245.2).

To encourage commercial utilization of NASA-owned inventions, it is NASA policy to grant licenses to commercial concerns. Although NASA encourages nonexclusive licensing to promote competition and achieve the widest possible utilization, NASA will consider the granting of a limited exclusive license, pursuant to the NASA Patent Licensing Regulations, when such a license will provide the necessary incentive to the licensee to achieve early practical application of the invention

Address inquiries and all applications for license for this invention to NASA Patent Counsel Goddard Space Flight Center Code 204 Greenbelt, MD 20771.

Approved NASA forms for application for nonexclusive or exclusive license are available from the above address.

Serial No.: 07/754,828
Filing Date: 9/4/91

GSFC

(NASA-Case-GSC-13161-1) FLEXIBLE ROBOTIC ARM Patent Application (NASA) 14 p CSCL 13I

N92-24060

Unclas

G3/37 0087690

AWARDS DIGEST

GSC13,161-1

FLEXIBLE ROBOTIC ARM

As shown in Figure 1, a serpentine type robotic arm is realized by a plurality of identical modules 10_1, 10_2, 10_3 which are serially connected together. Each module (Figure 3) includes a base plate 16 and a beveled top plate 14 interconnected by a ball joint assembly 20 so that the top plate is adapted to pivotally nutate around the base plate to describe a cone in space. This operation is provided by a plurality of electromagnets 40 arranged in a ring around the periphery of the base plate 16, and energized in sets of three. Sequential energization of the sets of electromagnet causes a rim portion 54 of the top plate 14 to be magnetically attracted to opposing pole pieces 56. The tilt or cocked position of each top pivot plate 14 is controllable over a range of 360°, thus permitting a series string of modules 10_1 ... 10_n to assume any desired elongated configuration.

Novelty is believed to reside in the circular array of electromagnets located on the periphery of the base plate and which is selectively energized to attract the rim portion of the top plate which also includes a beveled bottom surface at the center which permits it to nutate on an opposing flat upper surface of the base plate.

Inventors: Israel A. Moya and Philip A. Studer

Employer: National Aeronautics and Space Administration

Serial No.: 07/754,828
Filing Date: September 4, 1991

FLEXIBLE ROBOTIC ARM

This invention was made by employees of the United States Government and therefore may be used by or for the Government for governmental purposes without the payment of any royalties thereon or therefor.

Background of the Invention

Field of the Invention

This invention relates generally to a robotic arm and more particularly to a flexible robotic arm comprised of a plurality of series connected modular sections.

Description of the Prior Art

Conventional robotic arms generally fall into two categories, one being a structure which is similar to the human arm and having shoulder, elbow and wrist joints, the other being a serpentine type of structure comprised of a plurality of pivotally connected links. Both types of arms include means for selectively moving the respective parts so that an element located or grasped at the far or distal end can be manipulated and placed at a predetermined destination or alternately retrieved therefrom. The selection of the particular type of robotic arm utilized depends on its intended use, whether it be for supporting and/or manipulating a tool, or for the grasping and positioning of a structural element.

Summary

It is an object of the present invention, therefore, to provide an improvement in robotic apparatus.

It is another object of the invention to provide an improvement in robotic arms.

It is a further object of the invention to provide an improvement in flexible robotic arms.

And it is yet another object of the invention to provide an improvement in flexible robotic arms which can operate in outer space with low energy consumption, has a large degree of flexibility for obstacle avoidance, and is extremely reliable.

Briefly, the foregoing and other objects are achieved by a serpentine type of robotic arm comprised of a plurality of identical modules which are serially connected together. Each module includes a base plate and a top plate interconnected by a ball joint assembly so that the top plate is adapted to pivotally rock around the base plate to describe a cone in space. This operation is provided by a plurality of individually energized electromagnets arranged in a ring around the periphery of the base plate. Selective energization of the electromagnets causes a rim portion of the top plate to be magnetically attracted to the electromagnet(s) which are energized. The tilt or cocked position of the top pivot plate is a controllable nutation over a range of 360°, thus permitting a series string of modules to assume any desired elongated configuration.

Brief Description of the Drawings

The following detailed description of the invention will be more readily understood when considered together with the accompanying drawings in which:

Figure 1 is a partial central longitudinal cross section of a first embodiment of the invention;

Figure 2 is a schematic diagram illustrative of the planar arrangement of electromagnets and positional feedback components utilized in operating each module of the flexible robotic arm according to the subject invention;

Figure 3 is a central longitudinal cross section of one module of the embodiment shown in Figure 1;

Figure 4 is a central longitudinal cross section of one module of a second embodiment of the invention; and

Figure 5 is an electrical schematic drawing illustrative of the driver circuit utilized for energizing sets of three electromagnets shown in Figure 2.

Detailed Description of the Invention

Referring now to the drawings wherein like reference numerals refer to like parts throughout, in Figure 1 there is shown a serially connected string of three identical modules 10_1, 10_2 and 10_3 of a flexible robotic array, with the lowest module 10_1 being further shown secured to a support member or pedestal 12.

As further shown in Figure 3, each module 10 of the embodiment shown in Figure 1 is comprised of three major parts, a generally circular top plate 14 which is pivotally connected to a circular base plate 16 and a circular interface plate 18. The pivotal connection between the top plate 14 and the base plate 16 is by way of a ball joint assembly 20 which is held in place by a pair of fastener elements 22 and 24 which may consist, for example, of a pair of metal screws or bolts as shown.

The interface plate 18 provides a means whereby the base plate 16 of one module can be coupled to the top plate 14 of the next module and is basically comprised of an annular intermediate section 26 which include a circular arrangement of threaded bores 28 for receiving fastening elements, e.g. metal screws 30 for attaching the base plate 16 located on the top thereof. Inwardly adjacent the section 26 is a circular arrangement of bolt holes 34 and shoulder portions 36 for seating and attachment to a top plate 14, not shown, of the module which is attached thereto directly beneath it.

With respect to the base plate 16, it is comprised of a generally circular metallic member on which there is mounted a plurality, typically twenty eight, of equally spaced electromagnets 40, including coils 39, arranged on the periphery as schematically shown in Figure 2 and which are energized in sets of three from a controller 41 via the wiring assemblies 43-1 ... 43-8. Inwardly of the ring of electromagnets 40 is one half of a capacitive type proximity sensor comprised of a segmented annular ring 42 and a plurality of capacitor plates 66 which oppose the other half of the proximity sensor comprised of a plurality, typically twenty-eight top segments 44 and capacitor plates 64, which are secured to the underside of the top plate 14 as shown in Figure 3.

In the second embodiment of the invention shown in Figure 4, the capacitive type proximity sensor is deleted in favor of an electromagnetic type sensor including two positional determining elements 46 comprising well known linear variable differential transformers (LVDT) 46. The LVDT's 46 are energized by and feed top plate positional signals back to the controller 41 by electrical wiring assemblies 47-1 and 47-2 shown in Figure 2.

Further as shown in Figure 3, the segmented bottom ring 42 is held in place by suitable hardware such as one or more selectively spaced bolts 45. In the center of the base plate 16, as shown in both Figures 3 and 4, is a raised island portion 48 which in addition to providing a mount for the centrally located ball joint assembly 20, also provides a supporting surface for a generally flat annular shaped permanent magnet 50 over which is placed a like shaped metal spacer member 52.

The top plate 14 comprises a generally circular metallic member having an inverted concave periphery including a lower outer edge 54 which is adapted to contact the upper surface of pole pieces 56 of the electromagnets 40. The top plate 14 acts like a rocker plate and further includes an enlarged midsection 60 having a beveled bottom surface 62 which is adapted to contact the upper surface of the underlying spacer member 52 located on the base plate 16.

Between the inverted rim surface 54 and the mid-section 60 of the top plate there is, as noted above, is the set of capacitor segments 44 which are aligned with the capacitor segments 42 of the base plate 16. Each of the top segments 44, moreover, include respective outer surface portions which are beveled along the same line as the beveled surface 62 and include the capacitor plates 64 which became parallel with the lower capacitor plates 66 when the top plate 14 is attracted magnetically towards any one set of three energized electromagnets 40 as shown in Figure 2. The top ring segments 44 are secured to the top plate 14 by a set of fastening screws or bolts 68. The top plate also includes a set of circularly arranged threaded bores 70 on its upper surface 71 for attachment to the interface plate 18 of another module 10 which will be mounted on top of the top plate 14.

Energization of the circular array of electromagnets 40 and more particularly their respective coils 39 are energized in sets of three coils each as noted above. Circuitry for providing the energization is shown in Figure 5 and is located in the controller 41. Referring now to Figure 5, shown thereat are three electromagnet coils 39 connected in series between the collector 72 of an n-p-n transistor 74 and a +V supply potential applied to terminal 76. The transistor 74 comprises the output transistor of an emitter follower circuit configuration including n-p-n transistor 78, the base 80 of which is coupled to an input terminal 82. Terminal 82 is adapted to receive a turn-on signal when energization of the coils 39 is required. Resistor 84 acts as the collector load resistor for transistor 78 while resistors 86 and 88 comprise base bias resistors therefor. A diode 90 is further shown coupled in parallel with the three coils 39 and provides a discharge path therefor upon deenergization.

In operation, each of the modules $10_1 \ldots 10_n$ is composed of the same basic components as an electric motor having a stator and a rotor except that the stator and rotor are arranged differently and take a different form. In the module 10, the base plate 16 comprises the stator and incorporates both the central permanent magnet 50, the spacer 60, which in actuality comprises a magnetic flux carrier washer, and the circular array of electromagnets 40 comprised of the respective pole pieces 56 and windings 39 arranged around the outer perimeter thereof. The top plate 14 corresponds to a motor rotor. The difference is that it nutates, i.e. has a conical rotation, instead of a rotation about a single centralized axis. Here the top plate 14 conically pivots around the ball joint 20 in response to the instantaneous magnetic state of the base plate 16.

It should also be pointed out that the permanent magnet 50 which also comprises a ring, provides a clamping force between the two plates 14 and 16 and contributes significantly to the torque capability of the device. The torque T, for any point in time, is:

$$T \approx 4CB_{coil}\, B_{pm} \qquad (1)$$

where C is a constant that relates to the area and distance from the point of minimum gap to the centroid of the area containing the effective flux density of a coil

39 and B_{pm} is the flux density due to the presence of permanent magnet 50 at that particular location.

Accordingly, when three series connected coils 39 of the sets of electromagnets 40 are energized in a sequential fashion, from the left and right of a point of minimum gap, one set of electromagnets will be pulling on one side of the top plate 14, while the other set will be pushing on the opposite side.

While respective capacitance readings can be obtained from the opposing sets of plates 64 and 66 to determine the position of the top plate 14 relative to the bottom plate, the linear variable differential transformers 46 provide an output voltage between a predetermined maximum and minimum voltage which is a function of the depression of the respective plunger elements 47 by the top plate 14. Each LVDT output voltage is converted into an angle in the controller 41 which enables a formulation of the correct angle of the top plate relative to a datum, or reference point on the periphery. The double inclusion of the linear voltage differential transformers 46 eliminates any quadrant ambiguity which is possible with a single LVDT plate position measurement. The direction in which plate nutation is taking place provides a means by which sets of electromagnets 40 should be next energized so that any specific orientation can be commanded by the controller 41. Thus each module 10_1, 10_2, 10_3 is individually controlled and monitored for the specific location of their respective top plates 14_1, 14_2 and 14_3. Thus they can be made to assume any specific configuration in space.

It is to be noted that the modular assembly shown in Figure 1 can be also used as a gimbal system for a pointing device, not shown, to scan a cone in space. Such an application is suited for such an arrangement because it can scan in a continuous manner without changing speed or direction. Additional applications include end-effectors, pumps, and high gear reductions. The two most important attributes of the flexible robotic arm in accordance with this invention are its flexibility and obstacle avoidance capability; however, its performance will be directly proportional to the number of modules utilized.

Having thus shown and described what is at present considered to be the preferred embodiment of the invention, it should be noted that the same has been made by way of illustration and not limitation. Accordingly, all modifications, alterations and changes coming within the spirit and scope of the invention are herein meant to be included.

FLEXIBLE ROBOTIC ARM

ABSTRACT

A plurality of identical modules are serially connected together with each module including a base plate and a top plate interconnected by a ball joint assembly so that the top plate is adapted to pivotally nutate around the base plate to describe a cone in space. An array of twenty-four electromagnets, sequentially energized in sets of three, are arranged in a ring around the periphery of the base plate. Selective energization of the eight sets of electromagnets causes the rim of the top plate to be magnetically attracted to the energized electromagnets. The tilt of the top pivot plate is detected and controlled over a range of 360°, thus permitting a series string of modules to assume any desired elongated configuration.

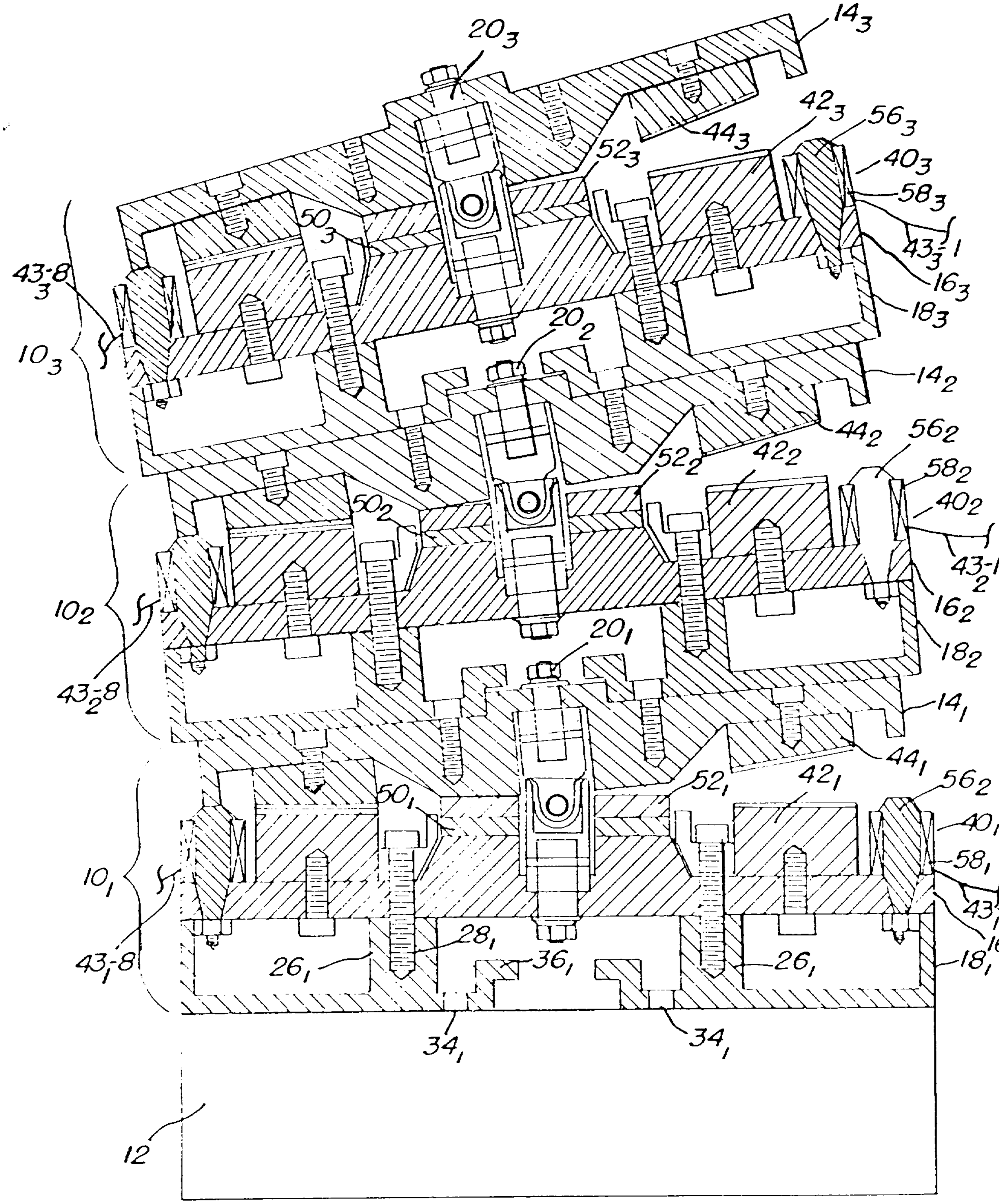
20_3
14_3
44_3
42_3
56_3
52_3
40_3
58_3
43_3-1
16_3
50_3
43_3-8
18_3
10_3
20_2
14_2
44_2
56_2
52_2
42_2
58_2
40_2
50_2
43_2-1
16_2
10_2
18_2
43_2-8
20_1
14_1
44_1
52_1
42_1
56_2
50_1
40_1
58_1
10_1
43_1-1
16
43_1-8
28_1
26_1
36_1
26_1
18_1
34_1
34_1
12

FIG. 1

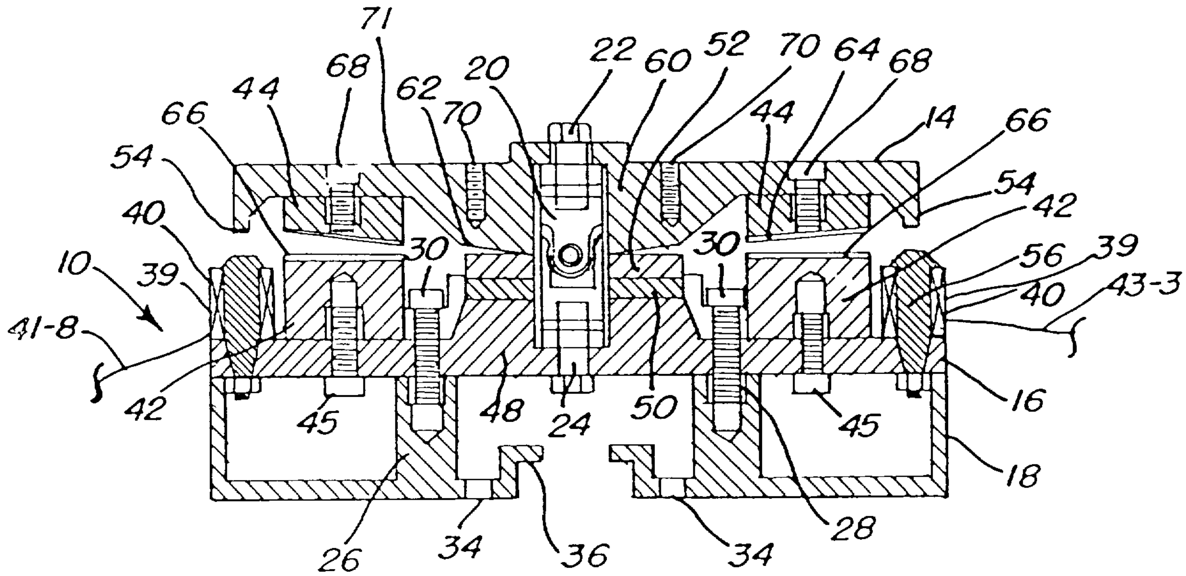
71
68
22
60
52
70
64
68
20
62
70
44
44
66
14
66
54
54
42
40
30
30
56
39
10
39
40
43-3
41-8
42
45
48
24
50
45
16
18
26
34
36
34
28

FIG. 3

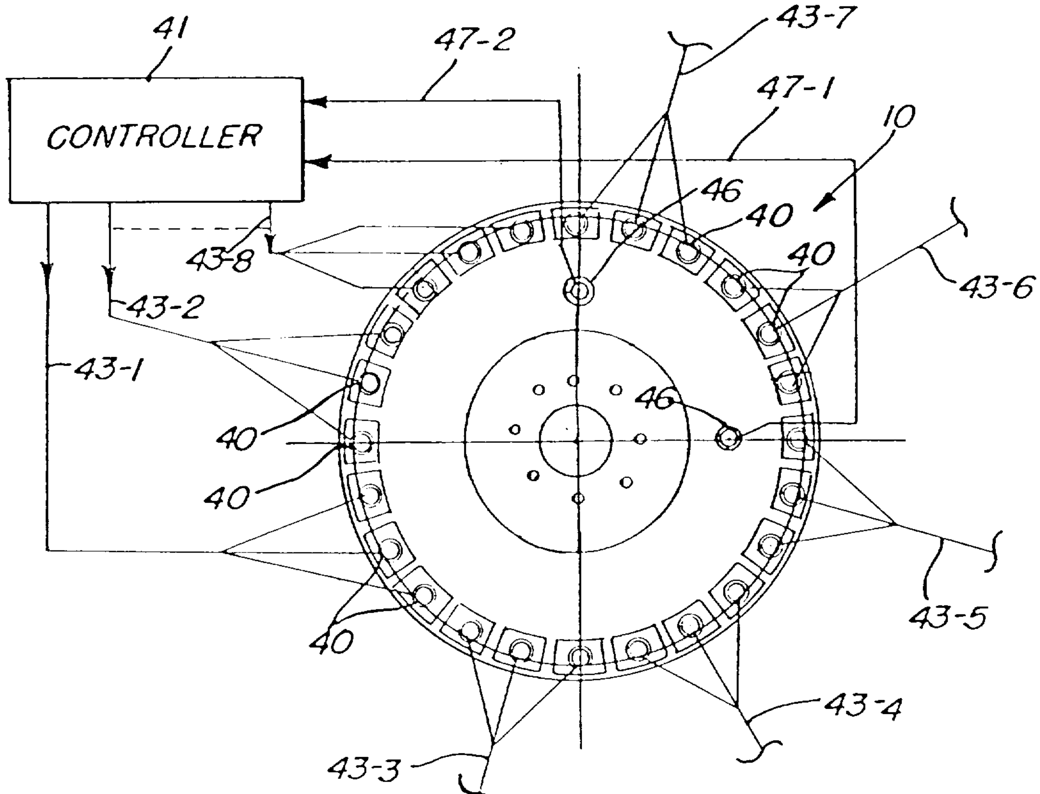
41
CONTROLLER
47-2
43-7
47-1
10
46
40
40
43-8
43-6
43-2
43-1
40
46
40
40
43-5
40
43-4
43-3

FIG. 2

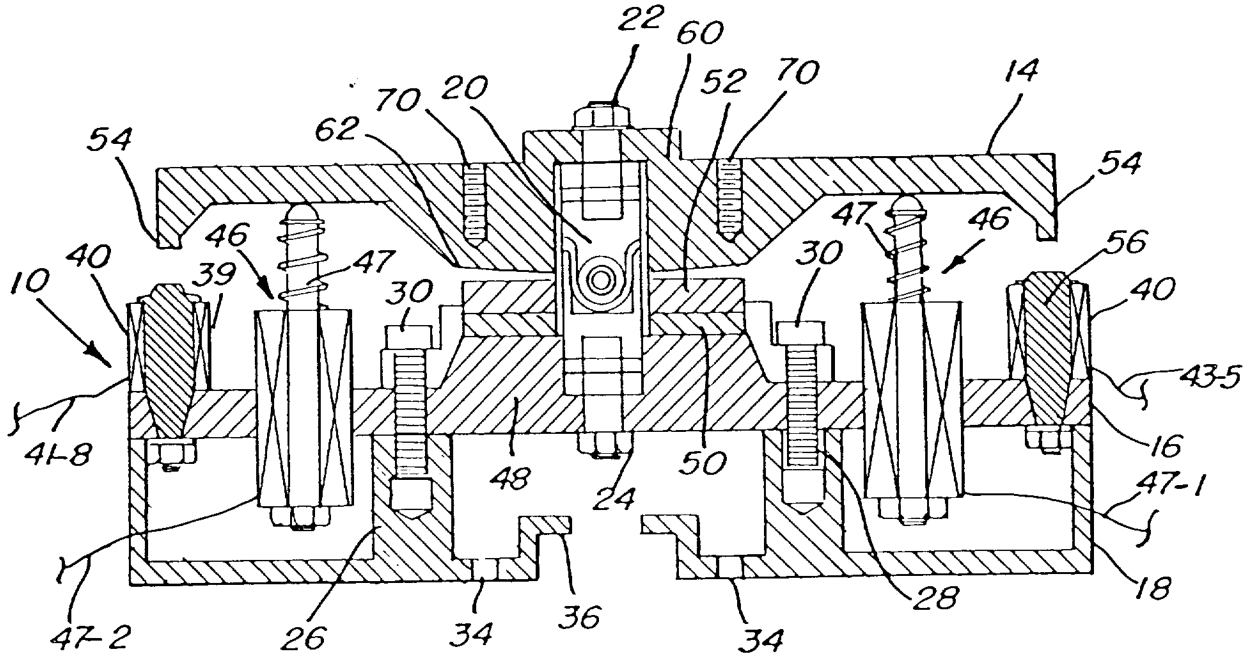
22
60
70
20
52
70
14
62
54
54
47
46
46
56
40
39
47
30
30
40
10
43-5
41-8
16
48
50
24
47-1
47-2
26
34
36
34
28
18

FIG. 4

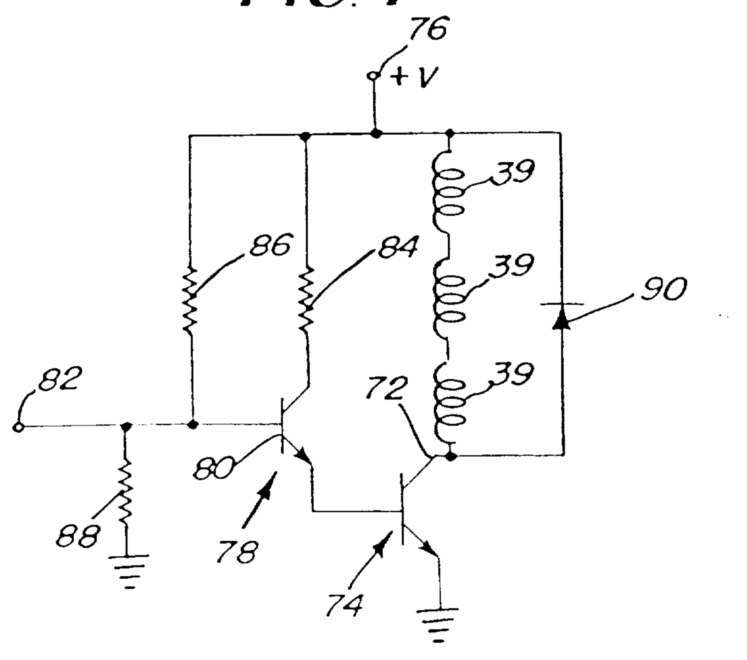
76
+V
39
86
84
39
90
82
72
39
80
88
78
74

FIG. 5