NASA CASE NO. <u>MFS-28930-1</u>

PRINT FIG. <u>4</u>

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Serial Number <u>08/246,460</u>

Filing Date <u>May 20, 1994</u>

NASA/MSFC

TECHNICAL ABSTRACT   MFS-28930-1

This invention relates to torsion springs, particularly to variable stiffness torsion springs, and to their use in gimballed scanning devices or instruments focused on objects in outer space. One form of variable stiffness torsion spring is illustrated in the accompanying drawing. This spring 41 includes a shaft 40 whose resisting torque is the moment of the internal shear forces about the axis of torsion spring element 46. This torsion spring element 46 is in the form of a cruciform spring made of metal or rubber. The torsion spring element (46) is part of shaft 40 consisting of shaft portion 40a, torsion spring element 46, constraint 48 and shaft portion 40b. One end of torsion spring element 46 is attached to shaft portion 40a through plate 45 to which the spring element is attached. The other end of torsion spring element 46 is coaxial with, and attached to, boss 47. Boss 47 is slidable within a constraint 48. Essentially then torsion spring 46 is positioned in a cruciform hole in boss 47 which is slidable within constraint 48. Constraint 48 includes restraining plate 49. As the restraining plate of constraint 41 moves, the spring constant of torsion spring 46 is changed. Thus a variable stiffness torsion spring is provided utilizing a conventional torsion spring. Torsion springs have been employed industrially for years in the form of torsion strips, rods, or bars, generally termed shafts, which rely on the variations in shearing forces to furnish a given or fixed internal restoring torque. To the contrary, the variable stiffness torsion spring herein can be so adjusted as to have any given spring constant. Such torsion springs are extremely useful in gimballed payloads such as sensors, telescopes and electronic devices on such platforms as a space shuttle, a space station. The adjustable spring constant torsion springs herein eliminate the need for installing a different torsion spring in a scanning instrument each time the scan frequency is changed.

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MFS-28930-1   Patent Application

VARIABLE STIFFNESS TORSION SPRINGS
ORIGIN OF THE INVENTION

The invention described herein was made by employees of
the United States Government and may be manufactured and used by
or for the Government of the United States of America for
Governmental purposes without payment of any royalties thereon or
therefor.

FIELD OF THE INVENTION

This invention, in one of its aspects, pertains to
torsion springs. In another of its aspects the invention is
directed to variable stiffness torsion springs. In still another
of its aspects the invention relates to gimballed scanning
devices or instruments focused on objects in or from outer space,
specifically, with instruments whose scanning is produced by
rotating unbalanced mass devices.

BACKGROUND OF THE INVENTION

A torsion spring is an elastic element capable of being
flexed by twisting about its axis. The spring action, or spring
constant, is primarily a result of the relationships between the
torque applied in twisting the spring, the angle through which
the torsion spring twists, and the modulus of elasticity of the
spring material in shear. The twisting action on a torsion

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spring is produced by couples, that is, two equal forces producing partial rotation by moving in parallel but opposite directions and acting normal to the axis of the shaft.

As we understand the state of the art, torsion springs
5   employed industrially have been strips, rods, or bars, generally termed shafts, usually with square, elliptical, rectangular, circular, or triangular cross-sections. As such they are used in machines, passenger cars and trucks. Tubular members find application in aircraft and the like. Shear stresses are assumed
10   uniform over the tube wall thickness. Cylindrical bars can be visualized as helical springs with a resisting torque equal to applied torque. When non circular shafts are twisted, their sections become warped and stresses do not vary linearly as in the case of shafts having circular cross-sections.

15   Torsion springs have been used as springs for years, generally in the form of torsion bars. There is, then, a need for a different type of torsion spring, especially for such uses as scanning devices which are extensively employed in space research. In addition to their use in scanning the earth and
20   other planets, x-ray, gamma-ray, and similar scanning instruments perform important functions in space exploration, As will become apparent the torsion springs of this invention lend themselves to such usage.

By another embodiment of this invention a variable stiffness torsion spring is provided. In other words a torsion spring can be made which can be so adjusted as to have a given spring constant. These torsion springs are extremely useful in

5　gimballed payloads such as sensors, telescopes and electronic devices on such platforms as a space shuttle, a space station, on experimental balloons, and on free-flying spacecraft. As will be seen, variable stiffness torsion springs are particularly useful in scientific instruments in which scan patterns are

10　achieved through the use of rotating unbalanced masses. Such rotating unbalanced mass (RUM) devices are the subject of our U.S. Patent 5,129,600 and our copending patent application Ser. No. 08/123,629 filed September 15, 1993. As will be explained, the adjustable spring constant torsion springs provided herein

15　eliminate the need for installing a different torsion spring in a scanning instrument when the scan frequency is changed.

SUMMARY OF THE INVENTION

Known torsion springs rely on variations in shearing forces thereacross to furnish an internal restoring torque. In the

20　torsion springs of this invention the restoring torque is external, and therefore independent of the shearing modulus of elasticity the torsion spring shaft. An external spring is used having one end attached to the periphery of the shaft and having

3

its opposite end anchored. The spring is so disposed that during the partial rotation of the shaft, it moves through a torsional angle dependent on the spring constant rather than on the shear modulus of elasticity of the shaft.

5   A variable stiffness torsion spring is also provided herein. It includes a modification of the external spring torsion device, or the conventional shaft type capable of being twisted about its longitudinal axis by an input torque. The shaft type is a torsion spring member with a restoring torque which is a function

10   of shaft length, cross-sectional area and modulus of elasticity in shear. The variable stiffness torsion spring includes a slidable constraint capable of confining the shaft or the external springs, and means anchoring the constraint so that the constraint prevents a portion of the shaft or of the springs from

15   flexing. In other words the constraint changes the effective length of the shaft or springs and consequently the torsion spring constant.

THE INVENTION

We have noted that unique torsion springs, along with novel

20   variable stiffness torsion springs are the subject of this invention. The invention can, it is believed, best be understood from a discussion thereof in conjunction with drawings illustrating various features of the torsion springs and their

4

uses.

Brief Description of the Drawings

Fig. 1 is an isometric view of a unique torsion spring.

Fig. 2 is an isometric view of a variable stiffness torsion

5   spring.

Fig. 3 is a diagrammatic view showing either of the torsion
springs (Fig. 1 or Fig. 2) in a stressed condition.

Fig. 4 is a view, partially in section, of a conventional
torsion spring converted by this invention to a variable

10   stiffness torsion spring.

Fig. 5 is a sectional view through 5-5 of Fig. 4.

Fig. 6 is an isometric view of a drive means for the
embodiment of the invention shown in Figs. 4 and 7.

Fig. 7 diagrammatically illustrates the application of the

15   torsion springs in a RUM scanning device.

Detailed Description of the Invention

As previously indicated, in torsion springs heretofore
variations in shearing forces provided internal restoring
torques. Herein, on the other hand, the restoring torque is

20   external. One form of such a torsion spring is illustrated as 2
in Fig. 1. In this device the shaft or torsion bar 4 is twisted
about its axis as a torque is applied. Normally the twist of
such a cylindrical bar can be visualized as the accumulated

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rotational displacement of imaginary disks over a section of the
bar or shaft. Shearing forces vary across the section and
together furnish the internal resisting torque. Herein, however,
flat springs 6 and 8 are attached to shaft 4 at **a** and **b**. These

5   springs 6 and 8 can be welded to the shaft at **a** and **b**, or the end
of shaft 4 can be provided with a slot through which a long flat
spring passes. The spring can then be pinned to the shaft by a
suitable pin means.

The outer ends of springs 6 and 8 are slidably held in

10   standards or blocks 10 and 12. The blocks are stationary or
fixed to some base (not shown) so as to anchor the springs.

It can be seen that a torque applied to the shaft will cause
the springs 6 and 8 to flex as shown in Fig. 3. Since the outer
ends of these springs 6 and 8 are confined by the slots in blocks

15   10 and 12 the springs will resist this flexure, conferring on
shaft 4 a resisting torque which in this instance is external,
and proportional to the angle of rotation of shaft 4. The
torsion spring illustrated in Fig. 1 is, therefore, independent
of the shearing modulus of elasticity of the torsion spring

20   shaft, in this case shaft 4, because the shaft 4 is much stiffer
in torsion than the springs 6 and 8 in bending.

It has been pointed out that as embodiment of this invention
variable stiffness torsion springs are provided. Such a spring

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will now be described with reference to Fig. 2. The torsion

spring 20 is similar to torsion spring 2 illustrated in Fig. 1,

except that anchors 10 and 12 are no longer used. A shaft 24,

similar to shaft 4 of Fig. 1, is shown, along with springs 26 and

5   28 which confer on shaft 24 a resisting torque. Rather than

anchor blocks 10 and 12, constraints 21 and 22 are employed, and

springs 26 and 28 pass through slots in these constraints. In

torsion spring 20 constraints 21 and 22 are so mounted that they

also cause springs 26 and 28 to flex as shown in Fig. 3. One

10   such mounting means can be a support beam 23 shown in Fig. 2.

This beam is attached near its center to a stand or stanchion

with the ends of the beam passing through slots in constraints 21

and 22 similar to those provided for springs 26 and 28. As in

the torsion spring of Fig. 1, the springs in Fig. 2 provide a

15   restoring torque counteracting shaft angular deflection. This

restoring force is determined by the effective torsional spring

constants of springs 26 and 28 in the system shown in Fig. 1..

It has been emphasized that one of the determinants

affecting the torsional spring constant in the system in Fig. 1

20   is spring length. It will be shown that the lengths of springs

26 and 28 can be changed in the torsion spring illustrated in

Fig. 2. Support beam 23 carries a differential spur gear 25

capable when driven by drive shaft 27 of rotating a traverse rod

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or worm screw 29. The ends of worm screw 29 are oppositely threaded, and these threaded ends are confined in matching threads in constraints 21 and 22 as can be seen in Fig. 2. Referring to that figure, it will be apparent that as the traverse rod 29 is rotated by differential spur gear 25 the constraints 21 and 22 will be moved toward or away from each other, depending upon whether the rotation of worm screw 29 is clockwise or counterclockwise. As constraints 21 and 22 move toward or away from each other, stabilized by support beam 23, they will change the lengths of springs 26 and 28. As the lengths of these springs change, so will the effective torsion spring constants of the system. A variable stiffness torsion spring is, thus, one of the features of this invention.

A variable stiffness torsion spring which is somewhat more conventional is illustrated in Fig 4. This spring 41 is deemed to be more conventional because it includes a shaft 40 whose resisting torque is the moment of the internal shear forces about the axis of torsion spring element 46. This torsion spring element 46 is in the form of a cruciform spring as illustrated in Fig. 4, and shown in cross-section in Fig. 5, and it is made of metal or rubber. The torsion spring element (46) thus is part of shaft 40 consisting of shaft portion 40a, torsion spring element 46, constraint 48 and shaft portion 40b. Shaft portions a and b

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are mounted in bearings 42 and 44 as can be seen in Fig. 4. One

end of torsion spring element 46 is, thus, attached to shaft

portion 40a through plate 45 to which the spring element is

attached. The other end of torsion spring element 46 is coaxial

5   with, and attached to, boss 47. Boss 47 is slidable within a

constraint 48. Essentially then torsion spring 46 is positioned

in a cruciform hole in boss 47 which is slidable within

constraint 48. Constraint 48 includes restraining plate 49, a

cylinder 50, a collar 52 and a spindle 55. Restraining plate 49

10   is provided with a cruciform hole matching, in cross-section, the

cruciform torsion spring element so that the cruciform spring is

slidable therein. The restraining plate is attached to a

cylinder 50 which is provided with a cavity adapted to receive

boss 47. Cylinder 50 is locked in a sleeve or collar 52 by means

15   of key (not shown) in slot 53. The collar is anchored (by means

not shown) so that the cylinder and attached restraining plate 49

cannot be rotated. Cylinder 50 and restraining plate 49 are,

however, able to be moved axially across torsion spring element

46. To move restraining plate 48 a threaded base plate 54 is

20   attached to the end of cylinder 50 opposite restraining plate 49.

Within threaded base plate 54 is a spindle 55, which when

rotated, advances or retracts cylinder 50 along slot 53 and

within anchored collar 52. This is accomplished by gear 56.

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Large gear 58 will be described hereinafter in conjunction with Fig. 7. It can be seen that as the restraining plate of constraint 41 moves the spring constant of torsion spring 46 is changed. Thus a variable stiffness torsion spring is shown

5   utilizing a conventional torsion spring.

Having described a variable stiffness torsion spring, we will now illustrate its importance in scanning instruments. In this regard consider the spring described in conjunction with Fig. 4 when it is used in conjunction with a rotating unbalanced

10   mass or RUM device. Such a device is shown in Fig. 7 wherein the parts carry the same numbers used in Fig. 4.

As indicated, scanning is an important aspect of space science. Sensors, telescopes and electronic devices on platforms in space perform important functions in exploration. In using

15   such scanning instruments three general types of scan patterns are well known. The first is a circular scan, in which the line of sight is repeatedly traced in a circle. The second type of scan pattern is a line scan. Here the line-of-sight is linear, with the scanning device line-of-sight moving back and forth in a

20   line. The third form of scan pattern is a raster scan, which is based on a line scan further complemented with some relatively slower motion, usually perpendicular to the original line scan.

To achieve these scan patterns some means must be provided

10

which impart to the payload an oscillatory motion. Although drive means are generally known, a preferred drive means which is particularly effective is a rotating unbalanced mass or RUM device which has been referred to briefly hereinbefore. This RUM device consists of a mass, m, on a lever arm r, located at a distance, d, from the center-of-mass of the gimballed payload on which it is mounted. The mass is driven at a constant angular velocity ω which produces a cyclical centrifugal force $m\omega^2 r$ on the payload. This force, in turn, produces a cyclic torque, about the payload center-of-mass, with an amplitude of $m\omega^2 rd$. Two RUM devices are required to scan gimballed payloads. They are mounted on each end of the payload and they rotate 180° out-of-phase producing a cyclic torque couple with an amplitude of $2m\omega^2 rd$.

The most frequently employed method for achieving the various scan patterns is to gimbal the scanning device. The gimbal or gimbals must be so suspended that they can be actuated to generate the scan pattern. Such a suspension system is provided in my copending patent application Ser. No. 08/123,829. It is a suspension means for payloads rotatably supported in gimbals wherein payload rotation is restricted so that the payload moves in a scan pattern. It includes a gimbal and a payload to be supported in the gimbal. A first axle means has

one of its ends attached to one side of the payload and its other end attached to the gimbal. A second axle means has one of its ends attached to the gimbal, and its other end attached to the other side of the payload. The first axle means also has one of

5   its ends journaled to permit payload rotation. The second axle means on the other hand is a pivot, flexible about a torsional moment, but inflexible about bending moments. This construction restricts payload rotation, effecting oscillation of that payload. The rotation of the payload is limited by the torsional

10   spring constant of this flexible pivot. It is this flexible pivot which is replaced by the variable stiffness torsion spring of this invention. Drive mean, of course impart an oscillatory motion to the payload to effect its scan pattern as described in U. S. 5,129,600.

15   RUM devices require an auxiliary control system to position and reposition the scan pattern relative to a target or a number of targets. The auxiliary control system is also required if a raster scan pattern is to be generated by the RUM device. It confers on the payload a slow complementary motion perpendicular

20   to the line scan to form the raster scan. Such auxiliary control systems are also discussed in my copending patent application.

As indicated, for line and raster scanning, a single gimbal device is necessary. Only on one scan axis is the mechanism

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provided with a flexible pivot, in this instance a torsion

spring, since scanning is performed only in this axis. Any

positioning device in the other axis is used only to reposition

the scan in this axis and/or to provide the slow complementary

5   motion for raster scanning.

For ease of understanding, then, a single gimbal suspension

system for linear scanning is shown in Fig. 7. An instrument or

payload 70, preferably a RUM device, is carried by a gimbal 72

through an axle system to be described. For other scan patterns

10   gimbal 72 will be a ring within an outer gimbal. In the

embodiment herein the base of the gimbal is embedded in or is

part of a platform 74. In order to permit payload movement the

axle system includes two axle means. One of the axle means is an

axle 76. One side of the payload is attached at d to one end of

15   axle 76. The other end of axle 76 is attached to gimbal 72 at e.

To allow movement or rotation of the payload, insofar as

possible, axle 76 is journaled in housing 78 holding bearings in

a race, not shown.

The other axle means is the torsion spring 41 shown in Fig.

20   4. Cruciform spring element 46 of Fig. 4 can be seen in Fig. 7.

Side 82 of the payload is supported by this torsion spring 41,

the spring being that illustrated in Fig. 4. Within gimbal ring

72 are bearings 42 seen in Fig. 4. Unlike axle 76 torsion spring

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41 is not journaled or otherwise adapted for rotation. Rather it is firmly secured by constraint unit 41 described in conjunction with Fig. 4, and supported in bearings 44 as shown in Fig. 4.

During operation the payload must be positioned or repositioned to the center-of-scan in one axis. This positioning means, shown in Fig. 6, in addition to torsion spring 41, includes a stepper motor 90, an N:1 gear train 92, and an encoder 56. Gear train 92 includes large gear 58, mentioned in describing the device shown in Fig. 4, For clarity only a simple one pass gear train is shown. The stepper motor stator is attached to the support structure. The rotor is connected to the low torque side of the gear train and the torsion spring is connected to the high torque side. The other end of the torsion spring is attached to the payload. An encoder is mounted on the high torque side of the gear train to provide a position measurement of the payload center-of-scan. An operator issues step commands to stepper motor 90 until he observes that the measured payload position matches the desired centered position. Stepper motor 90 actuates gear train 92, which in turn partially rotates, or twists torsion spring 41 to position the payload center-of-scan. The payload is now ready for scanning. The RUM devices 77 begin to rotate at a prescribed constant angular velocity, while being maintained 180° out-of-phase with respect

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to each other. This produces the desired scan.

During scanning, due to the action of the torsion spring and its flexibility in the scan axis, rotation is restricted. In addition, the holding torque of stepper motor 90, amplified by
5   the gear train 92 (Fig. 6), creates a large restoring torque that prevents the center of scan from drifting. In Fig. 7 stepper motor 90, encoder 56 and gears 58 and 92 are contained in housing 95.

RUM devices are superior to previous scanning apparatus in
10   terms of power, weight, cost, and accuracy, but there are still certain disadvantages accompanying their use. Even though power requirements are less than in other scan generating devices there is still room for improvement in the area of power consumption. One way to achieve power savings is through resonance. Even
15   though we have described the torsion springs herein in terms of displacement angles and restoring forces or torque, it is to be noted that this torque gives the spring element an angular acceleration provided we do not exceed the elastic limit of the spring. The ensuing motion is angular simple harmonic motion.
20   As such it is characterized by an amplitude, period and frequency. The torsion spring, then, is an oscillating device. This oscillating frequency f_p, coupled with the inertia of the payload I_p, is the resonant frequency f_p, and $f_p = \sqrt{K_p/I_p}$ where K_p

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is the torsional spring constant of the torsion spring.

Important herein is the fact that when the resonant
frequency matches the scan frequency, amplification can be
achieved. In other words, the resonant frequency f_p can be tuned

5   to the scan frequency to amplify the scan. In our copending
application this amplification was achieved through use of a flex
pivot as illustrated in the following example taken from that
application.

<div align="center">EXAMPLE</div>

10   In this example each RUM has a 5 lb mass on a 0.5 ft lever
arm. The RUM torque motor constant is 0.61 ft-lb/ $\sqrt{watt}$.
Consequently, 17 watts or less is required to counteract the
gravity torque on the RUM mass. If the positioning means of this
invention, including the flex pivot, were used in place of the

15   conventional feedback auxiliary control system and the flex pivot
amplified the scan by 10X, then the RUM mass will be reduced to
0.5 lb and the power required to counteract the gravity torque to
0.17 watts. Two RUM devices reduce the system weight by 9 lb and
the peak power by 34 watts, which are significant where weight

20   and power are critical. Circular scanning using conventional
gimbal torques requires 1376 watts in the worst case orientation
in one-g. Using RUM devices and a conventional feedback
auxiliary control system requires 42 watts. Using RUM devices
and the variable-stiffness torsion-spring
mechanism described herein

5-16-94
m?p
pcA

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require only 8 watts.

It is evident that by the use of a flex pivot RUMs having less mass and smaller sizes could be utilized to achieve the same sized scan. For example, if the flex pivot amplified the scan by

5   10X, the masses of the RUM devices could be reduced by that factor. The disadvantage of using a flex pivot was that the spring constant of the flex pivot in the scan axis had to be chosen to enhance the operation. This meant that a different flex pivot had to be used for each different scan frequency.

10   This problem has been overcome herein by the use of variable spring constant torsion springs. It is evident that by changing the spring constant through the constraints as described hereinbefore the device can be "tuned" to a resonant frequency at which scanning takes place. The user observes the amplitude of

15   the scan. Its maximum value indicates a torsion spring/inertia condition, that is, in resonance with the scan frequency. This tunability is achieved by the use of a torsion spring having an effective length which can be lengthened or shortened to tune the scan, thus overcoming the use of separate flex pivots for each

20   scan frequency. The invention also allows the scan amplitude to be changed in real time by tuning for more or less scan amplification. In addition, system parameters such as the payload inertia I_p do not have to be accurately known because the

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tuneable RUM auxiliary control mechanism can compensate for parameter uncertainties.

Another advantage of the tuneable RUM device of this invention is that it acts as a variable frequency isolator that can be tuned to filter mounting base vibrations above a selectable frequency. The device can also be tuned down; that is it can be tuned below or above the resonant frequency. As an example, in some applications, it will be desirable to choose the spring constant of the torsion spring in the scan axis so the resonant frequency, $f_p = \sqrt{K_p/I_p}$ is below the payload scan frequency. This can be readily accomplished by the variable spring constant torsion spring of this invention. When so chosen the torsion spring will not affect the motion created by the RUM devices. It serves only to provide a low-amplitude low-frequency restoring torque to keep the center-of-scan from drifting.
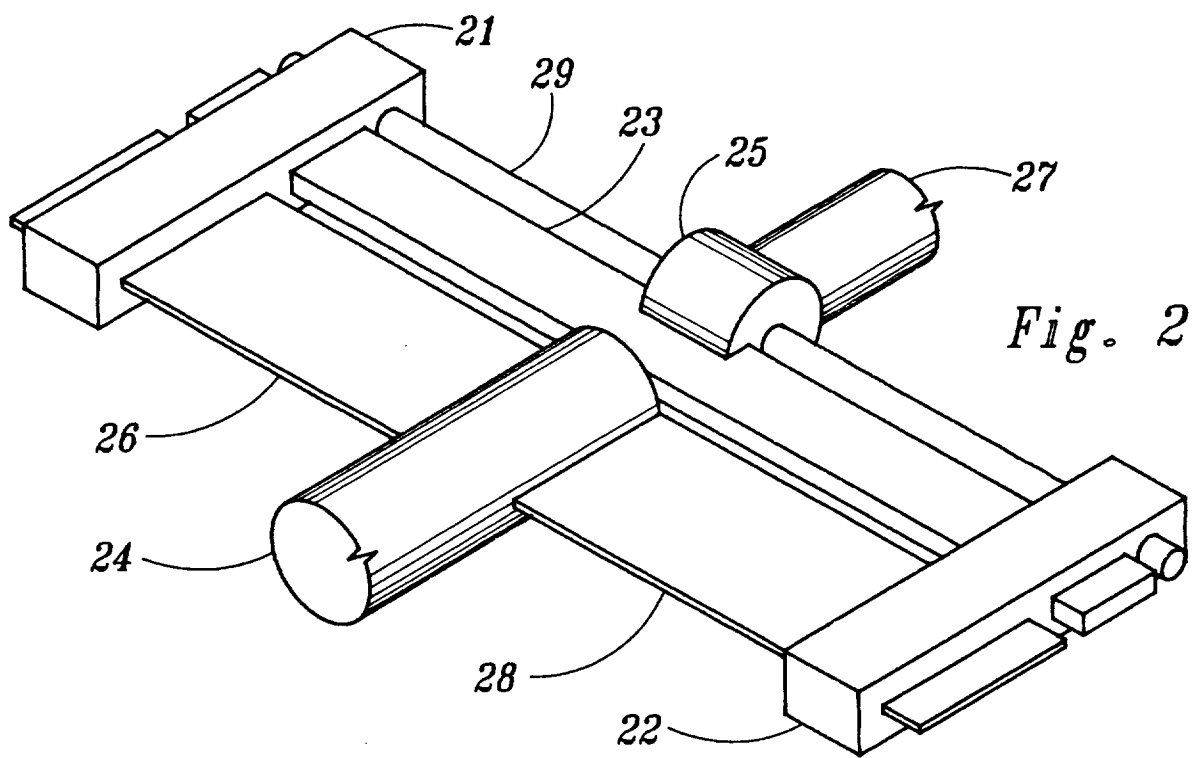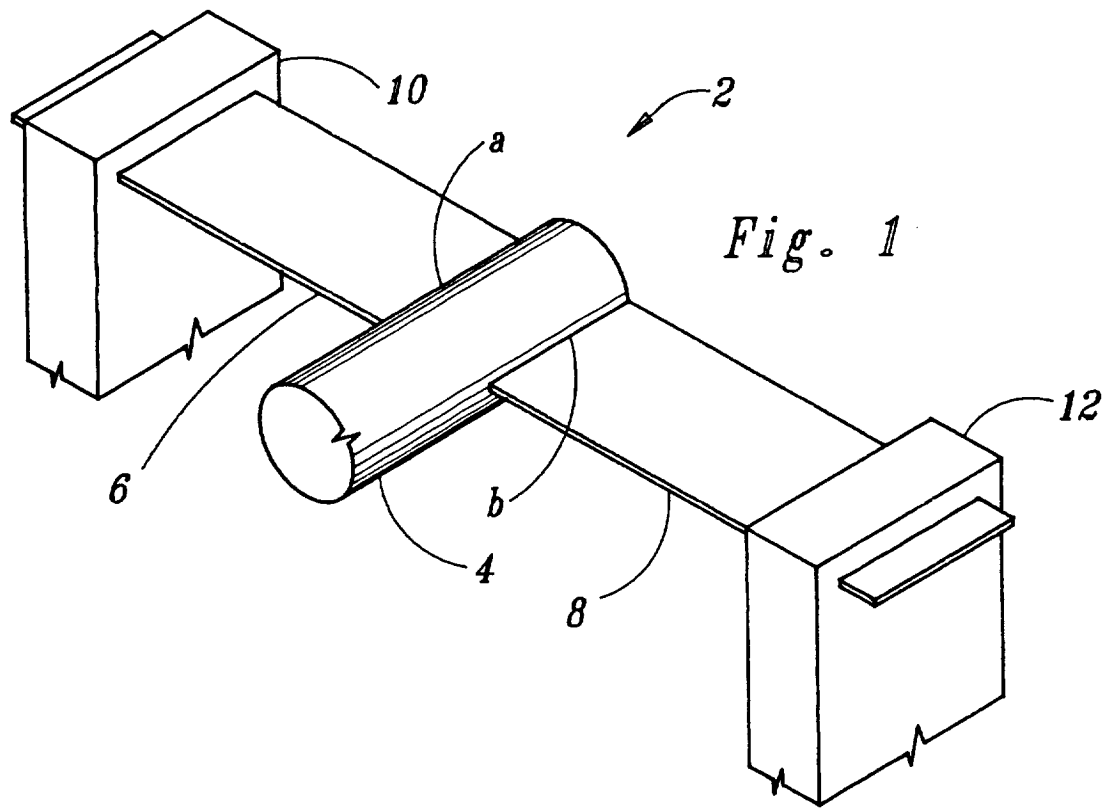
Summarizing, by the practice of this invention RUMs having less mass and smaller sizes can be utilized to achieve the same sized scan. The system uses less system power and mass because it amplifies the scan, allowing smaller RUM masses to achieve the same size scan. It is cheaper and less complicated, and its use leads to less chance of a stability problem because there is no feedback controller. It also allows mounting base disturbance vibrations above the resonant frequency of the torsion
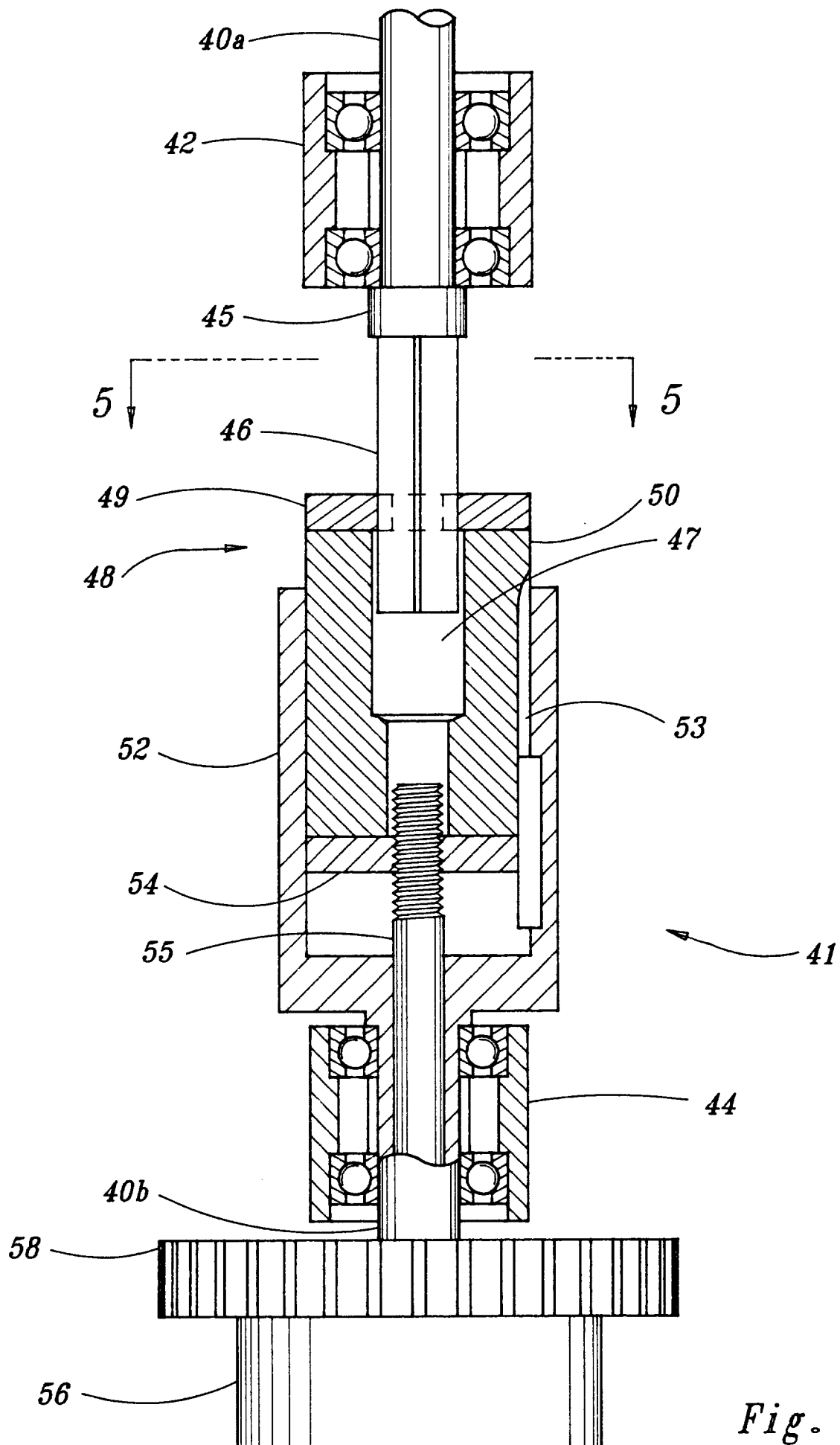
18

spring/inertial to be isolated from the payload.

The device of the invention not only amplifies the scan pattern, allowing smaller RUM devices requiring less power to be used, but it permits open loop operation for

5 positioning/repositioning the scan to keep it from drifting.

Having been given the teachings of this invention, variations and ramifications will occur to those skilled in the art. It will be appreciated, for instance that external springs taking forms other than those shown in Fig. 1 can be used to

10 return a torsion bar. As another variation rollers can be incorporated in supporting blocks 10 and 12 (Fig. 1) for ease of operation as blades 6 and 8 flex and move in the slots in the blocks. In addition constraints other than the cylindrical collar shown in Fig. 4 will occur to those skilled in the art.

15 Various clamps and grippers are available. This is also true of the gear shown in Fig. 2. Other gears can be used for the purpose of moving constraints 21 and 22. In fact they could be moved manually by means of a knob and the like. Further, as set forth in our copending application two gimbals and two

20 positioning means can be employed, and each positioning means will have its torsion spring. Moreover, to maximize the scan amplitude adjustable trim masses on lead screws can be used as disclosed in our copending application. This is also true of the

linear viscosity-coupled inertial dampers and the feedback

controller discussed in our copending application.   Such

ramifications as these are, of course, within the scope of this
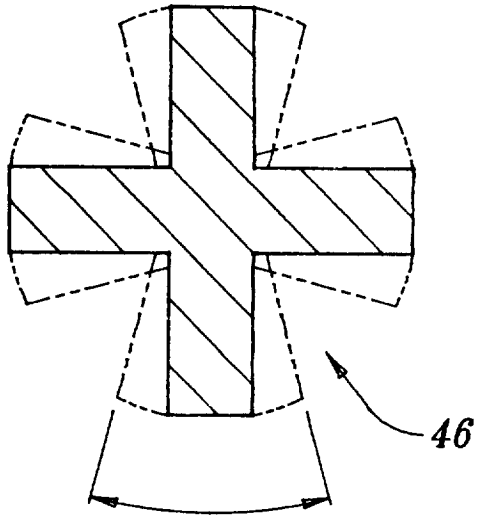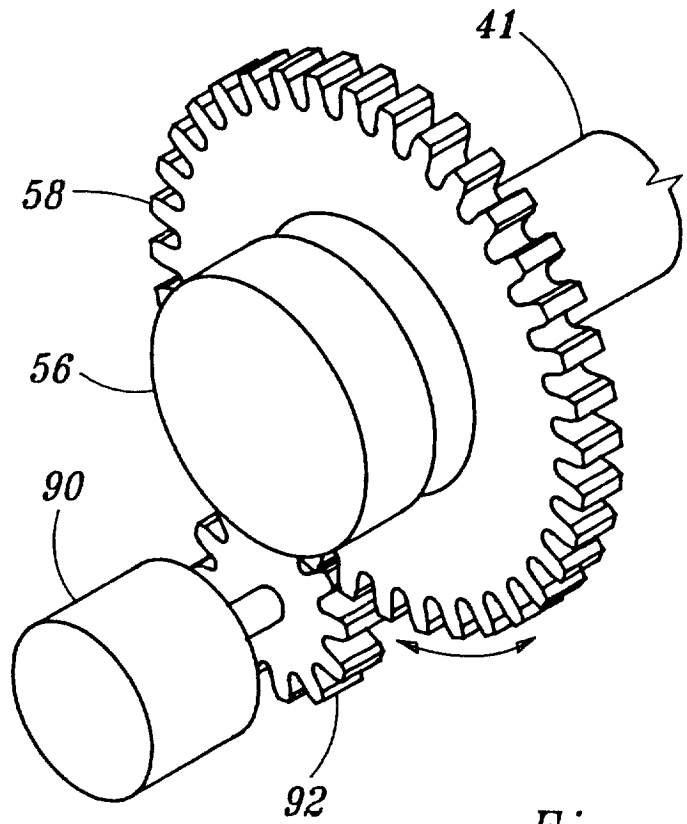
invention.

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Fig. 1

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a

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b

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Fig. 2

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29

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22

Fig. 3

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24

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22

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40a

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5 ↓ 5

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48 →

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41 ↰

44

40b

58

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Fig. 4

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Fig. 5

46

Fig. 6

58

56

90

92

41

Fig. 7

95

41
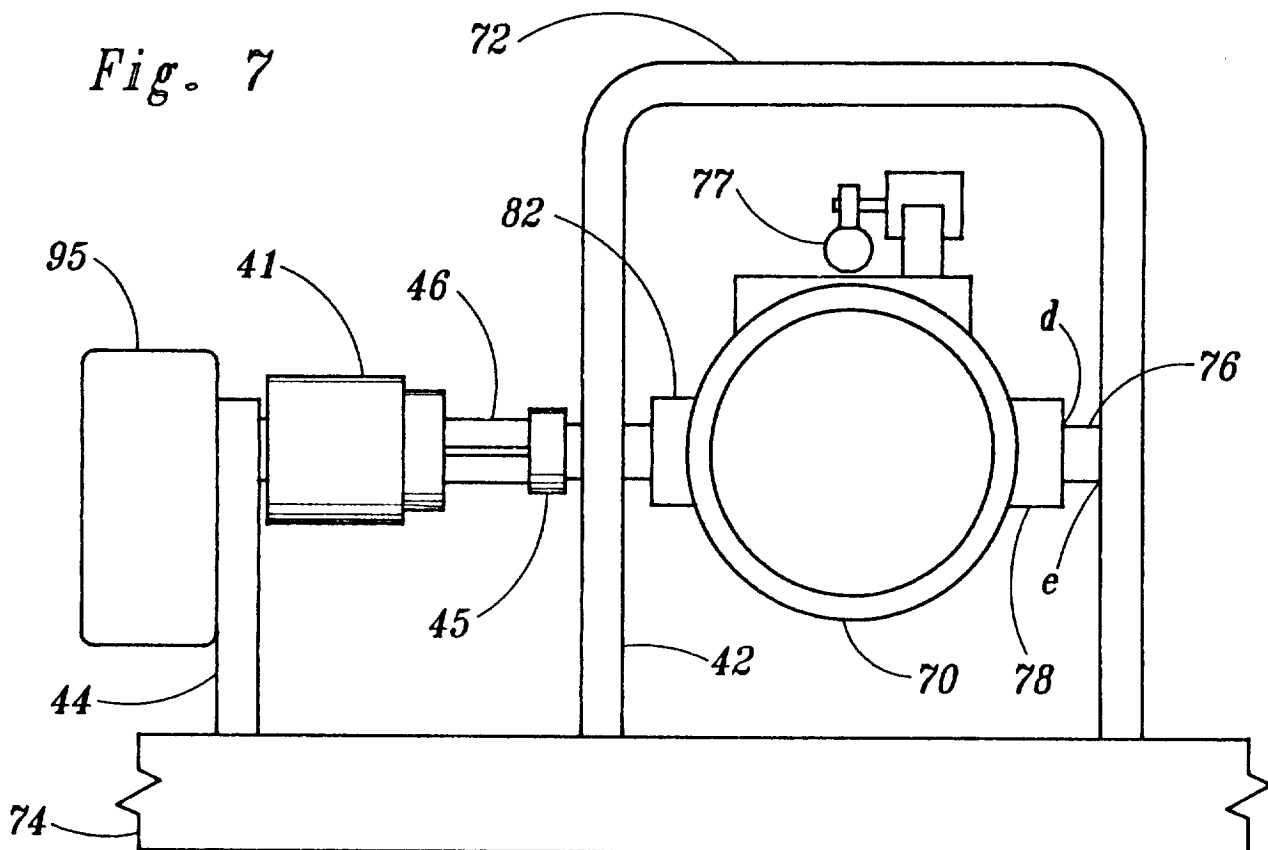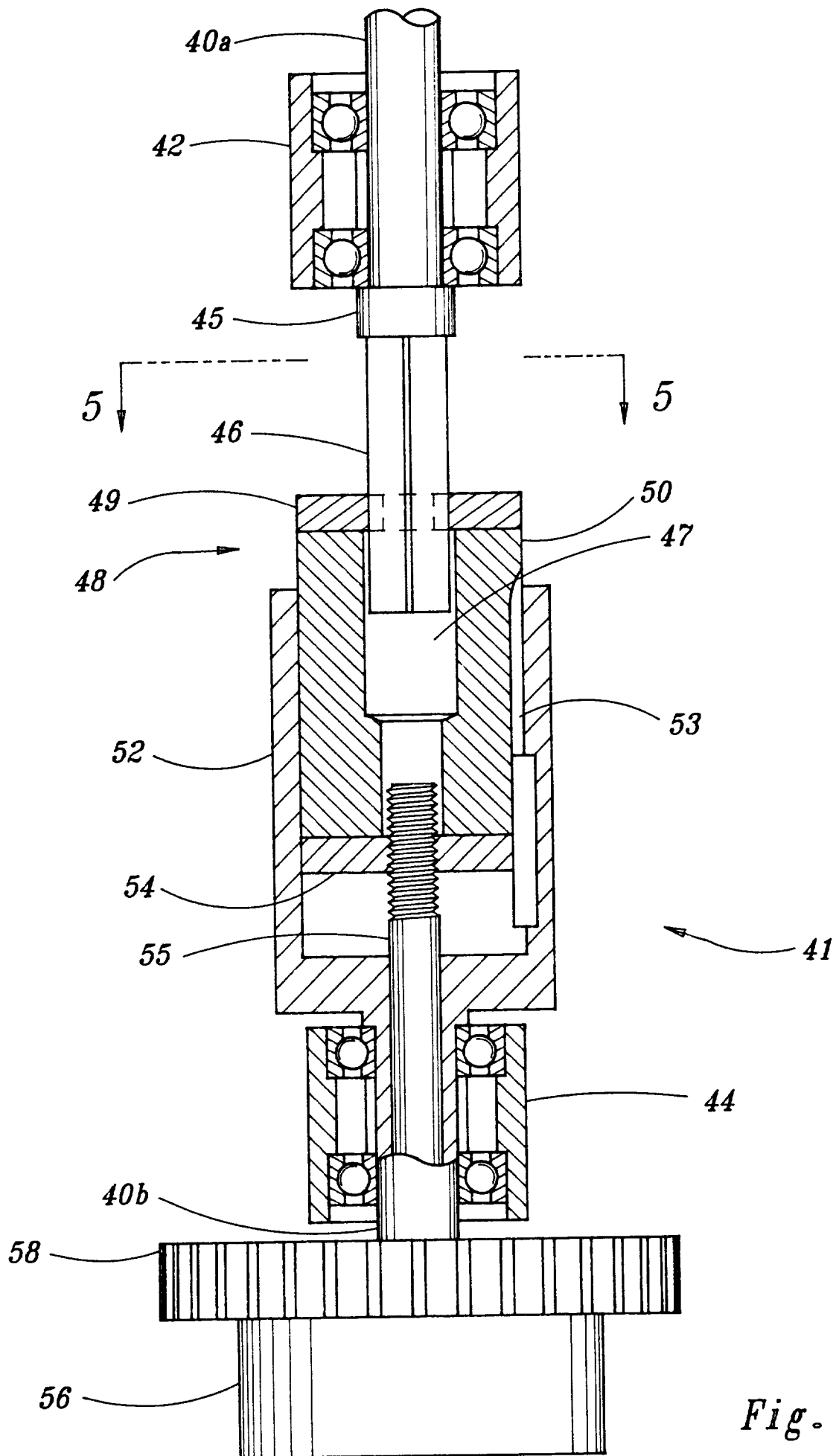
46

82

77

d

76

45

44

42

70

78

e

72

74

Fig. 4
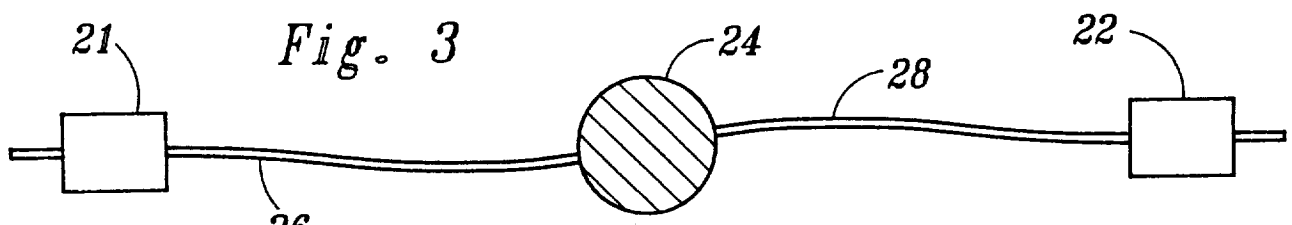
VARIABLE STIFFNESS TORSION SPRINGS

In a torsion spring the spring action is a result of the relationships between the torque applied in twisting the spring, the angle through which the torsion spring twists, and the modulus of elasticity of the spring material in shear.
Torsion springs employed industrially have been strips, rods, or bars, generally termed shafts, capable of being flexed by twisting about their axes. They rely on the variations in shearing forces to furnish an internal restoring torque. In the torsion springs herein the restoring torque is external, and therefore independent of the shearing modulus of elasticity the torsion spring shaft. Also provided herein is a variable stiffness torsion spring. This torsion spring can be so adjusted as to have a given spring constant. Such variable stiffness torsion springs are extremely useful in gimballed payloads such as sensors, telescopes and electronic devices on such platforms as a space shuttle, a space station.