July 5, 1966 M. C. SWANSON 3,258,980

ROTARY ACTUATOR

Filed April 16, 1963

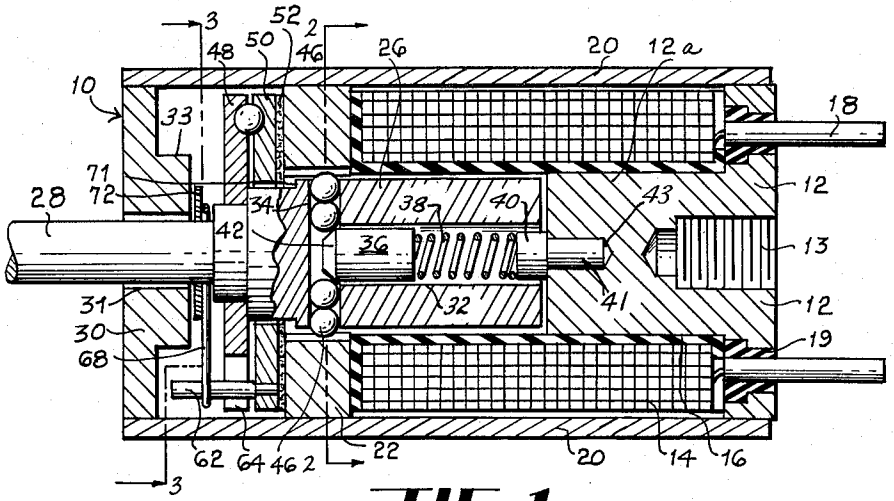


FIG. 1

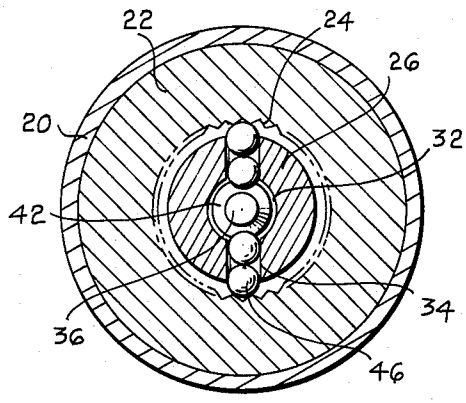


FIG. 2

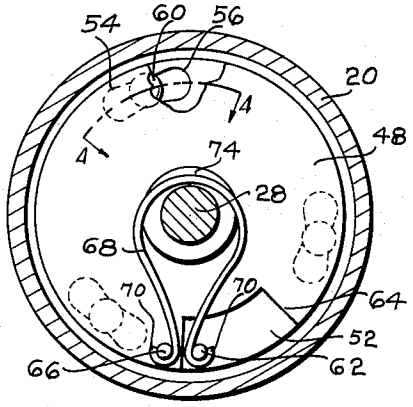


FIG. 3

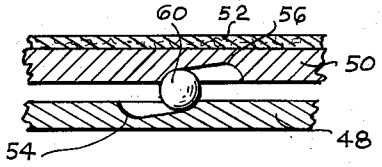


FIG. 4

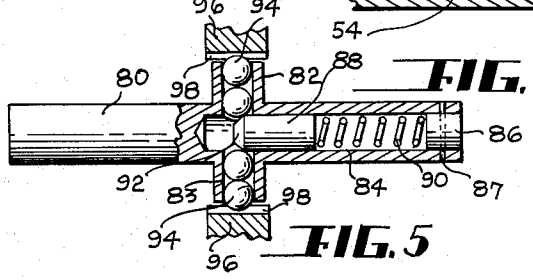


FIG. 5

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ROTARY ACTUATOR

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This invention relates to an improved rotary actuator and to a detent construction therefor, however, the invention is not necessarily so limited. This invention is an improvement upon the structure disclosed in copending application Serial No. 85,926, filed January 30, 1961 by Roger W. Biser, which is a continuation-in-part of Serial No. 606,711, filed August 28, 1956 (now abandoned), and results from efforts to miniaturize a device of the type disclosed in said applications.

In one of its forms, the device of the aforementioned applications is an electromagnetically energized actuator which produces a rotary stroke in an output shaft. The device involves a rotary conversion mechanism which is reset after each stroke of the output shaft and a spring is typically used to accomplish this reset operation. Also, for many applications, the device requires a detent mechanism for checking rotary motion of the output shaft during the reset operation and one or more springs are employed in the detent mechanism.

One of the problems involved in miniaturizing devices of this type resides in the design and location of the springs employed in the reset and detent mechanisms. Thus, for compactness, it is desirable to locate these springs interiorly of the operating parts, and, at the same time, for adequate tension and reliability of operation, it is essential to accommodate springs which are as large as possible.

Accordingly, it is an object of the present invention to provide a new and improved rotary actuator device having a novel construction and location for the spring elements associated therewith.

Another object of the present invention is to provide a new and improved mechanism for checking rotary movements.

Still another object of the present invention is to provide an improved rotary actuator construction including a detent mechanism for checking the rotary output and characterized by a compactness and reliability of operation.

Other objects and advantages reside in the construction of parts, the combination thereof, the method of manufacture and the mode of operation, as will become more apparent from the following description.

In the drawings, FIGURE 1 is a sectional view illustrating the interior construction of a rotary actuator device embodying the present invention.

FIGURE 2 is a sectional view, taken substantially along the line 2—2 of FIGURE 1.

FIGURE 3 is a sectional view, with a portion broken away, taken substantially along the line 3—3 of FIGURE 1.

FIGURE 4 is a fragmentary, sectional view, taken substantially along the line 4—4 of FIGURE 3.

FIGURE 5 is a plan view, with a portion shown in section, illustrating a modified detent mechanism embodying features of the present invention.

Referring to the drawing in greater detail, the rotary actuator **10** of FIGURE 1 includes a ferromagnetic element **12** having a cylindrical projection serving as a core **12***a* for an electromagnet. This core is surrounded by a solenoid coil **14**, the interior periphery of which is insulated from the core by an insulating sheath **16**. Electrical connection to the coil **14** is made through pins **18** supported in insulating inserts **19** mounted in the base of

the element **12**. For mounting of the rotary actuator, the element **12** may have a threaded bore **13** therein, as shown.

The element **12** has press-fitted thereon a hollow cylindrical housing **20** of ferromagnetic material which encloses the core **12***a*, the solenoid coil **14**, and the operative elements of the rotary actuator. Press-fitted in the housing **20** is an annular ring **22**, this ring being positioned adjacent the outer or forward end of the solenoid coil **14**. As best illustrated in FIGURE 2, this ring **22** has closely spaced axially extending flutes **24** in the inner periphery thereof, providing an irregular surface. As will be described more fully in the following, this fluted surface is utilized in checking rotary movement in the actuator output.

An armature **26**, responsive to the magnetic field of the electromagnet established in the core **12***a* by the coil **14**, passes centrally through the annular ring **22**. This armature supports an axially disposed output shaft **28** formed integrally thereon and projecting forwardly to the exterior of the housing **20**. A circular plate **30**, having a centrally disposed aperture **31** to receive the shaft **28**, is press-fitted into the end of the housing **20**, the plate **30** cooperating with the element **12** to substantially fully enclose the housing **20**.

The armature **26** has an axially disposed bore **32** entering the rearward end thereof. A second radially disposed bore **34** passes diametrically through the armature **26** at the forward end of the bore **32**. Disposed for axial movement in the bore **32** is a loosely fitting cylindrical piston or wedge member **36** having a frustum-conical forward end portion **42**. The piston **36** is biased in a forward direction, that is, in the direction of the radially disposed bore **34**, by means of a spring **38** acting against an abutment **40** having a stem **41** seated in a centrally disposed axially extending bore **43** formed in the core **12***a*.

The forward bias on the piston **36** is utilized to accomplish a detent or checking action in the following manner. Positioned in each of the opposite ends of the transverse bore **34** are two ball elements **46**. The forward bias on the piston **36** forces the frustum-conical end **42** thereof against the innermost balls **46** disposed in the bore **34**, thereby forcing these balls radially outwardly. This outward force is transmitted to the adjacent outer balls **46**, which are thereby urged into the flutes of the ring **22**. As best seen in FIGURE 2, the flutes **24** have a V-shaped cross section, so as to permit a rotation of the armature **26** provided the torque applied to the armature is sufficient to enable the sloping side walls of the flutes **24** to cam the balls **46** inwardly of the armature, overriding the outward bias applied by the spring **38**. The axial extent of the flutes **24** is such as to permit limited axial movement of the armature without the ball elements **46** traveling axially out of the flutes.

The use of pairs of ball elements, as shown, for the detent action, offers a number of benefits. The outermost balls, of course, are free to roll on the inner periphery of the ring **22**, as the armature rotates and, accordingly, a new surface is continually presented to the irregular inner surface of the ring **22**. Thus, frictional wear, both in the ball elements and in the inner periphery of the ring **22** is minimized. At the same time, the rolling action of the outer ball elements **46** is transmitted to the inner ball elements, uniformly distributing the wear occasioned by contact of the inner ball element with the frustum-conical end portion of the piston **36**. As further benefit, the ball elements **46** have a very small area of contact with the internal walls of the bore **34** and, accordingly introduce no appreciable frictional drag resisting the outward bias created by the spring **38**.

It will be clear to those skilled in the art that the number of balls **46** to be used in accomplishing the foregoing detent action depends upon the dimensions of the rotary actuator unit. Thus, if the diameter of the actuator unit as disclosed is to be reduced substantially, one of the ball elements **46** may be eliminated from each end of the bore **34**. Similarly, if the dimensions are such that the diameter of the armature **26** may be increased, the number of ball elements **46** may be increased accordingly. It will also be apparent that without any significant change in the overall dimensions of the rotary actuator disclosed, the number of ball elements **46** employed may be reduced to two, one at each end of the bore **34**, by substantially increasing the diameter of the bore to accommodate ball elements having a substantially increased diameter. However, for optimum detent action, balls of comparatively small diameter are preferred and it is accordingly preferable to use a series of ball elements stacked one against the other, as shown.

For developing a rotary torque in the armature **26**, an annular ferromagnetic plate or cam member **48** is press-fitted onto the forward end of the armature in surrounding relation to the output shaft **28**. Interposed between the plate **48** and the forward wall surface of the ring **22** is a second annular plate or cam member **50**, which is freely rotatable with respect to the armature **26**. For reasons which will become more apparent in the following, the rearward surface of the plate **50** has bonded thereto a brake lining **52**, adapted to frictionally engage the forward surface of the ring **22** when pressed thereagainst.

The opposing faces of the plates **48** and **50** are provided with arcuate inclined recesses **54** and **56** respectively, there being three recesses spaced 120° apart in each of the plate members **48** and **50**. As best seen in FIGURE 4, the bases of these recesses are oppositely inclined and, as best seen in FIGURE 3, the side walls of the recesses diverge as the bases of the recesses penetrate more deeply into their respective plates.

Ball elements **60**, there being three such ball elements, are interposed between opposing pairs of the recesses **54** and **56**. The divergence of the side walls of the recesses is such as to permit these ball elements to roll into the deeper ends of the recesses. The arrangement of the recesses **54** and **56** is such that, with the interposed ball elements **60** disposed in the shallow ends of the recesses, an axially disposed force pressing the plates **48** and **50** toward one another, will cause the ball elements **60** to roll into the opposing recesses **54** and **56**, at the same time, causing the plates **48** and **50** to rotate one relative to the other. For positioning the ball elements **60** in the shallow ends of the recesses **54** and **56**, a crank arm **62** is fitted into an aperture in the plate **50** near the outer periphery of this plate. This crank arm **62** projects forwardly through an arcuate cut-out portion **64** in the plate **48**. This cut-out portion **64** subtends an angle in the periphery of the plate **48** sufficient to accommodate the full angle of rotation between the plates **48** and **50** produced by the ball elements **60** operating in their opposing recesses **54** and **56**.

A second crank arm **66**, best seen in FIGURE 3, also projecting in a forward direction, is press-fitted into a suitable aperture in the plate **48**, this crank arm **66** being disposed adjacent the cut-out portion **64** in the plate **48**, as shown in FIGURE 3. Engaging both of the crank arms **62** and **66** is a hairpin spring **68**, which loops around the output shaft **28** and which has ends **70** curled about the crank arms **62** and **66**. The tension in the spring draws the crank arms **62** and **66** toward one another and, when the actuator is idle, the spring occupies substantially the position illustrated in FIGURE 3. In such position, the ball elements **60** are seated in the shallow ends of the recesses **54** and **56**, as illustrated in FIGURE 4.

The construction is such that, upon energization of the solenoid coil **14**, the element **12**, housing **20**, plate **48**, and armature **26** form a flux path for the magnetic field created. The magnetic field attracts the armature toward the core **12***a*. This draws the plate **48** toward the plate **50** and, through the medium of the ball elements **60**, the axial rearward thrust of the armature is transmitted to the plate **50** and applied to the ring **22** through the brake lining **52**. This causes the plate **50** to frictionally engage the ring **22**, so as to be temporarily non-rotatable relative to the housing **20**.

The axial thrust of the armature **26** operating on the ball elements **60** causes these ball elements to roll into the opposing recesses **54** and **56**, with the result that the plate **48** is caused to rotate relative to the plate **50**. Since the plate **50** is non-rotatable relative to the housing **20**, the rotary motion occurs only in the plate **48**, the armature **26** attached thereto and the output shaft **28** integral with the armature. Thus, as the armature **26** moves rearwardly, it is also induced to rotate.

As the armature **26** and, more specifically, the plate **48** rotates, the crank arm **66** is caused to move away from the crank arm **62**, in opposition to the tension in the spring **68**. The amount of rotation developed in this manner is determined by the lengh of the recesses **54** and **56** and, as previously mentioned, the angle subtended by the cut-out portion **64** and the plate **48** is sufficient to accommodate this rotation.

The rotary motion of the armature forces the ball elements **46** to move across one or more of the flutes **24** in the inner periphery of the ring **22**. It is unimportant whether or not the ball elements **46** seat squarely in new flutes **24** at the end of the rotary stroke.

When the solenoid coil **14** is deenergized and the magnetic field attracting the armature **26** has collapsed, the tension in the hairpin spring **68** induces a relative rotation between the plate **50** and the armature **26**. Since the armature **26**, together with its integral shaft **28** and any driven load attached thereto will ordinarily be considerably more massive than the plate **50**, the rotary torque produced by the spring **68** will cause rotation primarily in the plate **50** with only a slight reaction in the armature **26**. In the event the detent balls **46** are not squarely seated in flutes **24** at the end of the rotary stroke of the armature, the slight reaction in the armature, due to operation of the spring **68** coupled with the outward force on the ball elements **46** produced by the spring **38**, causes the ball elements **46** to seat squarely in the closest available flutes **24** in the annular ring **22**. Of course, once the ball elements **46** have seated squarely in flutes **24**, all of the rotary torque induced by the spring **68** is transmitted to the plate **50**, with the result that the plate **50** is returned to its initial operating position, seating the ball elements **60** in the shallow ends of the opposing recesses **54** and **56**.

As the plate **50** returns to its initial position, the ball elements **60** react in their respective recesses **54** and **56** to drive the plate **50** rearwardly relative to the armature toward the annular ring **22**. This would ordinarily introduce a frictional drag opposing return of the plate **50**. In the present invention, this frictional drag is substantially eliminated by having the spring **38** act on the balls **46**, which in turn act on the armature **26**, so as to push the armature forward as the spring **68** acts to return the plate **50**. This forward armature movement offsets the rearward movement of the plate **50** relative to the armature required for return of the plate **50** to its initial operating position. To insure this result, the spring **38** is made substantially stronger than the spring **68**.

As can be noted in FIGURE 1, the armature has an annular shoulder **71** which engages the inner margin of the plate **50** as the armature returns forwardly under pressure of the spring **38**. The shoulder **71** functions to provide a definite clearance between the plate **50** and annular ring **22** upon return of the armature to its initial position after deenergization of the electromagnet, thus

removing frictional drag such as would resist manual rotation of the shaft **28** when the electromagnet is deenergized.

In the present construction, the forward motion of the armature **26** caused by pressure from the spring **38** is limited by an inwardly directed projection **33** on the end plate **30**. An annular shoulder **74** on the armature **26** engages the spring **68** and drives this spring forwardly against a washer **72** buttressed by the projection **33**. The dimensions of the projection **33** and washer **72** are such as to preclude a separation between the plate **50** and the annular ring **22** sufficient to permit escape of the ball elements **46** from the opposed pairs of recesses **54** and **56**.

FIGURE 5 illustrates a modification of the detent assembly of FIGURE 1 and, furthermore, illustrates use of the detent mechanism in checking the rotary motion of a shaft **80**. For housing the detent mechanism, the shaft **80** has integral radially disposed arms **82** through which passes a diametrically disposed boring **83**. Communicating with the boring **83** is an axially disposed boring **84** entering one end of the shaft **80**. Upon assembly of a piston **88** and biasing spring **90** inside the boring **84**, this boring is closed with a plug **86** retained by a transverse pin **87**.

Four ball elements are fitted in the boring **83**, there being two on each side of the piston **88**. The piston **88** has a frustum-conical forward end portion which, under the action of the spring **90**, presses against the innermost ball elements **94** to urge the assembled balls outwardly of the arms **82**.

The shaft **80** is encircled by an annular ring **96** having axially disposed flutes **98** disposed circumferentially around the inner periphery of the ring. The ring **96** may be supported by any suitable mounting, not illustrated.

The operation of the modification of FIGURE 5 is substantially the same as that of the preferred embodiment, in that the spring **90** acting against the piston **88** constantly urges the ball elements **94** against the inner periphery of the ring **96**, the outermost ball elements seating in flutes **98** in the inner periphery of the ring **96** to check rotary movement of the shaft **80**.

It will be noted that both the embodiments of FIGURES 1 and 5 offer the advantage that the detent mechanism is assembled within the body to be checked, thus affording compactness to the apparatus in which the mechanism is employed. The essential difference between the embodiments of FIGURE 5 and FIGURE 1 is that in the embodiment of FIGURE 5, the spring **90** acts entirely within the shaft **80**, due to containment by the plug **86**, whereas, in the embodiment of FIGURE 1, the spring **38** reacts against an abutment **40** which is supported independently of the armature **26**. In the embodiment of FIGURE 1, the spring **38** is permitted to act against the abutment **40** to give the armature **26** a forward thrust, which is utilized to break a friction connection. It is to be recognized, however, that for other applications, such forward thrust may serve no useful purpose and in such cases, the detent assembly of FIGURE 5 will suffice.

In both the detent constructions illustrated, the detent balls **94** are confined within an annular ring and, accordingly, there is no necessity for caging the balls **46** or **94** in their boring. For some assemblies, however, it is recognized that caging of the balls **46** or **94** may be advantageous and, in such cases, it is within the purview of the present invention to employ any suitable means, such as an inwardly directed lip at the outer ends of the boring, for retaining the ball elements in the boring.

Although the preferred embodiment of the device has been described, it will be understood that within the purview of this invention various changes may be made in the form, details, proportion and arrangement of parts, the combination thereof and mode of operation, which generally stated consist in a device capable of carrying out the objects set forth, as disclosed and defined in the appended claims.

Having thus described my invention, I claim:

1. In an apparatus for producing rotary movement of a driven element, said apparatus comprising a housing receiving said driven element and in which said driven element has freedom for limited axial and rotary movement on a predetermined axis, said housing having a brake surface occupying a plane normal to said predetermined axis, motive means to deliver a rearward axial thrust to said driven element along said predetermined axis, and motion conversion means connected with said driven element responsive to said rearward thrust and engageable with said brake surface to cause rotation of said driven element relative to said housing, the improvement comprising resilient means coacting between said driven element and said housing to oppose said rearward axial thrust and operable upon relaxation of said rearward thrust to drive said driven element forwardly to release the frictional engagement between said motion conversion means and said brake surface.

2. In an apparatus for producing rotary movement of a driven element, said apparatus comprising a housing receiving said driven element and in which said driven element has freedom for limited axial and rotary movement on a predetermined axis, said housing having a brake surface occupying a plane normal to said predetermined axis, motive means to deliver a rearward axial thrust to said driven element along said predetermined axis, and motion conversion means connected with said driven element responsive to said rearward thrust and engageable with said brake surface to cause rotation of said driven element relative to said housing, the improvement comprising resilient means coacting between said driven element and said housing to oppose said rearward axial thrust and operable upon relaxation of said rearward thrust to drive said driven element forwardly to release the frictional engagement between said motion conversion means and said brake surface, said motion conversion means including a first cam member carried by said driven element, a second cam member spaced axially from said first cam member and adapted to frictionally engage said brake surface, means operating between said cam members to induce relative rotation thereof in one direction upon relative axial movement thereof one toward the other, and to induce relative axial movement thereof one away from the other upon relative rotation thereof in the opposite direction, and yielding means coacting between said cam members to oppose relative rotation thereof in said one direction, the construction and arrangement thereof being such that said second cam member is pressed against said brake surface upon rearward movement of said driven element whereby the relative rotation between said cam members in said one direction induced by such rearward movement results in rotation of said first cam member and said driven element relative to said housing, said yielding means acting upon relaxation of said axial thrust to reverse the induced relative rotation of said cam members and thereby cause relative axial movement of said cam members one away from the other, said resilient means driving said driven element forwardly upon relaxation of said rearward thrust to offset the relative axial movement of said cam members caused by said yielding means, thereby releasing the frictional engagement between said second cam member and said brake surface.

3. In a rotary actuator assembly including a pair of opposing plate members, cam means operable between said plate members for inducing relative rotation thereof through a limited angle in one direction upon an application of pressure forcing said plate members one toward the other, first yielding means coacting between said plate members to oppose said rotary movement in said one di-

rection and operable upon relaxation of said pressure to rotate said members relatively in the reverse direction, said cam means operating in response to said reverse rotation to force said plate members one away from the other, a driven element, first connecting means to connect a first of said plate members to said driven element, a supporting structure, second connecting means to connect the second of said plate members to said supporting structure, one of said first and second means including a brake surface positioned adjacent one of said plate members to form a brake therewith, and actuator means to apply a pressure to said plate members and said brake surface one through the other whereby said clutch is engaged at substantially the same time said plate members are forced one toward the other to induce relative rotation thereof, the improvement comprising second yielding means effective to bias said brake surface and the other of said plate members apart, said second yielding means acting upon relaxation of the pressure from said actuator means to push said other plate member away from said brake surface offsetting the movement of said plate members one away from the other induced by said first yielding means and thereby releasing the brake engagement between said one plate member and said brake surface.

4. The rotary actuator assembly according to claim 3, wherein said relative rotation between said plate members occurs about an axis passing normally through the opposing surfaces of said plate members and wherein said cam means comprises opposed arcuate inclined recesses in the opposing surfaces of said plate members concentric to said axis of relative rotation and a roller element interposed between said opposed recesses.

5. In a rotary actuator assembly, the improvement according to claim 3, wherein the other of said first and second connecting means is a fixed connection and wherein said second yielding means is a compression spring operating between said supporting structure and said driven element, one of which carries said one plate and the other of which includes said brake surface.

6. In a rotary actuator assembly, the improvement according to claim 3, wherein the other of said first and second connecting means is a fixed connection and wherein said second yielding means is a compression spring operating between said supporting structure and said driven element, one of which carries said one plate and the other of which includes said brake surface, said driven element rotating relative to said supporting structure about an axis passing therethrough in response to pressure applied to said plate members and said brake surface by said actuator means, said supporting structure including an annular ring encircling said driven element concentric to said axis of rotation, said annular ring having an irregularly surfaced inner periphery opposite said driven element, said driven element having a first boring therein parallel to said axis receiving one end of said compression spring, said assembly including a piston disposed slidably in said first boring for engagement with said spring so as to receive an axial thrust therefrom, said driven element having a second boring therethrough transverse to and intersecting with said first boring, said second boring being disposed in the plane of said annular ring and opening at each end thereof to the inner periphery of said annular ring, said piston having a wedge portion entering said second boring, and said assembly including detent means disposed in said second boring, there being one detent means in each end of said second boring and engaging opposite sides of said wedge portion, said compression spring acting on said piston to drive said detent means outwardly of the ends of said second boring against the irregularly surfaced inner periphery of said annular ring to thereby yieldingly check the rotation of said driven element.

7. Apparatus for inducing rotary movement of a driven element and checking the rotary movement thereof comprising: a housing receiving said driven element and in which said driven element has freedom for limited axial and rotary movement on a predetermined axis, said housing having a brake surface occupying a plane normal to said predetermined axis and spaced radially therefrom, motive means to deliver a rearward axial thrust to said driven element along said predetermined axis, motion conversion means responsive to said axial thrust to induce a simultaneous rotary movement of said driven element, said motion conversion means including a first cam member carried by said driven element and disposed in axially spaced relation to the brake surface of said housing, a second cam member interposed between said first cam member and said clutch surface, said second cam member having a rearward surface opposing the brake surface of said housing and adapted to engage in friction contact therewith, said second cam member having a forward surface opposing said first cam member, means coacting between said cam members to induce relative rotation thereof about said predetermined axis upon delivery of an axial thrust to said driven element, and yielding means opposing said relative rotation for resetting said cam members upon release of said axial thrust, said coacting means transmitting said axial thrust from said first cam member to said second cam member and thereby causing the forward surface of said second cam member to frictionally engage the surface of said housing whereby said driven element is induced to rotate relative to said housing, and check means to check the rotary movement of said driven element for which said housing has an interior cylindrical and irregularly surfaced wall encircling said driven element concentric to said predetermined axis and said driven element has first and second communicating passages therein, said first passage traversing said driven element radially with respect to said predetermined axis and said second passage entering the rearward end of said driven element and extending forwardly of said driven element parallel to said predetermined axis to communicate with said first passage, said check means comprising a wedge member disposed for axial movement in said second passage and having forwardly converging external surfaces projecting into said first passage, a pair of detent means disposed in said first passage, there being one detent means on each side of said wedge member, each said detent means projecting radially from said wedge member to the exterior surface of said driven element, resilient means located in said second passage rearwardly of said wedge member, and abutment means secured fixedly to said housing for engaging said resilient means, said abutment means acting with said resilient means to bias said wedge member forwardly whereby said detent means are urged outwardly of said driven element through coaction of the converging surfaces of said wedge member to seat in irregularities of said cylindrical wall and thereby check the rotary movement of said driven element, said resilient means acting upon relaxation of such axial thrust to drive said driven element forwardly thus alleviating the frictional engagement between said brake surfaces.

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