April 1, 1958 G. V. HALL 2,828,636

ELECTROMAGNETICALLY OPERATED ROTARY ACTUATOR

Filed Jan. 25, 1957

Fig. 1.

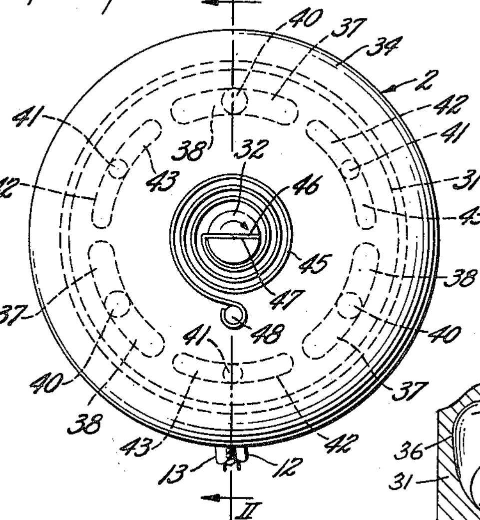
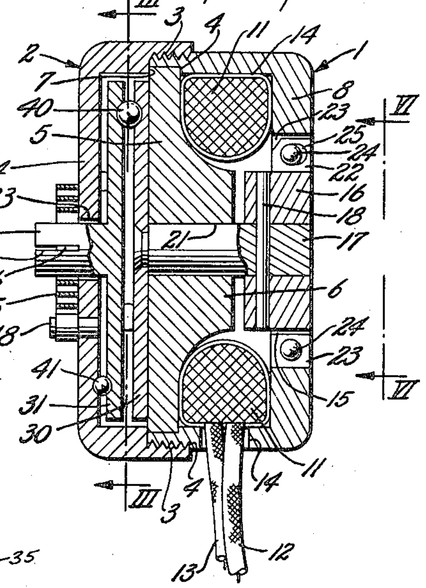


Fig. 2.



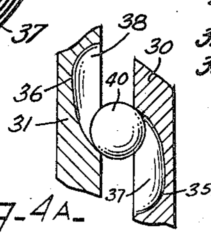
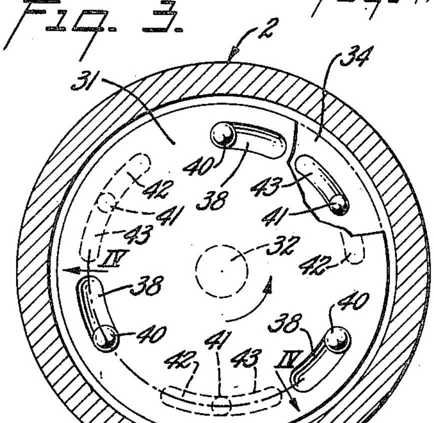


Fig. 4A

Fig. 3.



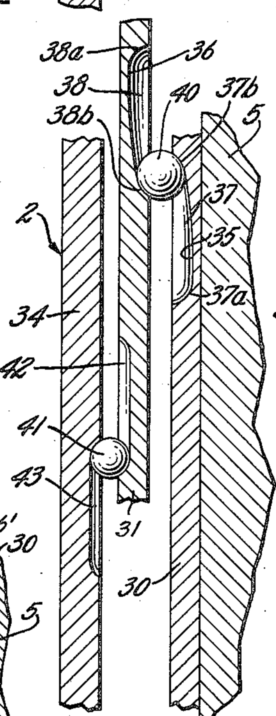


Fig. 4.

Fig. 5.

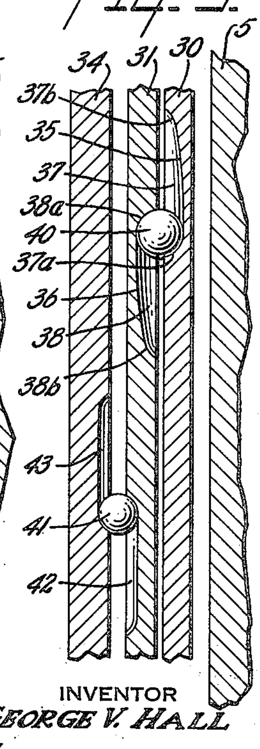


Fig. 6.

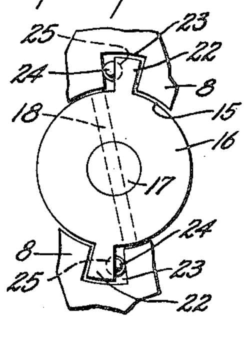
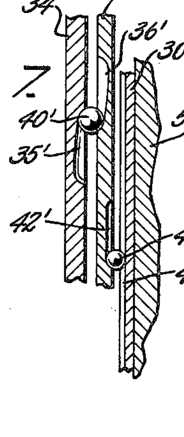


Fig. 7.



INVENTOR
GEORGE V. HALL
BY
Norman Friedman
ATTORNEY

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ELECTROMAGNETICALLY OPERATED ROTARY ACTUATOR

George V. Hall, Orange, N. J., assignor to Monroe Calculating Machine Company, Orange, N. J., a corporation of Delaware

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16 Claims. (Cl. 74—99)

This invention relates to electromagnetically operated rotary actuators.

More specifically, it pertains to devices wherein the axial movement of an armature toward an energized electromagnet is utilized to produce a rotary output movement.

In devices of this character, it will be evident that fixed attachment of the rotary output member with the armature will result in both axial and rotary movement of both the output member and of the armature. Furthermore it will be apparent that the inertia of both the output member and of the armature must be overcome with respect to both the axial and rotary movement.

While prior art actuators of the nature indicated in the preceding paragraph have been found to be generally satisfactory, in many applications the fact that the output is axial as well as rotary unnecessarily complicates the nature of the coupling between the actuator and the device to be actuated. Thus, where it is essential that the actuated device partake only of rotary movement, it has been necessary to make provision in the coupling for taking up the axial component of the output movement of the actuator. This has resulted in a more complicated and more expensive coupling than would be required if the output were rotary only.

In one form of the present invention I have avoided the disadvantages flowing from an output movement which is axial as well as rotary by providing an arrangement in which the armature is restrained against rotary movement, and the axial movement of the armature utilized to impart solely rotary movement to an output member through suitable interposed camming means.

It is therefore one object of the invention to provide an electromagnetically operated rotary actuator whose output is rotary only.

It is a further object to provide an actuator in which rotary movement is imparted to those operating components of the actuator which have a relatively small moment of inertia. As a result, a smaller portion of the total available energy is utilized to overcome rotational inertia of the parts and consequently a greater portion of said total energy will appear as useful output energy.

It is a still further object to provide an electromagnetically operated rotary actuator whose magnetic circuit is axially isolated from rotary components thereby affording greater flexibility in the location and size of the rotary components.

In the drawing:

Fig. 1 is an end view of an actuator according to the invention.

Fig. 2 is a sectional view taken on line 2—2 of Fig. 1.

Fig. 3 is a sectional view with parts broken away taken on line 3—3 of Fig. 2.

Fig. 4 is an enlarged fragmentary sectional view taken on line 4—4 of Fig. 3, showing the relative position of parts of the device in normal, unoperated condition.

Fig. 4A is a fragmentary view similar to Fig. 4 showing in exaggerated fashion the slope of the opposed inclined surfaces provided on the two cooperating plates of the instant actuator.

Fig. 5 is a sectional view similar to Fig. 4, showing the same parts in operated condition.

Fig. 6 is a fragmentary end view taken on line 6—6 of Fig. 2, showing the means for restraining the armature of the actuator against rotation.

Fig. 7 is a view, similar to Fig. 4, showing a modified form of the invention.

Referring now to the drawing, and noting particularly Fig. 2 thereof, the electromagnetically operated rotary actuator of the present invention includes an exterior casing comprising two opposed cup-shaped members 1, 2 joined together at their open ends by mating screw threads 3 to define an enclosed substantially cylindrical volume in which the main operating portions of the device are housed. Member 1 is formed of magnetically permeable material while member 2 is of non-magnetic material.

Casing member 1 is provided at its open end with an annular internal slot 4 which receives the outer peripheral portion of a circular magnetically permeable core 5 having a central protuberant portion 6. Core 5 is rigidly held in slot 4 by engagement of an overhanging shoulder 7 of casing member 2 with the large end face of the core.

Disposed and securely held between core 5 and end wall 8 of casing member 1 is an electromagnetic coil 11 of toroidal form adapted to be energized by application of a potential difference across the two coil leads 12, 13 which extend through a suitable lateral opening 14 provided in casing member 1.

End wall 8 of casing member 1 is formed with an axial opening 15 in which is disposed a magnetically permeable armature 16 located to one side of the core, the armature being closely spaced to the right end of the protuberant portion 6 of core 5 for axial movement toward the core upon energization of magnetizing coil 11. Armature 16 is supported for axial movement by a non-magnetic stainless steel shaft 17 to one end of which it is secured fast by a pin 18. Shaft 17 is mounted for longitudinal sliding movement in a central longitudinal bore 21 of core 5.

Armature 16, while free for axial movement toward and away from core 6, is restrained against rotary movement relative to the core and coil 11 by means of radially outwardly extending ribs 22 (Figs. 2, 6) of the armature, said ribs extending into radial slots 23 formed in end wall 8. Friction between the ribs and slots in axial movement of the armature toward the core is minimized by balls 24 in rolling contact with a side of each slot, said balls being seated in a longitudinal raceway 25 of each rib 22.

A circular non-magnetic plate 30 is disposed to the opposite side of core 5 from armature 16 and is rigidly secured to the left end of shaft 17 (Fig. 2). In normal deenergized condition of the actuator, plate 30 is substantially in abutting relation with the end face of the core as seen in Figs. 2 and 4. Since plate 30 is rigid with shaft 17 which in turn is fast with armature 16, the plate and armature are movable axially as a unit and are both restrained against rotary movement by ribs 22 cooperating with slots 23. Accordingly, when coil 11 is energized, armature 16 will be attracted to core 5 and will move plate 30 to the left.

Arranged in opposed relationship with plate 30 is another non-magnetic plate 31 having integral therewith a central shaft 32 which extends outwardly of the casing through a central aperture 33 of casing member 2. As described below, the arrangement is such that plate 31 and shaft 32 are substantially restrained from axial movement, and are caused to rotate in response to axial movement of armature 16 and plate 30 toward core 5 and plate 31 respectively upon energization of magnetizing coil 11. Shaft 32, which in the present embodiment serves as the output portion of the device, may be coupled in any suitable fashion to any other device to impart rotary motion thereto.

The means whereby axial movement of armature 16 and plate 30 is utilized to impart rotary movement to plate 31 and shaft 32 will now be described. Plates 30 and 31 are provided on their opposed faces with at least one pair and preferably a plurality of pairs of opposed oppositely inclined surfaces 35, 36 (best seen in Figs. 4, 4*a*, and 5) each of which forms the base of a recess 37, 38 respectively. Rotatable anti-friction elements in the form of hardened steel balls 40 are disposed between plates 30 and 31, each ball being seated at its diametrically opposite side portions in said respective recesses and in rolling engagement with said inclined surfaces.

Rotational friction between plate 31 and end wall 34 of the casing is reduced by the provision of balls 41 seated in rolling engagement with the bases of opposed raceways 42, 43 of substantially uniform depth formed in the opposed faces of said plate 31 and end wall 34, balls 41 serving as force transmitting spacer elements between said plate and end wall. Plate 31 is restrained against axial movement toward wall 34 by balls 41 and against axial movement in the opposite direction toward plate 30 by balls 40.

In normal deenergized condition of the actuator, plate 31 is maintained in such a rotational or angular position relative to plate 30 that the high portions of each pair of opposed inclined surfaces 35, 36 (or stated differently, the shallow portions of each pair of recesses 37, 38) are in overlapping relation as shown in Fig. 4, with ball 40 disposed between said portions of the inclined surfaces or recesses.

Upon energization of coil 11, armature 16 will be attracted to core 5 causing plate 30 to move axially to the left toward plate 31 (Figs. 2, 4, 5). The force exerted by plate 30 on each ball 40 will be transmitted by the ball to plate 31 interposed between plate 30 and end wall 34. Since plate 30 is restrained against rotation by ribs 22, while plate 31 is free for rotation, and because of the inclination of surfaces 35 and 36, rotary movement will be imparted to plate 31. In the course of such movement, ball 40 will rotate counterclockwise (Fig. 4) and roll from the shallow to the deep ends of recesses 37 and 38. There, as shown in Fig. 5, the ball engages shoulders 37*a* and 38*a* which respectively define the deep ends of said recesses and form a stop to prevent further rotation of plate 31.

The axial force exerted by the electromagnet on armature 16 will of course continuously increase as the armature approaches core 5 thus diminishing the length of the air gap between these parts. To provide that the torque output of plate 31 and shaft 32 remains reasonably constant throughout their angular operating stroke, the inclination of surfaces 35 and 36 is made somewhat greater at the shallow ends of the recesses than at the deep ends thereof.

Means is further provided to restore the parts to normal relative position upon deenergization of the electromagnet, said means comprising a spiral restoring spring 45 encircling shaft 32. The inner end 46 of the spring is bent radially and extends into a diametral slot 47 formed in the shaft and is thus constrained to rotate with the shaft, while the outer end of the spring is looped around and held against movement by a pin 48 secured to wall 34. During the operating stroke of plate 30 and shaft 32, these parts will rotate clockwise as viewed in Fig. 1 (counterclockwise, Fig. 3) causing spring 45 to be placed under torsional compression. When the electromagnet is deenergized, the spring will rock said plate and shaft in the reverse direction whereby plate 30 and shaft 17 will be shifted axially to their normal unoperated rightmost position of Fig. 1. The shoulders 37*b*, 38*b* which respectively define the shallow ends of recesses 37, 38 will be engaged by ball 40 to limit the return rotary movement of plate 31 and maintain the plate in its normal angular position relative to plate 30 (Fig. 4).

From the foregoing, it will be seen that there has been provided a rotary actuator which offers distinct operating advantages in the elimination of the axial component of the output movement.

By providing an arrangement in which the armature does not rotate, I achieve the further significant advantage of materially reducing the inertia of the moving parts of the actuator for the following reasons. The mass of the armature must be substantial in order that an adequate magnetic attractive force be developed between the armature and core. In the type of actuator wherein the armature rotates, the energy available to do useful work must therefore overcome the relatively large rotational inertia of the armature. Similarly, when the movable parts are restored from operated to unoperated position by the return spring 45 the spring must likewise overcome the rotational inertia of the armature.

In the actuator of the present invention, on the other hand, the armature partakes of axial movement only and those parts which do rotate have a considerably smaller moment of inertia than the armature. Accordingly, the portion of the total available operating energy which in the prior art devices is wasted in overcoming the rotational inertia of the armature is, in the device of the present invention, available as useful output energy.

For some uses, it may not be absolutely essential to eliminate the axial component of the rotary output movement. Fig. 7 shows a modified form of the invention in which plate 31 partakes of axial as well as rotary movement. In this modification, the opposed inclined surfaces 35′ and 36′ are provided on fixed end wall 34 and the adjacent opposed face of plate 31, as distinguished from the provision of the inclined surfaces on plate 30 and the adjacent face of plate 31 in the form of Figs. 1–6.

The species of Fig. 7 also includes opposed races 42′, 43′ of uniform depth provided in the adjacent opposed faces of plates 31 and 30 respectively, the race 43′ extending continuously about the face of plate 30. Balls 41′ are supported in said races between the plates and serve as anti-friction spacer means between these parts.

In operation, plate 30 will be moved axially to the left by armature 16 upon energization of coil 11. The resultant axial thrust will be transmitted by balls 41 and plate 31 to balls 40′, which will cause plate 31 to simultaneously rotate and move axially to the left.

If desired, the form of Fig. 7 can be provided with means to restrain the armature and plate 30′ against rotation. However, the only force tending to rotate plate 30 will be that produced by the friction of balls 41′ rolling in race 43′, and this force will be negligible in magnitude and usually insufficient to overcome the rotary friction between shaft 17 and the wall of bore 21. Thus, the form of Fig. 7 may be simplified by the omission of any special means for preventing rotary movement of plate 30 and the armature, the aforenoted rotary friction between shaft 17 and bore 21 acting to restrain the armature 16 and plate 30 from rotation. Even if the frictional force between balls 41′ and race 43′ were sufficient to cause rotation of plate 30, the acceleration and magnitude of rotation would be so slight as to be insignificant.

Also of significance in both forms of the present invention is the arrangement whereby magnetic armature 16 is disposed to one side of magnetic core 5 and non-magnetic plates 30 and 31 are both disposed to the opposite side of the core. This disposition of the parts makes possible considerable flexibilty in the choice of radial location of the inclined surfaces. While in the present embodiment I have shown the inclined surfaces at some radial distance from the axis of rotation of plate **31**, in certain applications it may be desirable to have the inclined surfaces in closely spaced relation to the longitudinal axis of the actuator. It will be apparent that by the present construction, the inclined surfaces (and also the races **42, 43; 42', 43'**) may be disposed as closely as desired to the axis of rotation regardless of the diameter of the armature.

While I have shown but two forms of the invention, it will be understood that various changes may be made in the form, detail, arrangement, and proportions of the parts without departing from the spirit and scope of the invention. Accordingly, it is intended that the foregoing disclosure be illustrative only and not limitative of the following claims.

I claim:

1. An electromagnetically operated rotary actuator comprising an electromagnet, an armature mounted for axial movement toward said electromagnet and restrained against rotary movement relative thereto, a member mounted for rotary movement relative to said armature, and means operable to impart rotary movement to said member in response to axial movement of said armature toward said electromagnet.

2. An electromagnetically operated rotary actuator comprising an electromagnet, an armature mounted for axial movement toward said electromagnet and restrained against rotary movement relative thereto, a first member fast with said armature for axial movement therewith, a second member arranged for rotary movement relative to said armature, one of said members being provided with an inclined surface, rotatable means operatively associated with the other member and disposed in rolling engagement with said inclined surface to impart rotary movement to said second member upon axial movement of said armature and first member.

3. An electromagnetically operated rotary actuator comprising an electromagnet, an armature mounted for axial movement toward said electromagnet and restrained against rotary movement relative thereto, a first member fast with said armature for axial movement therewith, a second member arranged for rotary movement relative to said armature, said members being provided with at least one pair of opposed inclined surfaces, and rotatable means disposed between said members in rolling engagement with said inclined surfaces to impart rotary movement to said second member upon axial movement of said armature and first member.

4. The invention set forth in claim 3, said members including opposed recesses, said inclined surfaces defining the bases of said recesses whereby each recess includes a shallow portion and a deeper portion.

5. The invention set forth in claim 4 further including spring means urging said members to and normally maintaining said members in a relative rotational position wherein the shallow portions of said recesses overlap.

6. An electromagnetically operated rotary actuator comprising an electromagnet, an armature mounted for axial movement toward said electromagnet and restrained against rotary movement relative thereto, a first member fast with said armature for axial movement therewith, a second member arranged for rotary movement relative to said armature and restrained against axial movement, said members being provided with at least one pair of opposed inclined surfaces, and rotatable means disposed between said members in rolling engagement with said inclined surfaces to impart rotary movement to said second member upon axial movement of said armature and first member.

7. The invention set forth in claim 6, said armature, second member, and rotatable means each being moved from an unoperated to an operated position upon operation of the device, and restoring means for urging said armature, second member, and rotatable means from operated to unoperated position.

8. The invention set forth in claim 7, said first and second members including opposed recesses, said inclined surfaces defining the bases of said recesses.

9. The invention set forth in claim 8, further including a wall portion fixed relative to the electromagnet, and anti-friction means between said second member and wall portion supporting said second member for rotary movement relative to said wall portion.

10. An electromagnetically operated rotary actuator comprising: an electromagnet including a core; an armature disposed to one side of the core and mounted for axial movement toward the core; first and second members disposed to the opposite side of said core, the first member being restrained against rotary movement relative to the electromagnet, the second member being free for rotary movement relative to the electromagnet, one of said members being coupled to the armature for axial movement therewith; an inclined surface provided on one of said members, and rotatable means operatively associated with the other member and disposed in rolling engagement with said inclined surface to impart rotary movement to said second member upon axial movement of the armature and member coupled thereto.

11. An electromagnetically operated rotary actuator comprising: an electromagnet including a core; an armature disposed to one side of said core, said armature being mounted for axial movement toward the core and restrained against rotary movement relative to said electromagnet; a first member disposed to the opposite side of said core and mounted fast with said armature for axial movement therewith; a second member disposed to said opposite side of the core and mounted for rotary movement relative to the electromagnet; an inclined surface provided on one of said members, and rotatable means operatively associated with the other member and in rolling engagement with said inclined surface to impart rotary movement to said second member upon axial movement of said first member with said armature.

12. An electromagnetically operated rotary actuator comprising: an electromagnet including a core; an armature disposed to one side of the core, said armature being mounted for axial movement toward the core; first and second opposed members disposed to the opposite side of the core, the first member being restrained against rotary movement relative to the electromagnet, the second member being mounted for rotary movement relative to the electromagnet, one of said members being coupled to said armature for axial movement therewith toward the other member; opposed oppositely inclined surfaces provided on said members; rotatable means disposed between and in rolling engagement with said inclined surfaces to impart rotary movement to said second member upon axial movement of the one member coupled to the armature toward the other member.

13. An electromagnetically operated rotary actuator comprising: an electromagnet including a core; an armature disposed to one side of the core, said armature being mounted for axial movement toward the core and restrained against rotary movement relative thereto; first and second opposed members disposed to the opposite side of said core, the first member being mounted fast with the armature for axial movement therewith, the second member being free for rotary movement relative to the electromagnet and restrained against axial movement; said members being provided with at least one pair of opposed inclined surfaces; and a ball disposed between and in rolling engagement with said inclined surfaces to impart rotary movement to said second member upon axial movement of said armature and first member.

14. An electromagnetically operated rotary actuator comprising an electromagnet, an armature mounted for axial movement toward said electromagnet, a first member fast with said armature for axial movement therewith, a wall member fixed relative to said electromagnet, an element interposed between said first and second mem-

bers and arranged for rotary movement relative to said wall member, force transmitting spacer means between said element and one of said members, said element and the other of said members being provided with a pair of opposed inclined surfaces, a rotatable element disposed between and in rolling engagement with said inclined surfaces to impart rotary movement to said element upon axial movement of the armature and first member.

15. The invention set forth in claim 14, said opposed inclined surfaces being provided on said element and first member.

16. The invention set forth in claim 14, said opposed inclined surfaces being provided on said element and fixed wall member.

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Notice of Adverse Decision in Interference

In Interference No. 90,408 involving Patent No. 2,828,636, G. V. Hall, Electromagnetically operated rotary actuator, final judgment adverse to the patentee was rendered Aug. 27, 1962, as to claims 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15.

[*Official Gazette December 4, 1962.*]

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[*Official Gazette December 4, 1962.*]