United States Patent

Hereford

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[54] ROTARY ELECTROMAGNETIC ACTUATOR

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[52] **U.S. Cl.** ..... **95/53 E**

[51] **Int. Cl.** **G03b 9/10**

[58] **Field of Search** ..... 95/53, 63, 53 E; 335/272

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[57] **ABSTRACT**

An electromagnetic actuator of the limited travel rotary-type having general servomechanism application. The actuator directly produces torque through the rotation of a rotor in a magnetic field, the rotor being formed of a pair of offset semicircular rotor portions.

10 Claims, 6 Drawing Figures

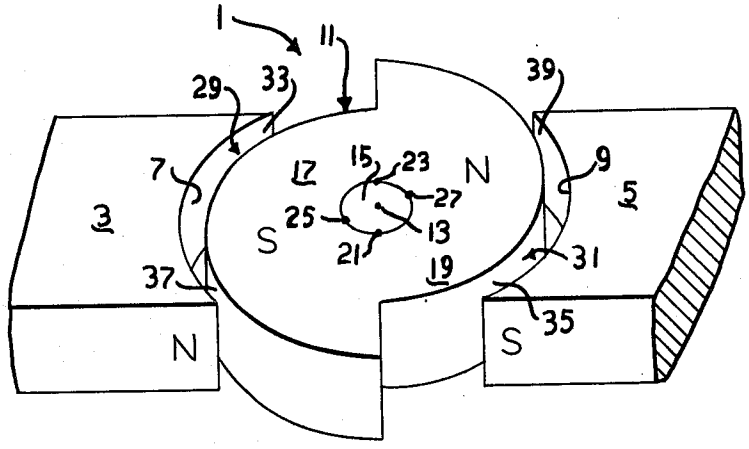


FIG. 1a

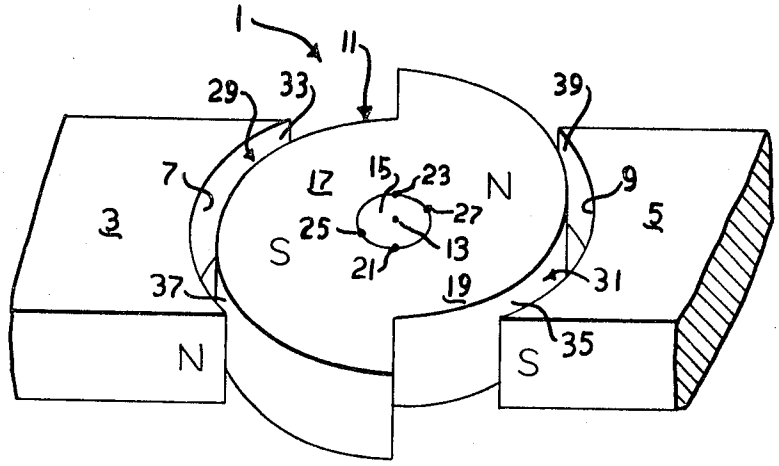


FIG. 1b

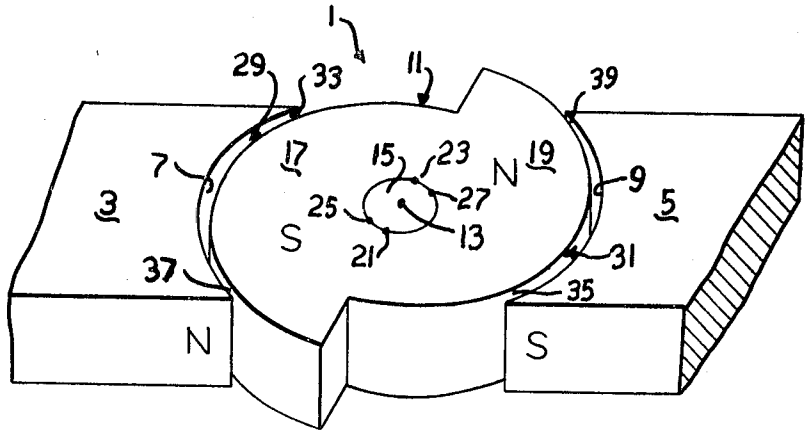
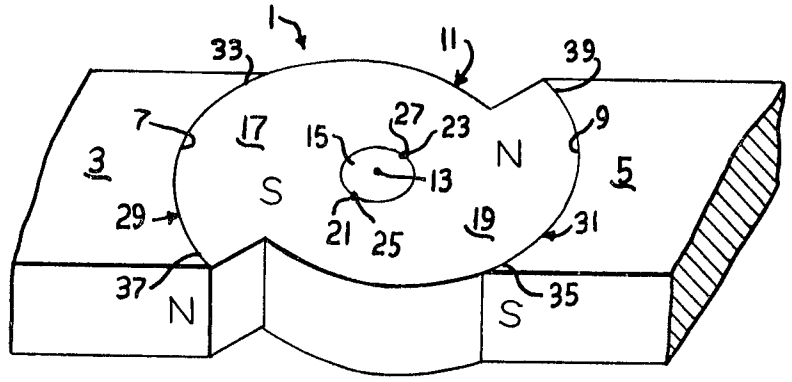


FIG. 1c



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FIG2.

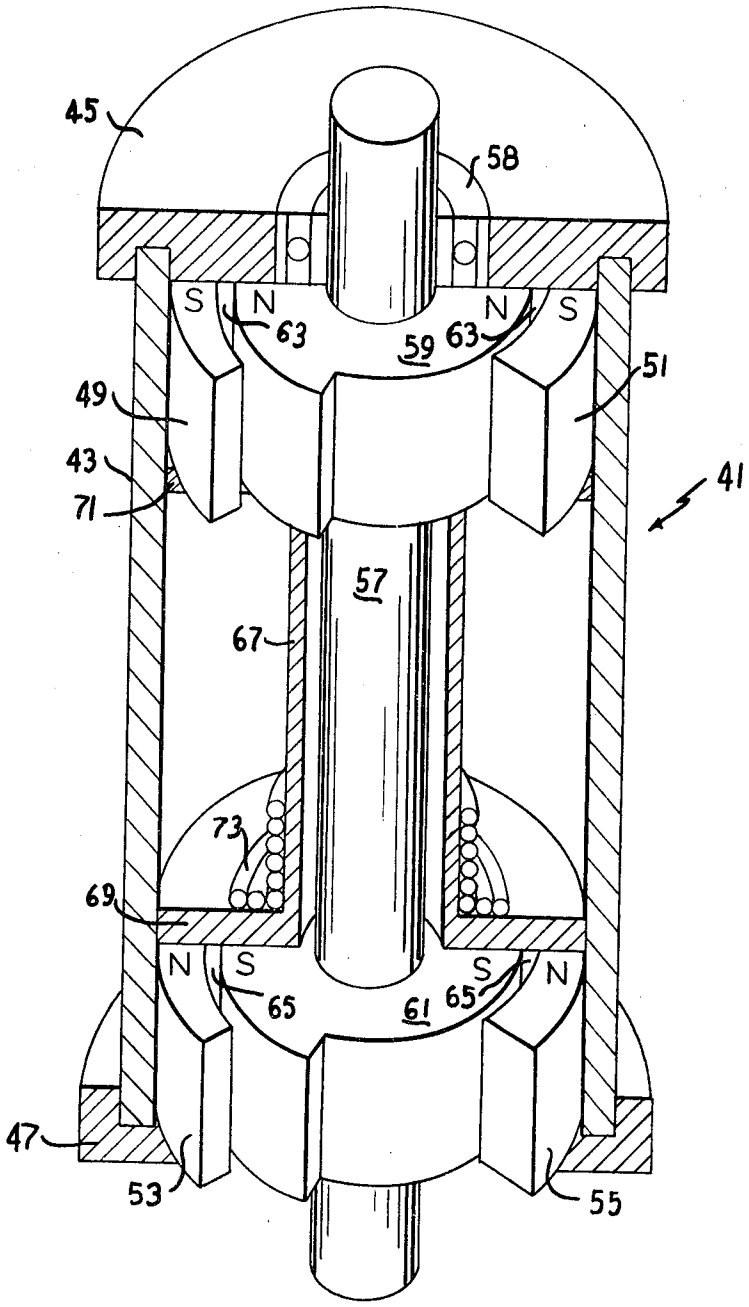


FIG. 3.

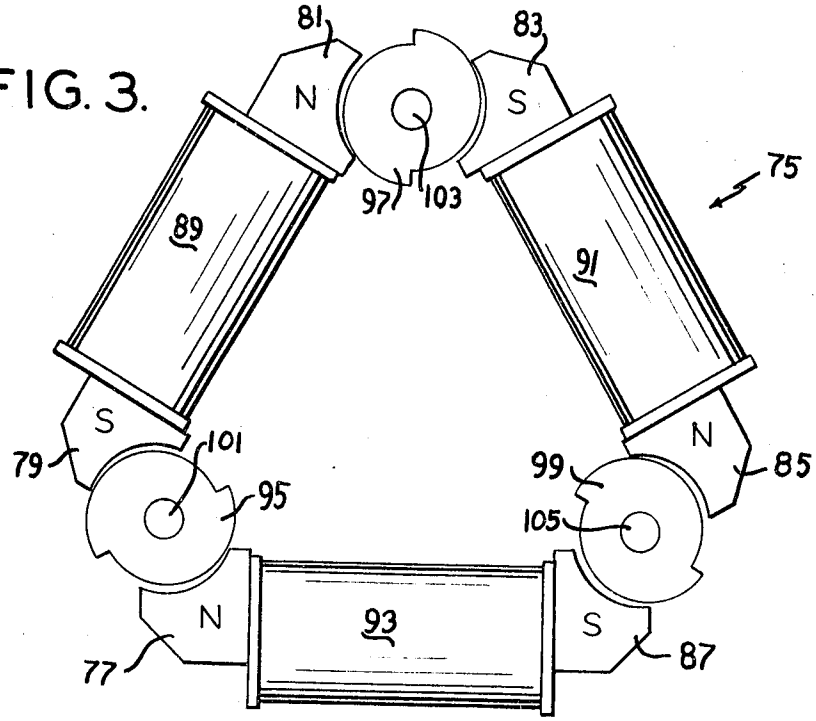
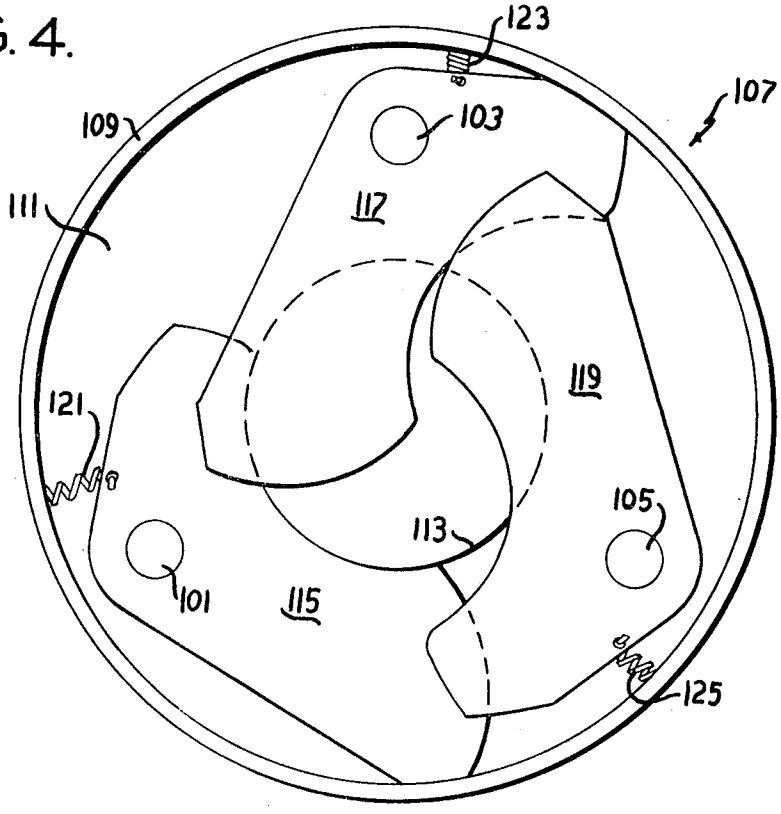

81
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75
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103
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79
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99
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N
93
S
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FIG. 4.


123
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101
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125

ROTARY ELECTROMAGNETIC ACTUATOR

BACKGROUND OF THE INVENTION

The present invention relates to electromagnetic actuators, and more particularly to an electromagnetic actuator capable of limited rotary travel.

In the past, rotary servomechanism actuators have generally employed a linear solenoid having a ball-screw linear-to-rotary motion converter. Although such actuators have generally served their intended purpose, they have not proven to be entirely satisfactory under all conditions of use because of the relatively high internal friction and inertia produced by the required motion converter. In addition, such mechanisms are often very complicated and costly and require servicing on a regular basis for satisfactory operation.

SUMMARY OF THE INVENTION

Accordingly, among the several objects of the present invention is the provision of an electromagnetic actuator which directly produces rotary motion; the provision of an actuator of the class described which is characterized by an extremely rapid response time and a high magnetic efficiency; and the provision of an electromagnetic actuator of the class described which is economical to produce yet reliable in operation.

Briefly, a rotary electromagnetic actuator constructed in accordance with the present invention is comprised of a pair of spaced pole pieces having a rotor mounted therebetween for rotation about an axis. The rotor is comprised of a first semicircular portion having its diameter in an axial plane and its center of curvature offset on one side of the axis and a second semicircular portion also having its diameter in the axial plane and its center of curvature offset on the other side of the axis. In addition, the pole pieces are provided with curved pole faces opposed to the rotor portions for forming a pair of gaps therebetween. Other objects and features will be in part apparent and in part pointed out hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1*a*, *b*, and *c* are perspective views of the present actuator in a deenergized, partially energized, and fully energized position, respectively;

FIG. 2 is a perspective view, partly in section and partly broken away, of a second embodiment of the present electromagnetic actuator with its rotor in a deenergized position;

FIG. 3 is a plan view of a third embodiment of the present actuator with its rotors in deenergized positions; and

FIG. 4 is a plan view of a shutter mechanism intended for use with the actuator embodiment of FIG. 3.

Corresponding reference characters indicate corresponding parts throughout the several views of the drawings.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIGS. 1*a*, *b*, and *c* of the drawings, a limited travel rotary electromagnetic actuator **1** is comprised of first and second stators or pole pieces **3** and **5** having first and second curved or arcuately configured pole faces **7** and **9**, respectively. The pole pieces **3**, **5** may be formed of any suitable magnetic material but preferably are formed of a nonretentive ferromagnetic material such as, for example, a high purity iron. Means such as a coil or winding (not shown) are provided for oppositely polarizing the pole pieces **3**, **5**. For example, as illustrated in the drawing, pole piece **3** may be polarized in a north magnetic sense and pole piece **5** in a south magnetic sense.

A rotor, generally indicated by reference character **11**, is mounted for rotation about an axis **13** between the pole pieces **3**, **5** by a shaft **15** journaled in a suitable manner on a support (not shown). The rotor **11** is also formed of a magnetic material, and preferably a nonretentive ferromagnetic material, and is comprised of first and second semicircular rotor halves or portions **17** and **19**. The diameters of the first and second rotor portions **17** and **19** lie in an axial plane with the axis **13** of the rotor **11** and are coincident over a major portion of their lengths. The center of curvature **21** of the first rotor portion **17** is offset on one side of the axis **13** while the center of curvature **23** of the second rotor portion **19** is offset by an equal amount on the other side of the axis **13**.

The pole piece **3** is positioned with respect to the rotor **11** such that the center of curvature **25** of the pole face **7** lies to one side of the axis **13** and the diameters of the rotor portions **17**, **19**. In a similar manner, the pole piece **5** is positioned such that the center of curvature **27** of the pole face **9** lies to the other side of the axis **13** and the diameters of the rotor portions **17**, **19**. The radii of each of the pole faces and rotor portions are substantially identical and therefore the rotor portions and pole faces are contiguous when the rotor **11** is in an energized position, as illustrated in FIG. 1*c*. However, when the rotor is in either the deenergized position illustrated in FIG. 1*a* or the partially energized position illustrated in FIG. 1*b*, a pair of airgaps **29**, **31** exist between the respective rotor portions **17**, **19** and pole faces **7**, **9**. Since the centers of curvature **25**, **27** of the pole faces **7**, **9** are offset from the axis **13** of the rotor **11**, the airgaps **29**, **31** vary in width from a maximum at their ends **33**, **35** to a minimum at their ends **37**, **39**. It will also be observed from FIG. 1*a* that the semicircular peripheries of the semicircular rotor portions **17** and **19** extend arcuately throughout the extent of the curved pole faces **7** and **9** when the rotor is in the deenergized position of FIG. 1*a*.

In operation of the electromagnetic actuator **1** illustrated in FIGS. 1*a*, *b*, and *c*, the pole pieces **3**, **5** may be polarized by a winding (not shown) encircling the pole pieces **3**, **5** for establishing, for example, a north magnetic pole at pole piece **3** and a south magnetic pole at pole piece **5**. As the pole pieces **3**, **5** are oppositely polarized, a magnetic flux is established from the pole piece **3**, across the airgap **29**, through the rotor **11**, across the gap **31**, and to the pole pieces **5** where it is returned to the pole piece **3**. The magnetic flux traversing the rotor **11** causes the rotor portions **17**, **19** to be oppositely polarized so that, for example, the rotor portion **17** is established as a south magnetic pole and the rotor portion **19** is established as a north magnetic pole. Thus, adjacent pole pieces and rotor portions are oppositely polarized by induction across the airgaps **29** and **31**. Upon polarization of the pole pieces **3**, **5** and rotor portions **17**, **19** in the manner indicated, the rotor **11** is caused to rotate about the axis **13** by the forces of attraction acting between the oppositely polarized pole pieces and rotor portions. These forces produce a resultant moment couple, tending to rotate the rotor **11** about the axis **13** until the rotor portions **17**, **19** are substantially contiguous with the pole faces **7**, **9**, respectively.

Rotor return means (not shown in FIGS. 1*a–c*) are provided for returning the rotor **11** from its energized position illustrated in FIG. 1*c* to its deenergized position illustrated in FIG. 1*a*. This may consist of a spring either coiled about the shaft **15** or included in the load connected to the shaft **15**.

It should be noted that the centers of curvature **21**, **23** of the rotor portions **17**, **19** should be maintained relatively close to the axis of rotation **13** so that the width of the airgaps **29**, **31** are minimized. Since the gain in force obtained by minimizing the airgaps varies as the second power of the gap distance, reducing the width of the airgaps increases the torque produced by the rotor even though the moment arm of the couple is simultaneously reduced since the latter represents a first power term in the torque equation. Thus, it is possible to exchange first and second power terms to optimize torque.

The embodiment of the electromagnetic actuator illustrated in FIG. 2 is substantially identical in operation to the embodiment illustrated in FIG. 1 but provides a more compact actuator assemblage for use as a utility servomechanism. The actuator **41** is comprised of a generally cylindrical housing **43**, formed of a magnetic material, having end closures **45**, **47** secured thereto, the latter being formed of a nonmagnetic material. A pair of upper pole pieces **49**, **51** are secured in flux conductive relationship to the upper portion of housing **43**

while a pair of lower pole pieces 53, 55 are secured in flux conductive relationship to the lower portion of housing 43.

A shaft of magnetic material 57, disposed along the longitudinal axis of the actuator 41, is rotatably mounted in the housing 43 by a pair of bearing assemblies 58 secured within the end closures 45, 47. The shaft 57 carries an upper rotor 59 and a lower rotor 61, the rotors 59, 61 being disposed between the respective pole pieces 49, 51 and 53, 55 for forming upper and lower pairs of airgaps 63 and 65, respectively. An annular bobbin 67 having a pair of end flanges 69, 71 is mounted within the housing 43 for carrying a coil or winding, a portion of which is shown at 73, which substantially fills the space between the inner bobbin wall 67, the housing 43, and the end flanges 69, 71. The ends (not shown) of the winding 73 may be extended through the housing 43 and connected to a suitable energizing source.

The geometrical configuration of the rotors 59, 61, the pole pieces 49, 51 and 53, 55 and the airgaps 63, 65 are identical to that discussed above in connection with the embodiment of the actuator illustrated in FIG. 1. Thus, each of the rotors 59 and 61 are formed of a pair of offset semicircular rotor portions which form a pair of variable width airgaps 63, 65 with each of their respective pole pieces 49, 51 and 53, 55.

In operation of the electromagnetic actuator 41 illustrated in FIG. 2, the winding 73 may be energized by any suitable source for rotating the shaft 57 and the load connected thereto. As the winding 73 is energized, a magnetic flux is established which is concentrated in and flows through the magnetic material of the cylindrical housing 43, the pole pieces 49, 51, across the airgaps 63, through the rotor 59 and shaft 57 to the rotor 61, across the airgaps 65, and to the pole pieces 53, 55 where it is returned to the cylindrical housing 43. Since the pole pieces 49, 51 and 53, 55 are at opposite ends of the magnetic field, opposite polarities are induced therein which in turn oppositely polarize the rotors 59, 61 associated therewith. As illustrated in FIG. 2, the upper pole pieces 49, 51 are polarized in a south magnetic sense and the upper rotor 59 in a north magnetic sense while the lower pole pieces 53, 55 are polarized in a north magnetic sense and the lower rotor 61 in a south magnetic sense. The polarity of the above components of course depends upon the direction of current flow through the winding 73 and may be reversed by merely reversing the flow of current therethrough. Upon completion of the magnetic circuit, which is substantially instantaneous with energization of the winding 73, the rotors 59, 61 are caused to rotate between the pole pieces 49, 51 and 53, 55 to their energized positions, thereby rotating the load connected to the shaft 57. Once again, the return means for the actuator 41 may consist of a spring connected to the shaft 57 and the housing 43, or may form a part of the load.

FIGS. 3 and 4 illustrate another embodiment of the electromagnetic actuator of the present invention for use in operating the shutter of a high-speed camera intended for use, for example, in aerial reconnaissance. The multiple actuator 75 is comprised of a plurality of pairs of pole pieces 77 and 79, 81 and 83, and 85 and 87 having a plurality of windings 89, 91 and 93 associated therewith for polarizing the pole pieces in the sense indicated in FIG. 3. The windings 89, 91 and 93 may be connected in series and to a suitable energizing source (not shown). A plurality of rotors 95, 97 and 99 are respectively mounted for rotation on shafts 101, 103 and 105 between opposed pairs of pole pieces 77 and 79, 81 and 83, and 85 and 87. As illustrated, the windings 89, 91 and 93, pairs of pole pieces 77 and 79, 81 and 83, 85 and 87, together with the rotors (ignoring the small airgaps therebetween) define a single closed magnetic path. That is, the magnetic flux generated by the passage of current through windings 89, 91 and 93 is essentially confined within this ring or closed path of magnetic material. Again, the geometrical configuration of the rotors, pole pieces, and airgaps is identical to that described above in connection with the actuator of FIG. 1 and will not, therefore, be repeated.

As illustrated in FIG. 4, the shutter 107 of a high-speed camera may consist of a shutter ring 109 having a shutter plate 111 secured thereto, the shutter plate 111 being provided with a light admitting aperture 113 at its center. As is conventional, the light admitting aperture 113 is intended to admit light to an unexposed web of light sensitive film for exposing the same. The remaining portions of the camera including the web of film and the means for moving the film past the aperture 113 are not illustrated and will not be described since they form no part of the present invention. The rotor shafts 101, 103 and 105 project upwardly through apertures in the shutter plate 111 and are secured respectively to the interleaves blades 115, 117 and 119 of the multiblade shutter 107. Although the blade 115 is shown in a fully open position, the blade 117 in a fully closed position and the blade 119 in a partially open position, it should be understood that this is done for purposes of clarity and that the blades operate simultaneously and at any instant will all be in the same position of rotation. A plurality of spring return means 121, 123 and 125 are respectively connected to the shutter blades 115, 117 and 119 for returning the shutter blades to the fully closed position illustrated by blade 117.

In operation of the shutter of FIGS. 3 and 4 for opening the light admitting aperture 113 and exposing the web of film passing thereby, the windings 89, 91 and 93 are simultaneously energized by a suitable source (not shown). Energization of the windings 89, 91 and 93 causes the pole pieces 77 through 87 and rotors 95, 97 and 99 to be polarized in the sense indicated in FIG. 3 and the rotors 95, 97 and 99 and shafts 101, 103 and 105 to rotate. Rotation of the shafts 101, 103 and 105 causes the shutter blades 115, 117 and 119 to simultaneously rotate from the fully closed position, as illustrated by blade 117 in FIG. 4, to the fully open position, as illustrated by blade 115. The web of film passing by the light admitting aperture 113 is then exposed until the energizing source for coils 89, 91 and 93 is interrupted, whereupon the springs 121, 123 and 125 return the shutter blades 115, 117 and 119 to their fully closed position. As the shutter blades 115, 117 and 119 are rotated to their fully closed position, rotors 95, 97 and 99 are rotated to their deenergized position and are again in a condition for actuation.

In view of the above, it will be seen that the several objects of the invention are achieved and other advantageous results attained.

As various changes could be made in the above constructions without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A rotary electromagnetic actuator comprising a pair of spaced pole pieces, and a rotor mounted for rotation from a deenergized position to an energized position about an axis between the pole pieces, said rotor having a first semicircular portion having its diameter in an axial plane and its center of curvature offset on one side of said axis, and a second semicircular portion also having its diameter in said axial plane and its center of curvature offset on the other side of said axis, said pole pieces having curved pole faces opposed to said rotor portions for forming a pair of curved gaps therebetween, the centers of curvature of said curved pole faces each being offset on an opposite side of said axis, the centers of curvature of said pole faces being coincident with the centers of curvature of adjacent rotor portions when said rotor is in its energized position, the radii of curvature of said rotor portions and the radii of curvature of said pole faces being substantially identical, the semicircular peripheries of said semicircular rotor portions extending arcuately throughout the extent of said curved pole faces when the rotor is in its said deenergized position and being contiguous to said curved pole faces when said rotor is in its energized position.

2. An actuator as in claim 1 wherein said pole pieces and rotor portions are formed of a nonretentive magnetic material, and means are provided for oppositely polarizing adjacent pole pieces and rotor portions.

3. An actuator as in claim 1 further comprising means for returning said rotor from its energized position to its deenergized position.

4. An actuator as in claim 1 wherein each of the curved gaps vary in width from a maximum at one of their ends to a minimum at the other of their ends.

5. A limited travel rotary electromagnetic actuator comprising a pair of spaced pole pieces having arcuately configured pole faces, said pole pieces being formed of a nonretentive magnetic material, a rotor mounted on a shaft between said pole faces for limited rotary motion about an axis from a deenergized to an energized position, said rotor comprising a pair of semicircular rotor portions having their respective centers of curvature spaced equally on opposite sides of said axis, said centers of curvature and axis establishing three points on a common diameter of said rotor portions, the rotor portions being formed of a nonretentive magnetic material, adjacent arcuately configured pole faces and rotor portions forming a pair of arcuate airgaps therebetween, said airgaps diminishing in width from a maximum at one end to a minimum at the other end, the centers of curvature of said pole faces each being offset on an opposite side of said axis, the centers of curvature of said pole faces being coincident with the centers of curvature of adjacent rotor portions when said rotor is in an energized position, the radii of curvature of said rotor portions and the radii of curvature of said pole faces being substantially identical, the semicircular peripheries of said semicircular rotor portions extending arcuately throughout the extent of said curved pole faces when the rotor is in its said deenergized position and being contiguous to said curved pole faces when said rotor is in its energized position, and means for oppositely polarizing adjacent pole pieces and rotor portions.

6. An electromagnetic actuator comprising a generally cylindrical housing having first and second pairs of spaced pole pieces secured thereto, a shaft journaled about a longitudinal axis of said housing for rotation therein, first and second rotors respectively mounted on said shaft between each of said pairs of spaced pole pieces to form first and second pairs of airgaps therebetween, said rotors being mounted for rotation from a deenergized position to an energized position, and means for oppositely polarizing adjacent pole pieces and rotors, each of said rotors comprising a first semicircular portion having its diameter in an axial plane and its center of curvature offset on one side of said axis, and a second semicircular portion also having its diameter in said axial plane and its center of curvature offset on the other side of said axis, said pole pieces being provided with curved pole faces disposed adjacent said rotor portions, the centers of curvature of said pole faces each being offset on an opposite side of said axis, the radii of curvature of said rotor portions being substantially identical, the semicircular peripheries of said semicircular rotor portions extending arcuately throughout the extent of said curved pole faces when the rotors are in their deenergized position and being contiguous to said curve pole faces with the centers of curvature of said curved pole faces coincident with the centers of curvature of adjacent rotor portions when said rotors are in their energized position.

7. An actuator as in claim 6 wherein said housing, pole pieces, shaft and rotors are formed of a nonretentive magnetic material, and said means comprises a winding disposed around said shaft between said pole pieces.

8. An actuator as in claim 6 wherein each of the airgaps vary in width from a maximum at one end to a minimum at the other end.

9. A multiblade electromagnetic actuator driven shutter comprising a plurality of rotary electromagnetic actuators comprised of a plurality of pairs of spaced pole pieces, said pole pieces having curved pole faces, a plurality of polarizing coils for polarizing said pole pieces, and a plurality of rotors, one for each pair of pole pieces, mounted for rotation from a deenergized position to an energized position on a corresponding plurality of shafts about an axis between each of said pairs of spaced pole pieces, said pairs of pole pieces, polarizing coils and rotors defining a single closed magnetic path, each of said rotors having a first semicircular portion having its diameter in an axial plane and its center of curvature offset on one side of said axis, and a second semicircular portion also having its diameter in said axial plane and its center of curvature offset on the other side of said axis, the centers of curvature of said curved pole pieces each being offset on an opposite side of said axis, the centers of curvature of said pole faces being coincident with the centers of curvature of adjacent rotor portions when said rotors are in their energized position, the radii of curvature of said pole faces being substantially identical, the semicircular peripheries of said semicircular rotor portions extending arcuately throughout the extent of said curved pole faces when the rotor is in its said deenergized position and being contiguous to said curved pole faces when said rotors are in their energized position, and a plurality of interleaved shutter blades, one for each actuator, secured to said shafts for rotation therewith, whereby said shutter blades are adapted to open an aperture upon energization of said polarizing coils for exposing a web of light sensitive film.

10. An actuator driven shutter as in claim 9 wherein said pole pieces and rotors are formed of a nonretentive magnetic material, and said polarizing coils oppositely polarize the pole pieces in each pair of pole pieces and adjacent pole pieces and rotor portions.

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