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March 30, 1965 L. H. FULTON ETAL 3,176,170

ELECTROMAGNETIC CONSTANT VELOCITY ACTUATOR

Filed May 1, 1962 2 Sheets-Sheet 1

Fig. 1.

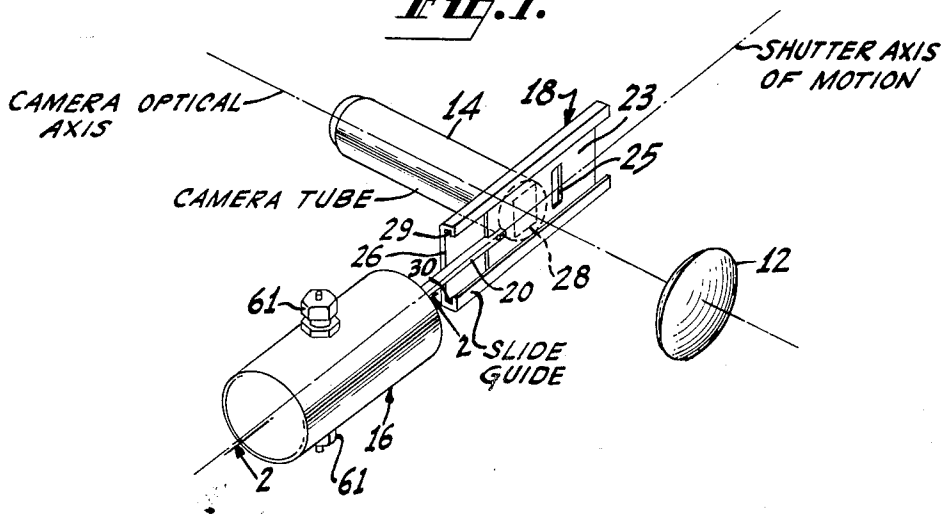


Fig. 2.

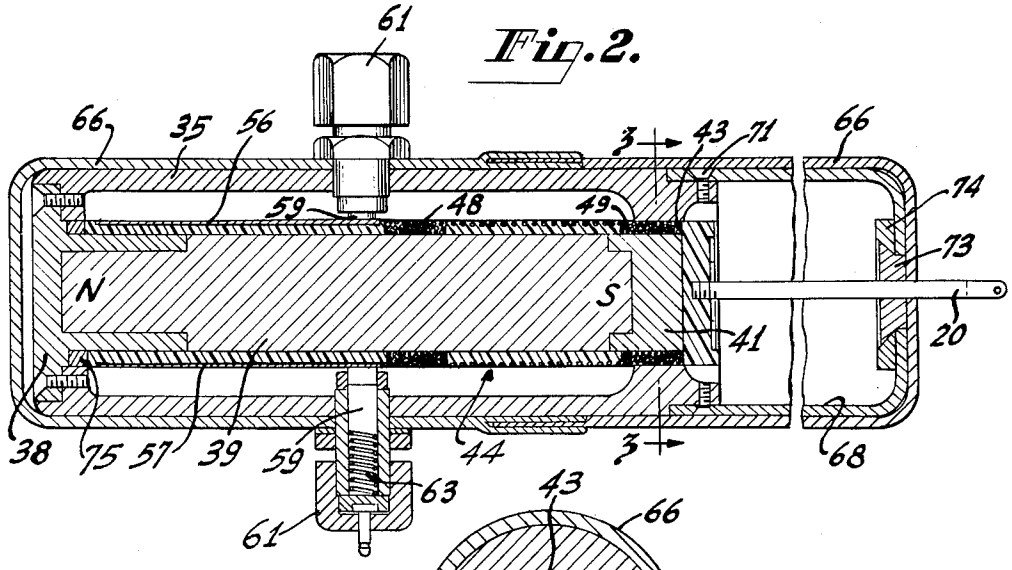
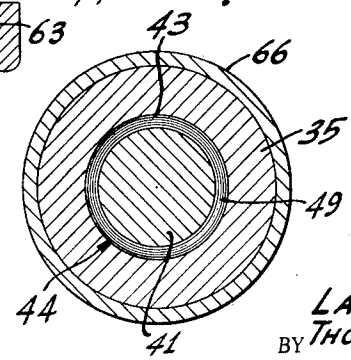


Fig. 3.



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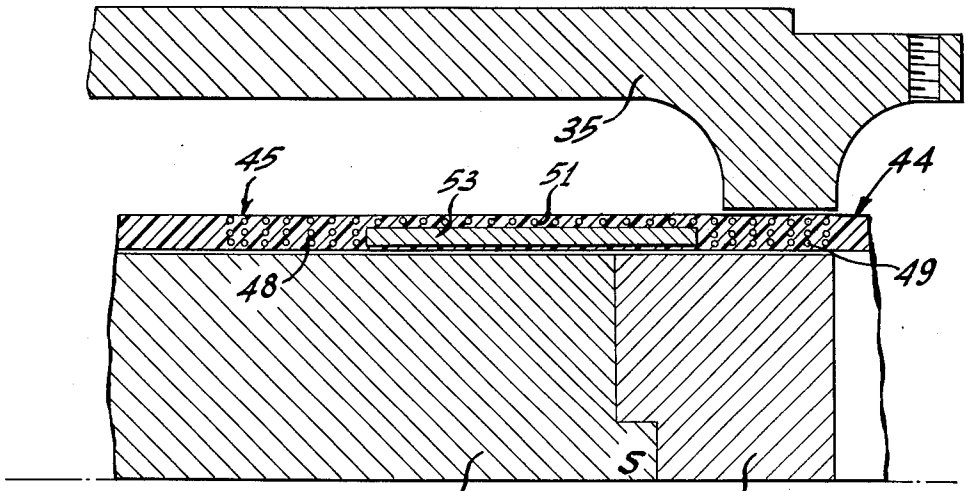


Fig. 4.

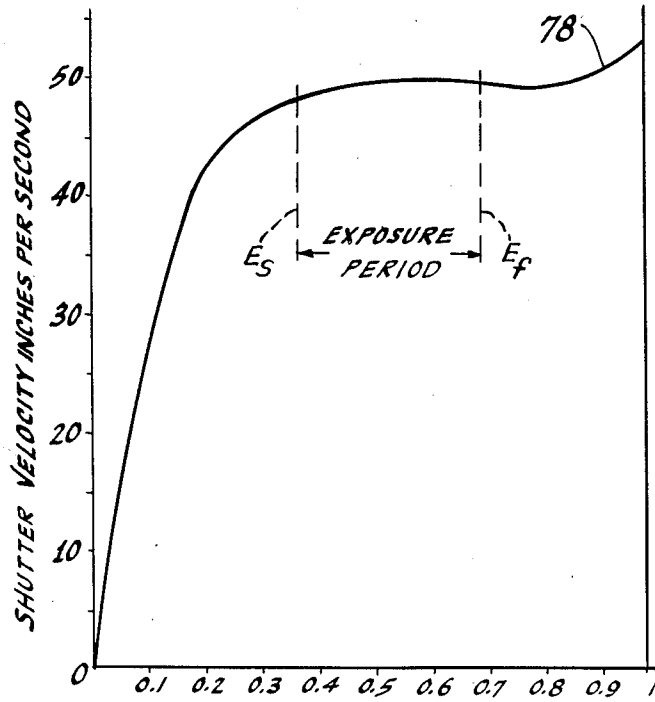


Fig. 5.

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ELECTROMAGNETIC CONSTANT VELOCITY ACTUATOR

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9 Claims. (Cl. 310—12)

The present invention relates generally to improved constant velocity actuators, and particularly to improved electrodynamic constant velocity actuators and also to combinations of such actuators with shutters of the focal plane type providing accurate timing and acceleration and deceleration of the shutter with an intervening interval of substantially constant velocity shutter travel.

The principal object of the present invention is to provide a novel electrically driven actuator providing substantially constant velocity actuation.

Another object of the present invention is to provide a novel reciprocating actuator which is capable of movement in either direction of travel.

A further object of the present invention is to provide a novel actuator, the movement of which is, in part, controlled by forces resulting from the generation of eddy currents throughout at least a portion of its shutter actuating movement.

Still another object of the present invention is to provide a novel electrodynamic actuator having a driving coil, the turns of which are distributed in a manner to cause acceleration, followed by movement at a substantially constant velocity during a desired period.

A still further object of the invention is to provide a novel electrodynamic actuator having a driving coil, the winding turns of which are distributed in a manner to provide initial acceleration in both the forward and reverse direction of travel.

A still further object of the present invention is to provide a novel reciprocating shutter and a shutter actuator which is compatible with a high vacuum space environment and which, because of its low moving mass and reciprocating motion, produces a minimum net disturbance to the attitude and spin velocity of a space vehicle in which it may be used.

In accordance with the present invention, generally speaking, motion is imparted to a mechanically movable member by an actuator having a single, continuous distributed winding substantially coextensive with the range of significant movement of the actuator, the turns of the winding being concentrated at least at one end of the winding with a less concentrated uniformly distributed portion of the winding successively adjacent the concentrated turn. Each concentration of the winding turns causes acceleration of the actuator during a brief accelerating period. Therefore, the actuator is or may be double acting having an essentially identical motion pattern in opposite directions on alternate strokes. An electrically conductive member having the form of an annular shell and being substantially coextensive with the uniformly distributed winding portion produces an eddy current induced retarding force of magnitude proportional to, and direction opposite to the actuator velocity, which tends to counterbalance the driving force of the coil causing the velocity to become uniform at a desired value for imparting constant velocity motion to the mechanically movable member. By way of example, the novel actuator of this invention may be employed to impart movement to a focal plane shutter as the mechanically movable member mentioned above. The uniform velocity will provide uniform exposure and can have a value needed for a desired exposure time.

Other objects and advantages of the present invention, in addition to those stated above, will become apparent and immediately suggest themselves to those skilled in the art to which the invention is directed from a reading of the following specification in connection with the accompanying drawing in which:

FIGURE 1 is a perspective view, more or less diagrammatic, of a camera having a shutter driven by an actuator of the present invention;

FIGURE 2 is a view in longitudinal section of the actuator housing of FIGURE 1, the section being taken on line 2—2 as viewed in the direction of the arrows;

FIGURE 3 is a view in vertical section taken on the line 3—3 of FIGURE 2 as viewed in the direction of the arrows;

FIGURE 4 is a fragmentary view to an enlarged scale of a portion of the coil structure shown in FIGURE 2 of the drawing; and

FIGURE 5 is a curve, including values by way of example, of the stroke velocity curve of the movable member of the actuator of FIGURE 1 of the drawing.

The combined shutter and constant velocity actuator of this invention as shown by FIGURE 1 of the accompanying drawing, are embodied in a camera having a lens system **12** and a television camera tube **14**. The actuator **16** will be described more in detail in connection with FIGURES 2, 3 and 4 of the drawing. The actuator **16** and the shutter **18** are mechanically interconnected by a driving rod **20** in the illustrative example. The driving rod **20** may be connected to any device to be driven. The shutter **18** comprises a shutter plate **23** having an exposure slit **25** and is supported and guided by a stationary aperture plate **26** having an aperture **28**. The aperature plate **26** is supported in any suitable manner (not shown) by a stationary part of the camera **10**. The aperture plate **26** has grooves **29** and **30** in which the shutter plate **23** slides.

The parts so far described will usually be mounted in a light tight camera case (not shown) admitting light only through the lens system **12**. This case may be completely sealed when the camera is used in air-borne, or space-borne vehicles. Obviously the shutter exposure slit may cooperate with any image receiving area. For example, a photographic film or plate may be exposed by the shutter and actuator of the invention rather than the face of the camera tube **14**. Also, it will be understood that the lens system **12**, shown as a single lens for convenience of description, may be any form of imaging optics designed to image any scene or object located at any viewing distance from the camera on the face of the camera tube **14**.

The actuator **16** comprises a magnetizable cylindrical member **35** (FIGURE 2), a magnetizable cap piece **38**, a permanent magnet **39** and a magnetizable pole piece **41**. The cylindrical member **35** had a restricted opening **43** at one end which together with pole piece **41** defines a cylindrical air gap across which flux produced by the permanent magnet **39** is concentrated. The magnet **39** may be made of "Alnico V" the composition of which is substantially aluminum 8%, nickel 14%, cobalt 24%, copper 3% and the remainder iron.

The movable coil structure is a self-supporting plastic thin walled cylinder **44** in which the coil **45** is embedded. This cylinder may be molded of a rigid organic resin containing reinforcing glass filaments, so that it presents smooth interior and exterior surfaces. The molded self-supporting coil structure has minimum mass and maximum mechanical strength. The inside diameter is such that it slides freely on the exterior surface of the magnet **39** and the pole piece **41** and the outside diameter permits it to be received in the restricted opening **43** sub-

stantially without friction. The coil **45** as shown in FIGURE 4 is made up of two concentrated winding portions **48** and **49** flanking a less concentrated uniformly distributed portion **51**.

A damping ring **53** of copper or similar material of high electrical conductivity is also embedded in the molded cylinder **44**. This ring is substantially co-extensive with the winding portion **51** so that eddy currents are induced in it as it moves through the air gap. The reactive force to the eddy currents tends to counterbalance the oppositely directed force exerted on the cylinder by the reaction of the air gap flux on the winding portion **51** to produce a viscous damping effect causing the cylinder velocity to level out at a desired value during exposure time.

Contact bars (FIGURE 2) **56** and **57** are embedded in the cylinder **44**, each of which is connected to an end of the coil **45**. Brushes **59** slidable in brush holders **61** ride respectively on the contact bars under the influence of pressure springs **63**. The driving rod **20** is secured, as by cementing, to the end of the cylinder **44**. The entire actuator **16** is enclosed by a two-part magnetic shield **66**. The end of the cylinder **44** as it moves outwardly is protected by a cap **68** secured to the cylindrical member **35** in any suitable manner, as by screws **71**. A guide **73** for the outer end of the driving rod **20** is mounted in the cap **68**. Limits of travel of the cylinder **44** are fixed by a cushioning ring **74** which surrounds the guide **73** and a bumper cushion **75**. To substantially eliminate bounce, the ring **74** and the cushion **75** are of elastomer material, silicone rubber for example. To aid in eliminating bounce, the time duration of application of current to the winding exceeds the time of travel of the actuator.

Operation of the shutter and actuator combination will now be described with reference to values of various factors given solely by way of example and for illustrative purposes. FIGURE 5 of the drawing is a velocity curve **78** for a shutter stroke of 0.97 inch. This curve is especially applicable to shutter travel in either direction. In the illustrative example, the exposure time is 1.2 milliseconds, this being the result of a stabilized shutter velocity of 50 inches per second with an aperture slit width of 0.060 inch since exposure time is equal to slit width in inches divided by shutter plate **23** velocity in inches per second. The exposure period indicated on FIGURE 5 is the time during which the slit **25** traverses the aperture **28**. The curve **78** indicates a substantially constant high rate of initial acceleration produced by the coil portion **49** assuming that shutter travel is toward the right viewed in FIGURE 1. The substantially horizontal or constant velocity part of the curve is produced by the combined action of the coil portion **51** and damping ring **53**. The curve **78** rises at its right hand end because of the coil portion **48** entering the air gap. Since the exposure is already complete this is immaterial. The coil portion **48** is in position for the next succeedng or return stroke and the velocity curve **78** also applies.

The actuator **16** and its associated shutter **18** may be driven by D.C. (direct current) pulses which may be **22** milliseconds in duration. Successive pulses are reversed in polarity to accomplish shutter actuator motion reversal. Switching circuits of any known type may be used to time and produce these pulses.

What is claimed is:

1. An actuator for producing mechanical movement of a member comprising means for producing a magnetic field of limited extent axially of said actuator, a coil supported for axial movement through said field, said coil comprising a winding portion adjacent one end thereof, said winding portion producing acceleration in one direction of said actuator from rest upon energization of said winding by an electric current as said winding portion moves through said field, a second winding portion next to said first named winding portion, and conductive material retarding means on said coil, said second winding portion upon continued energization of said winding in conjunction with said retarding means producing continued movement of said actuator at substantially constant velocity as said second winding portion moves through said field.

2. An actuator for producing mechanical movement of a member comprising means for producing a magnetic field of limited extent axially of said actuator, a coil supported for axial movement through said field, said coil comprising a winding portion adjacent one end thereof, said winding portion producing acceleration in one direction of said actuator from rest upon energization of said winding by an electric current as said winding portion moves through said field, a second winding portion next to said first named winding portion, and retarding means on said coil, said second winding portion upon continued energization of said winding in conjunction with said retarding means producing continued movement of said actuator at substantially constant velocity as said second winding portion moves through said field.

3. An actuator for producing mechanical movement of a member comprising means for producing a magnetic field of limited extent axially of said actuator, a coil supported for axial movement through said field, said coil comprising a winding portion adjacent one end thereof, said winding portion producing acceleration in one direction of said actuator from rest upon energization of said winding by an electric current of one polarity as said winding portion moves through said field, a second winding portion next to said first named winding portion, conductive material retarding means on said coil, said second winding portion upon continued energization of said winding in conjunction with said retarding means producing continued movement of said actuator at substantially constant velocity as said second winding portion moves through said field, a third winding portion next to said second winding portion to produce acceleration of said actuator in a direction opposite the acceleration produced by said first portion upon energization of said winding by an electric current of opposite polarity as said third winding portion moves through said field.

4. An actuator for producing mechanical movement of a member comprising means including an exciting magnet and a pair of opposed pole pieces for producing a radial magnetic field of limited extent axially of said actuator, a coil supported for axial movement through said field, said coil comprising a winding portion adjacent one end thereof, said winding portion producing acceleration in one direction of said actuator from rest upon energization of said winding by an electric current of one polarity as said winding portion moves through said field, a second winding portion next to said first named winding portion, conductive material retarding means on said coil, said second winding portion upon continued energization of said winding in conjunction with said retarding means producing continued movement of said actuator at substantially constant velocity as said second winding portion moves through said field, a third winding portion next to said second winding portion to produce acceleration of said actuator in a direction opposite the acceleration produced by said first portion upon energization of said winding by an electric current of opposite polarity as said third winding portion moves through said field.

5. An actuator for producing mechanical movement of a member comprising means for producing a magnetic field of limited extent axially of said actuator, a coil supported for axial movement through said field and comprising a winding portion adjacent one end thereof, said winding portion producing axial acceleration of said actuator upon energization of said winding by an electric current as said winding portion moves through said field, a second winding portion next to said first named winding portion, retarding means on said coil coaxial with said second winding portion, said second winding portion in conjunction with said retarding means producing continued movement of said actuator at substantially constant velocity during continued energization as said second

winding portion moves through said field, a third winding portion next to said winding portion to produce acceleration of said actuator in a direction opposite to the acceleration produced by said first portion upon energization of said winding by an electric current of opposite polarity as said third winding portion moves through said field.

6. An actuator for producing mechanical movement of a member comprising means for producing a magnetic field of limited extent axially of said actuator, a self-supporting coil supported for axial movement through said field and comprising a winding portion of concentrated turns adjacent one end thereof, said winding portion producing axial acceleration of said actuator upon energization of said winding by an electric current as said winding portion moves through said field, a second winding portion next to said first named winding portion, and a ring of conductive material on said coil coaxial with said second one portion, said second winding portion in conjunction with said ring producing continued movement of said actuator at substantially constant velocity during continued energization as said second winding portion moves through said field.

7. An actuator for producing mechanical movement of a member comprising means for producing a magnetic field of limited extent axially of said actuator, a self-supporting coil supported for axial movement through said field and comprising a winding portion of concentrated turns adjacent one end thereof, said winding portion producing axial acceleration of said actuator upon energization of said winding by an electric current as said winding portion moves through said field, a second winding portion next to said first named winding portion, a ring of conductive material on said coil coaxial with said second winding portion, said second winding portion in conjunction with said ring producing continued movement of said actuator at substantially constant velocity during continued energization as said second winding portion moves through said field, a third winding portion of concentrated turns next to said second winding portion to produce acceleration of said actuator in a direction opposite to the acceleration produced by said first portion upon energization of said winding by an electric current of opposite polarity as said third winding portion moves through said field.

8. An actuator for producing mechanical movement of a member comprising means for producing a magnetic field of limited extent axially of said actuator, a coil supported for axial movement through said field, said coil comprising a winding portion adjacent one end thereof,

said winding portion producing acceleration in one direction of said actuator from rest upon energization of said winding by an electric current as said winding portion moves through said field, a second winding portion next to said first named winding portion, and conductive retarding means on said coil coaxial with and substantially coextensive axially of said second winding portion, said second winding portion upon continued energization of said winding in conjunction with said retarding means producing continued movement of said actuator at substantially constant velocity as said second winding portion moves through said field.

9. An actuator having an identical motion pattern in opposite directions on alternate strokes for producing mechanical movement of a member comprising a magnet structure having a magnetizable cylindrical member closed at one end thereof, said cylindrical member having a constricted portion at the opposite end thereof, a cylindrical permanent magnet coaxial with said cylindrical member secured to said closed end of said cylindrical member, a magnetizable pole piece secured to the free end of said permanent magnet and projecting into the restricted portion of said cylindrical member whereby to provide a cylindrical air gap across which flux produced by said permanent magnet is concentrated, a movable coil structure axially slidable on said permanent magnet and said pole piece through said air gap, said coil structure comprising a molded cylindrical member having a coil embedded therein, said coil having two concentrated winding portions flanking a less concentrated uniformly distributed portion, said winding portions cooperating successively with said air gap upon axial movement of said molded member, a conductive damping ring embedded in said molded cylindrical member substantially coextensive with said uniformly distributed portion, and contact means on said molded member cooperating with stationary contact means projecting inwardly from said magnetizable cylindrical member to supply electric current to said coil.

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