Nov. 7, 1967 H. D. DEPEW, JR., ET AL 3,351,303

MISSILE CONTROL SYSTEM

Filed Oct. 12, 1960 4 Sheets-Sheet 1

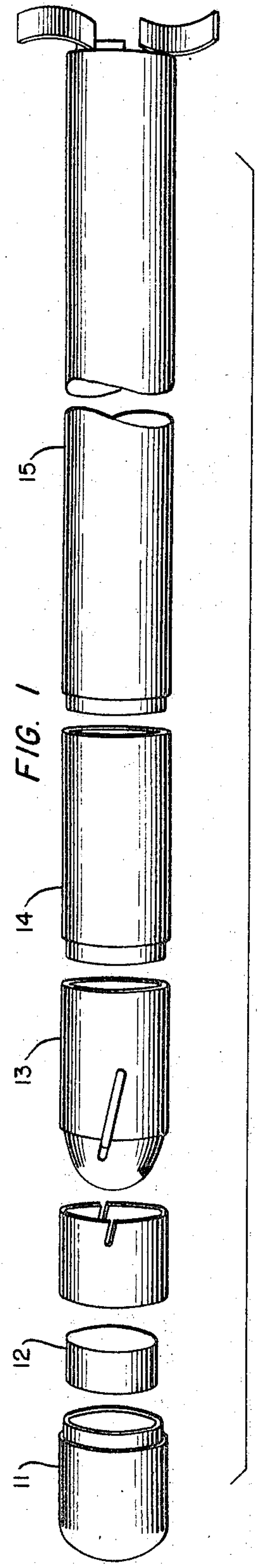


FIG. 1

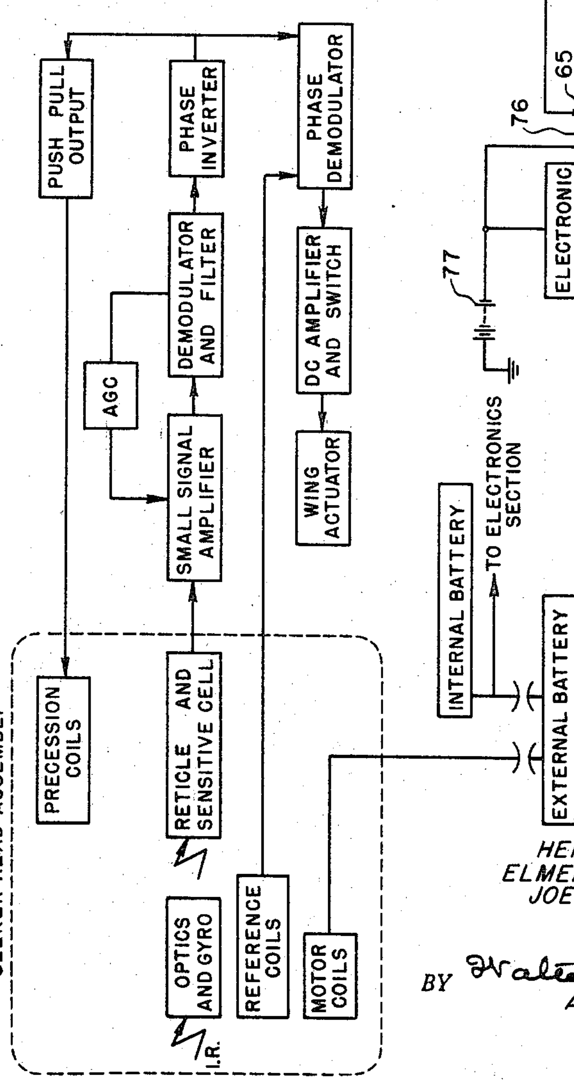


FIG. 10

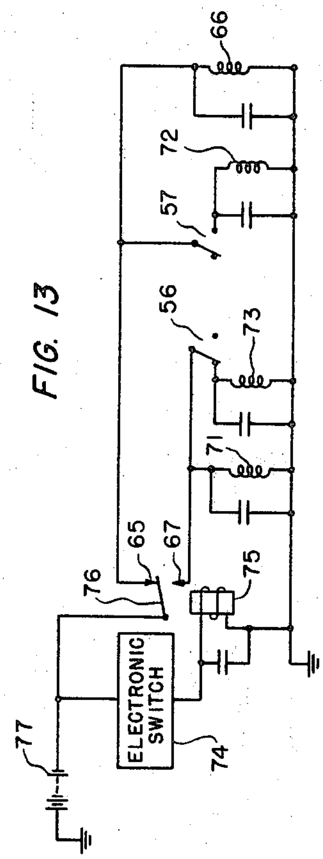


FIG. 13

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MISSILE CONTROL SYSTEM

Filed Oct. 12, 1960

4 Sheets-Sheet 2

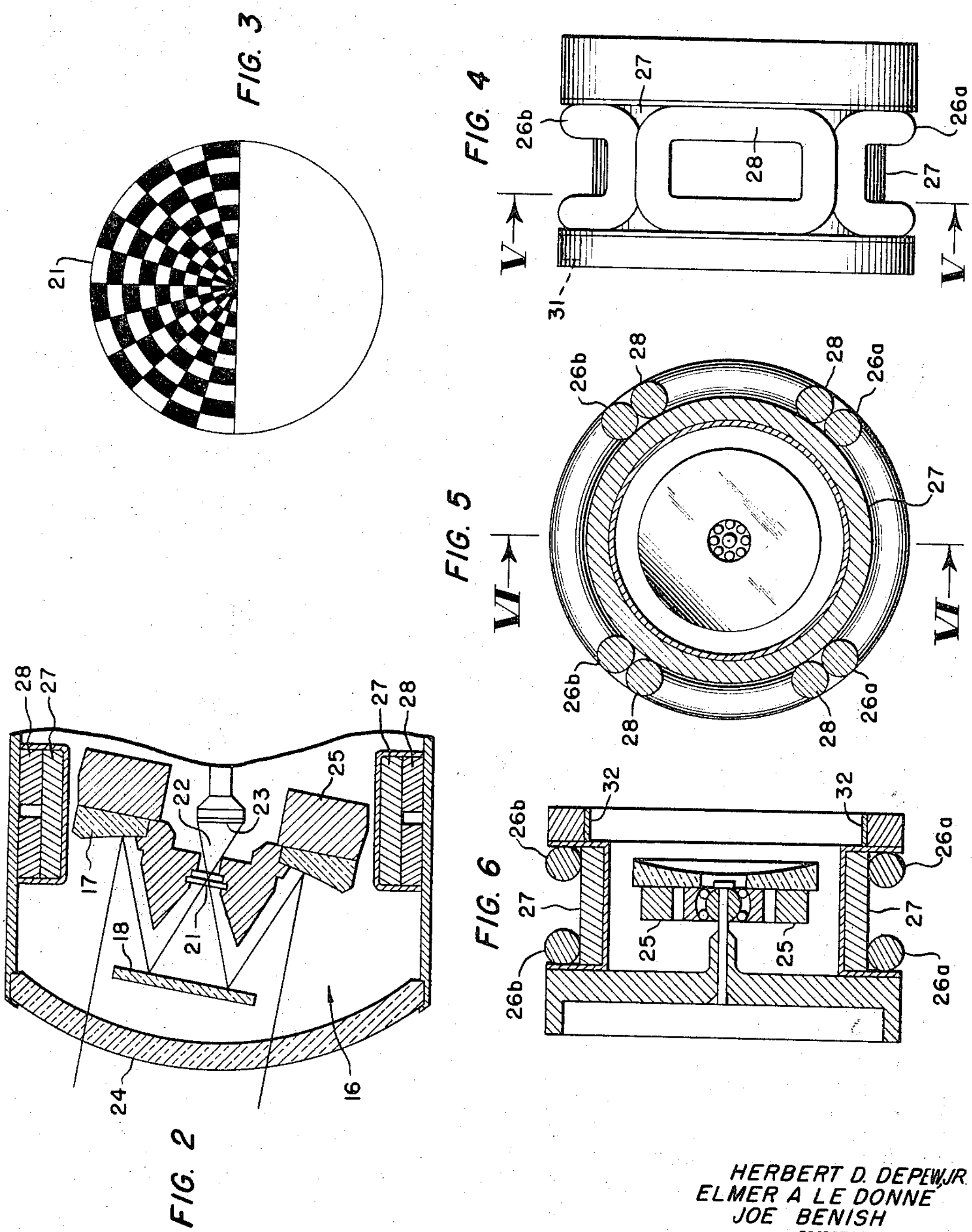

FIG. 2 FIG. 3 FIG. 4 FIG. 5 FIG. 6

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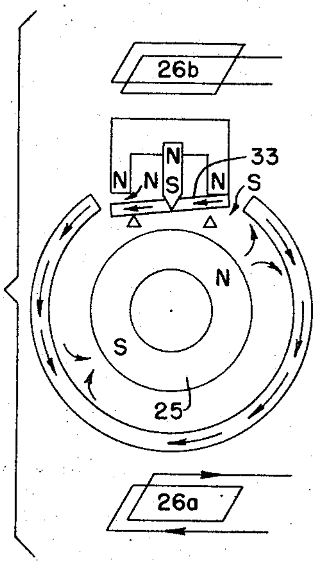



FIG. 7

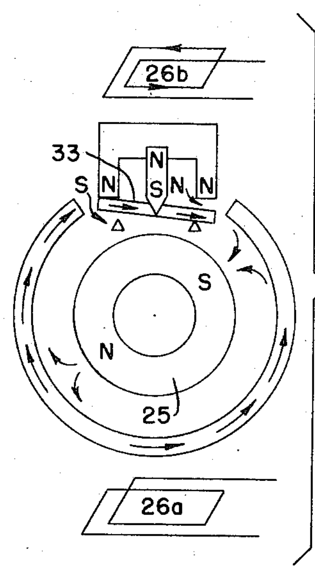
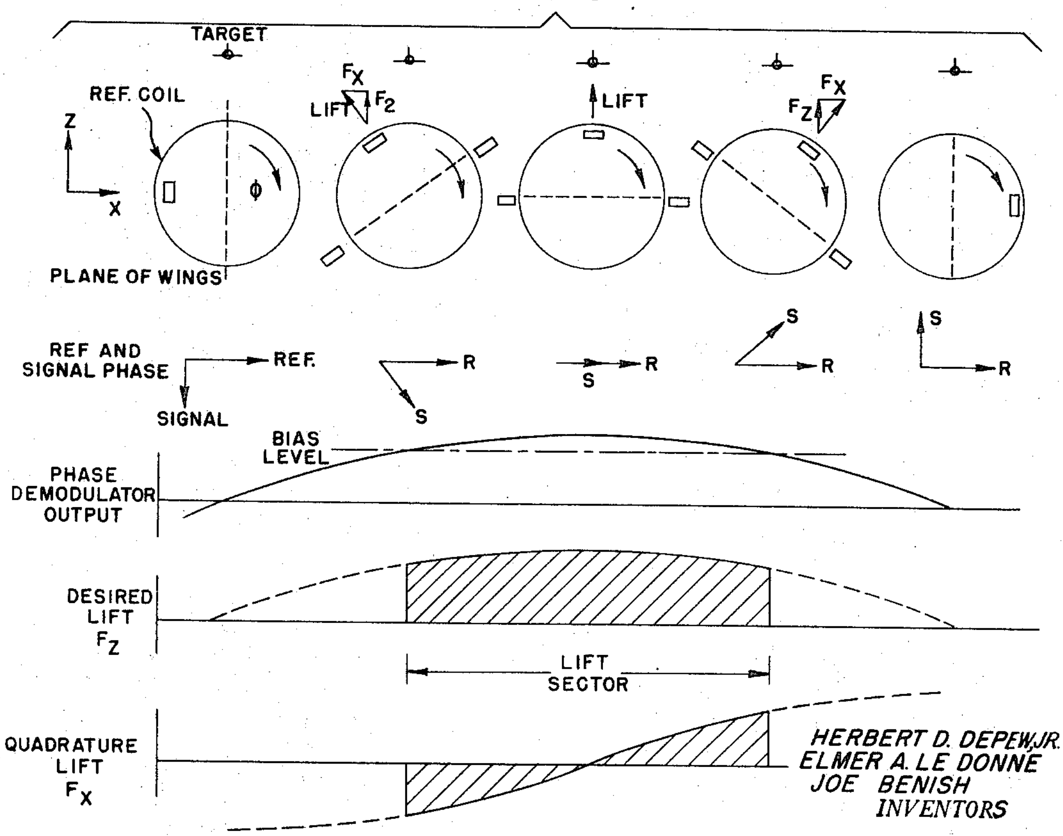



FIG. 8

FIG. 9

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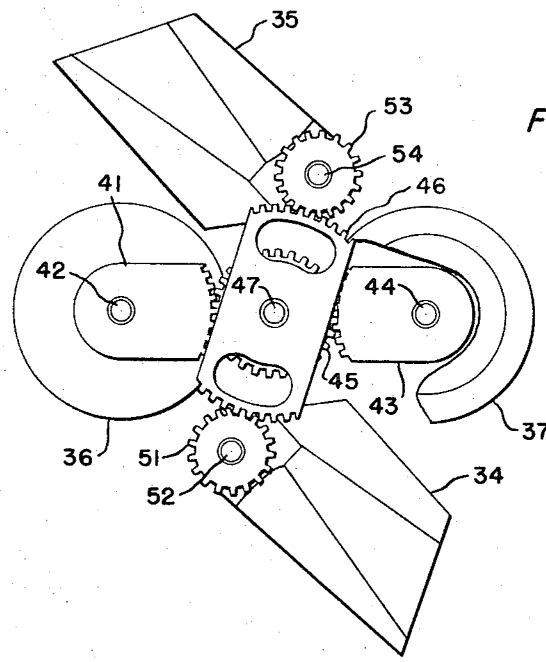


FIG. 11

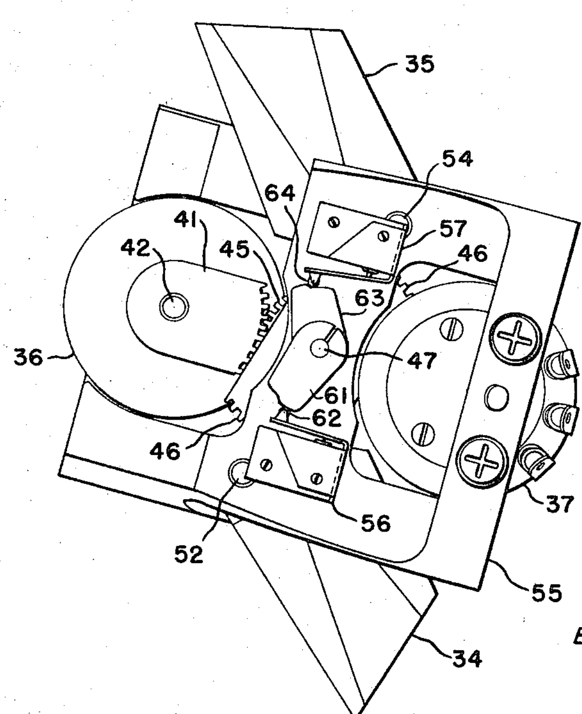


FIG. 12

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# 3,351,303
# MISSILE CONTROL SYSTEM

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8 Claims. (Cl. 244—3.16)

This invention relates to a missile control system, and more particularly to a control system for a rolling missile employing a pair of fixed incidence aerodynamic surfaces which may be readily and rapidly extended into and retracted from the airstream with small energy expenditure due to balancing of the forces acting thereon.

The control system of the present invention employs two aerodynamic control surfaces, one retracting forwardly and the other retracting backwardly, thereby balancing out aerodynamic drag and inertial forces. A rolling missile employs two control surfaces, rather than the four control surfaces usually required for maneuvering in three dimensions. The missile roll is utilized to achieve control in any direction, thereby enabling a light, simple, reliable control system.

A preferred embodiment of this invention employs a pair of opposedly extendable control surfaces powered by rotary solenoids, one being provided for extension, the other for retraction. The solenoids are actuated at appropriate times by an optical homing head which senses the direction of flight path error in polar coordinates.

It is, therefore, an object of this invention to provide a rolling missile control system with force-balanced retracting control surfaces.

Another object of this invention is to provide fast-acting control surfaces retracting means requiring little power.

Another object of this invention is to provide missile control means which are simple, reliable, compact, light in weight, and require little energy.

Other objects and features of the present invention will be readily apparent to those skilled in the art from the following specification and appended drawings, wherein:

FIGURE 1 is an exploded elevation of a missile utilizing the control system of the present invention;

FIGURE 2 schematically illustrates an optical seeker head which may be employed in this invention;

FIGURE 3 illustrates a reticle forming part of the seeker head;

FIGURE 4 is a simplified diagram of the seeker head spin motor coils and reference coils;

FIGURE 5 is a cross-section of FIGURE 4;

FIGURE 6 is a cross-section of FIGURE 5;

FIGURE 7 illustrates one phase of operation of a magnetic switch;

FIGURE 8 illustrates another phase of operation of a magnetic switch;

FIGURE 9 schematically illustrates the principle of control of a rolling missile with two retractable control surfaces;

FIGURE 10 is a block diagram of a circuit responsive to the seeker head and providing signals to actuate the control surfaces;

FIGURE 11 is one view of the control surface actuating mechanism;

FIGURE 12 is another view of the control surface actuating mechanism; and

FIGURE 13 is a schematic diagram of the control surface actuating circuit.

Referring now to FIGURE 1, a rolling missile incorporating the force balanced control surface actuator of the present invention includes a seeker **11**, an electronics section **12**, a control section **13**, a warhead **14**, and rocket motor **15**. A presently preferred seeker **11**, illustrated in



FIGURE 2, is a free gyro stabilized, infra-red sensing mechanism. Seeker **11** provides an output signal representing the angular rate of rotation of the line of sight in space. The entire optical unit **16** rotates, forming a gyroscopic rotor mass. Spherical primary mirror **17** and secondary mirror **18**, forming a Cassegrainian type reflecting telescope, reflect incident infra-red energy through a spinning reticle or chopper **21**, illustrated by FIGURE 3, a filter **22**, onto stationary infrared responsive cell **23**. Protective dome **24** and filter **22** are transparent to the desired region in the infrared spectrum, filter **22** being opaque to other regions and serving as an optical bandpass filter.

Reticle **21**, functioning in a manner well known to those skilled in the art, enables discrimination against such false targets as cloud edges, and permits sensing of tracking error by chopping the radiation passing to infrared responsive cell **23**.

Referring now to FIGURES 4, 5 and 6, illustrated therein are motor coils **26*a*** and **26*b***, employed to spin the optical head for gyroscopic effect, precession coils **27**, and position sensing pickoff coils **28**. A magnetic field actuated switch **31** is provided to alternately energize diametrically opposed motor field coils **26*a*** and **26*b***. A permanent magnet **25**, polarized in the plane of rotation, is mounted on spherical mirror **17** for rotation with the optical system. A ring **32**, made of a high permeability material such as the alloy commonly known as mu-metal, picks up flux from the magnet and carries it to magnetic switch **31**. Operation of magnetic switch **31** is illustrated in FIGURES 7 and 8. In FIGURE 7, flux collected by ring **32** flows through armature **33** in a direction aiding the normal armature-to-pole gap flux at the right hand side of the armature, and opposing the normal armature-to-pole gap flux at the left side, resulting in an unbalance of gap forces and closing the right hand gap. This closes the left-hand contact, enabling current to flow in coil **26*a***, repelling the south pole of the rotor and attracting the north pole, resulting in clockwise rotation of the rotor. As the rotor rotates, the position of the pole changes, as illustrated in FIGURE 8, causing the flux in the armature to reverse, enabling current to flow in coil **26*b***, resulting in continuing clockwise rotation of the rotor. Switch **31** is positioned a few degrees in advance of the motor coil centerline thus compensating for the inertia time constant of the switch armature. The rotor magnet is also phased approximately 30 degrees behind the reference radial on the rotating reticle. One half of the reticle is 50% transparent, and the other half is furnished with transparent and opaque areas, as illustrated in FIGURE 3. Since the reticle revolves clockwise with the rotor, the reference radial referred in hereinabove is the radius at the right side of FIGURE 3 separating the clear area from the opaque-patterned area.

Directional control of a rolling missile is accomplished by extending a pair of fixed incidence wings, housed in section **13**, during the period of the roll wherein a lift force is furnished to direct the missile to the target. The continuous roll required may be imparted to the missile by means of canted nozzles on the rocket motor, or by canted aerodynamic surfaces such as tail fins.

In the embodiment disclosed herein, the optical system, including reticle **21**, is spun at a frequency $f_0$ with respect to the target. The missile itself is simultaneously rolling at a rate $\dot{\phi}$ revolutions per second to enable production of a lefting force in any direction. Referring to FIGURE 9, the homing head senses the direction of flight path error in polar coordinates referenced to the roll axis of the missile, and extends the control surfaces during the proper portion of each revolution of the missile. A sinusoidal error signal of frequency $f_0$, proportional in amplitude to the magnitude of the off-axis tracking error, and whose phase indicates the direction of the error, is supplied by the homing head. Reference coils 28, fixed to the rolling airframe and sensing the magnetic field of the seeker rotor generates a reference signal $fr$ having frequency $f_0 - \dot{\phi}$, equal to the spin rate of the seeker head with respect to the missile airframe. The seeker and reference signals are compared in a phase sensitive demodulator, producing a filtered output signal having a frequency $\dot{\phi}$ and a phase $\phi$, as illustrated in FIGURE 9.

The D.C. amplifier is cut off unless the signal voltage is greater than an applied bias voltage. When the D.C. amplifier conducts, the control surfaces are extended. Thus, the control surfaces are extended for a period during each revolution of the missile during the period the sinusoidal error signal is greater than the bias voltage. The center of the portion of the roll cycle that the control surfaces are actuated coincides with the desired direction of lift. Similarly, the length of time the control surfaces are extended, labeled "lift sector" in FIGURE 9, is a function of the magnitude of the error signal. In addition to a lift force in the desired direction, quadrature lift vectors on either side are also produced. However, these are equal and opposite, and cancel out. A large portion of the actual lift force is produced by the missile body, the wings, or more properly, control surfaces, serving mainly to change the angle of incidence of the elongated missile body. The angle of incidence of the body axis with respect to the flight path results in lift, deflecting the flight path toward the desired path. The lead angle of the reference coil, disclosed hereinabove, is provided to compensate for the time lag required for the wing actuating mechanism to extend and retract the control surfaces, thereby enabling the net lift force of the control surfaces plus the body to act in the direction of the target.

A block diagram of the electronic circuitry is disclosed in FIGURE 10. The signal from the sensitive cell 23 is amplified to a desired amplitude, held constant by an automatic gain control circuit, and demodulated and filtered to recover the error signal. The error signal is applied to the seeker head precession coils, which rotate the seeker head toward the target. Simultaneously, the error signal is combined with the reference coil signal ina phase demodulator. The demodulator output signal is applied to the control surface actuator circuit, further disclosed hereinbelow, which extends the control surfaces at the proper times required to deflect the missile flight path toward the desired flight path.

Referring now to FIGURES 11 and 12, left control surface 34 and right control surface 35 are extended by rotary solenoid 37, placed toward the tail of the missile, and retracted by rotary solenoid 36, placed toward the nose of the missile. A retracting sector gear 41 is rigidly fastened to the shaft 42, for rotation therewith, of retracting rotary solenoid 36, and an extending sector gear 43, is rigidly fastened to the shaft 44 of extending rotary solenoid 37. Sector gears 41 and 43 both mate with a gear 45, on either side thereof. A double-ended sector gear 46 is fixed to gear 45 and shaft 47, and rotates therewith. Left control surface gear 51, mating with double-ended sector gear 46, is rigidly fastened to left control surface 34. Both are journalled on shaft 52. Similarly, right control surface gear 53, mating with double-ended sector gear 46, is rigidly fastened to right control surface 35, and journalled with right control surface 35 on shaft 54.

Rotary solenoids 36 and 37 and shafts 52 and 54 are rigidly fastened to a frame 55. Shaft 47 is journalled in frame 55. Frame 55 serves to maintain the parts in operative relationship with one another, and enable mounting the assembly in missile section 13 with the control surfaces at the desired angle of incidence with respect to the missile axis. Also fastened to frame 55, on either side of shaft 47, are an extension control snap acting switch 56 and retraction control snap action switch 57. A cam 61, fixed to shaft 47 and cam follower 62, actuates snap switch 56, and cam 63, also fixed to shaft 47, and cam follower 64 actuates snap switch 57.

Control panel extension and retraction are controlled by signals which open or close an electronic switch 74. Electronic switch 74 in turn actuates a relay 75 having a movable contact 76 connected to battery 77, a normally closed contact 65 connected to switch 57 and to retraction holding coil 66 of solenoid 36, and a normally open contact 67 connected to switch 56 and to extension holding coil 71 of solenoid 37. In addition to retraction holding coil 66, retracting solenoid 36 is furnished with an accelerating coil 72 connected to switch 57. Similarly, extending solenoid 37 is furnished with extension accelerating coil 73, connected to switch 56, as well as extension holding coil 71.

In operation the control surfaces may be considered to be normally retracted, whereby electronic switch 74 is open, and relay 75 is released. Movable contact 76 connects battery 77 to retracting holding coil 66, which, when excited, exerts a counterclockwise torque on sector gear 41, a clockwise torque on sector gears 45 and 46, and a counterclockwise torque on gears 51 and 53, keeping control surface 35 retracted forwardly, and control surface 34 retracted rearwardly.

Generation of a wing-extend signal by the seeker head and the electronic circuitry fires electronic switch 74, actuating relay 75 and transferring movable contact 76 to contact 67, opening the circuit to retraction holding coil 66. Current from battery 77 is applied to holding coil 71 and accelerating coil 73 of extension solneoid 37, causing solenoid 37 to exert a large clockwise torque on sector gear 43. Sector gear 43 rotates gears 45 and 46 counterclockwise, and control surface gears 51 and 53 clockwise, extending control surfaces 34 and 35. At a predetermined angle during the extension operation, cam 61, fastened to shaft 47, opens switch 56 and closes switch 57, disconnecting accelerating coil 73. Control surfaces 34 and 35 are further extended into the full-extended position and are held therein by the torque exerted by holding coil 71.

A wing-retract command signal cuts off electronic switch 74, and releases movable contact 76 of relay 62, opening the circuit to extension holding coil 71, and closing the circuit to retracting holding coil 66, and to retracting accelerating coil 72 through switch 57. Coils 66 and 72, in solenoid 36, exert a counterclockwise torque on sector gear 41, a clockwise torque on meshing gear 45 and double sector gear 46, and counterclockwise torques on gears 51 and 53, fastened to control surfaces 34 and 35, respectively, rotating the control surfaces from the extended position to the retracted position. At a predetermined angle, cam 63 actuates switch 57, opening the circuit to accelerating coil 72. Coil 66 continues to exert a retracting torque, holding the control surfaces in the retracted position.

It will be apparent, therefore, that the control system of the present invention reduces power and weight requirements for control surface actuation. Aerodynamic drag forces are balanced out, since drag on the surface moving forward is balanced by the aiding drag on the surface moving rearwardly. Similarly, forces due to longitudinal acceleration and deceleration are balanced out. Solenoids 36 and 37, therefore, need only provide enough torque to overcome rotating inertia of the control surfaces, friction, and centrifugal force. Retracting solenoid 36 may be somewhat larger than extending solenoid 37, since it must overcome the larger net force due to the centrifugal force generated by the rotating missile. By dividing the torque producing solenoids into two coils, the large current required for overcoming inertia is applied for a small portion of the cycle, reducing power supply requirements and allowing a short-time overload on the coil without excessive heating.

While a presently preferred embodiment of this invention has been disclosed hereinabove, it is understood that the invention is not limited thereto since many variations will be readily apparent to those skilled in the art, and is to be limited only by the scope of the appended claims.

What we claim is:

1. Rolling missile control means comprising first and second opposing retractable control surfaces, said first control surface retractable in a forward direction and said second control surface retractable in an aft direction, a torque producing electromagnetic solenoid including an accelerating coil and a holding coil, mechanical means connecting said torque producing solenoid to said first and second control surfaces, and a switch fastened to said mechanical means to disconnect said accelerating coil at a predetermined position of said control surfaces.

2. Rolling missile control means comprising first and second opposing control surfaces, said first control surface retractable in a forward direction and said second control surface retractable in an aft direction, a torque producing electromagnetic solenoid including an accelerating coil and a holding coil, gearing connecting said torque producing solenoid to said first and second control surfaces, and a switch fastened to said gearing to disconnect said accelerating coil at a predetermined position of said control surfaces.

3. Rolling missile control means comprising first and second opposing control surfaces, said first control surface retractable in a forward direction and said second control surface retractable in an aft direction, electromagnetic retraction torque producing means, electromagnetic extension torque producing means, mechanical means connecting said retraction and extension torque producing means to said first and second control surfaces, and an electrical control circuit controlling operation of said retraction and extension torque producing means.

4. Rolling missile control means comprising first and second opposing control surfaces, said first control surface retractable in a forward direction and said second control surface retractable in an aft direction, a retraction torque producing electromagnetic solenoid having an accelerating coil and a holding coil, an extension torque producing electromagnetic solenoid having an accelerating coil and a holding coil, gearing connecting said retraction and extension torque producing solenoids to said first and second control surfaces, and switch means fastened to said gearing to disconnect said accelerating coils at predetermined positions of said control surfaces.

5. Rolling missile control means comprising first and second opposing control surfaces, said first control surface forwardly retractable and said second control surface rearwardly retractable, a retraction torque producing electromagnetic solenoid having an accelerating coil and a holding coil, an extension torque producing electromagnetic solenoid having an accelerating coil and a holding coil, gearing connecting said torque producing solenoids to said first and second control surfaces, and a control circuit including switch means fastened to said gearing to disconnect said accelerating coils at predetermined positions of said control surfaces.

6. Rolling missile control means comprising first and second opposing control surfaces, said first control surface forwardly retractable and said second control surface rearwardly retractable, a retraction torque producing electromagnetic solenoid having an accelerating coil and a holding coil, an extension torque producing electromagnetic solenoid having an accelerating coil and a holding coil, drive sector gears fastened to said torque producing solenoids, a first idler gear meshing with said sector gears, a double sector idler gear fastened to said first idler gear, and first and second driven sector gears meshing with said double sector idler gear and fastened to said first and second control surfaces, and a control circuit controlling operation of said retraction and extension solenoids.

7. Rolling missile control means comprising first and second opposing control surfaces, said first control surface forwardly retractable and said second control surface rearwardly retractable, a retraction torque producing electromagnetic solenoid having an accelerating coil and a holding coil, an extension torque producing electromagnetic solenoid having an accelerating coil and a holding coil, gearing connecting said torque producing solenoids to said first and second control surfaces, and a control circuit including a current source, first switch means selectively connecting said current source to said extension and retraction holding coils, and second switch means connected to said first switch means and to said holding coils for selectively connecting said current source to said accelerating coils.

8. Rolling missile control means comprising first and second opposing control surfaces, said first control surface forwardly retractable and said second control surface rearwardly retractable, a retraction torque producing electromagnetic solenoid having an accelerating coil and a holding coil, an extension torque producing electromagnetic solenoid having an accelerating coil and a holding coil, gearing connecting said torque producing solenoids to said first and second control surfaces, and a control circuit including a current source, double throw switch means selectively connecting said current source to said holding coils, and a mechanically actuated switch connected to said first switch means and to said holding coils for selectively connecting said current source to said accelerating coils in accordance with the position of said control surfaces.

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