Dec. 10, 1968 H. A. POOLE, JR 3,415,466

TIME RESPONSE MATCHING PROCESS AND PRODUCT

Filed May 16, 1966 3 Sheets-Sheet 1

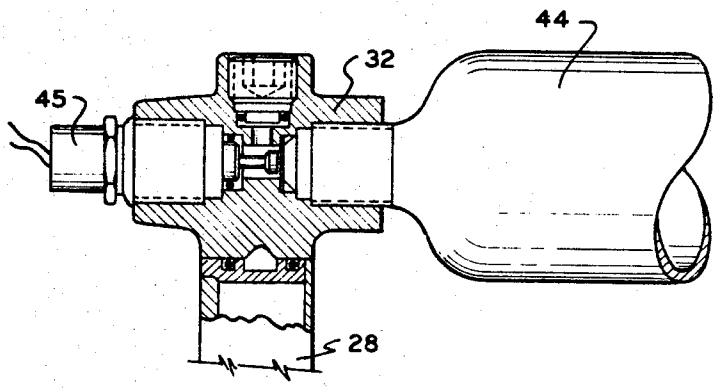

FIG. 2

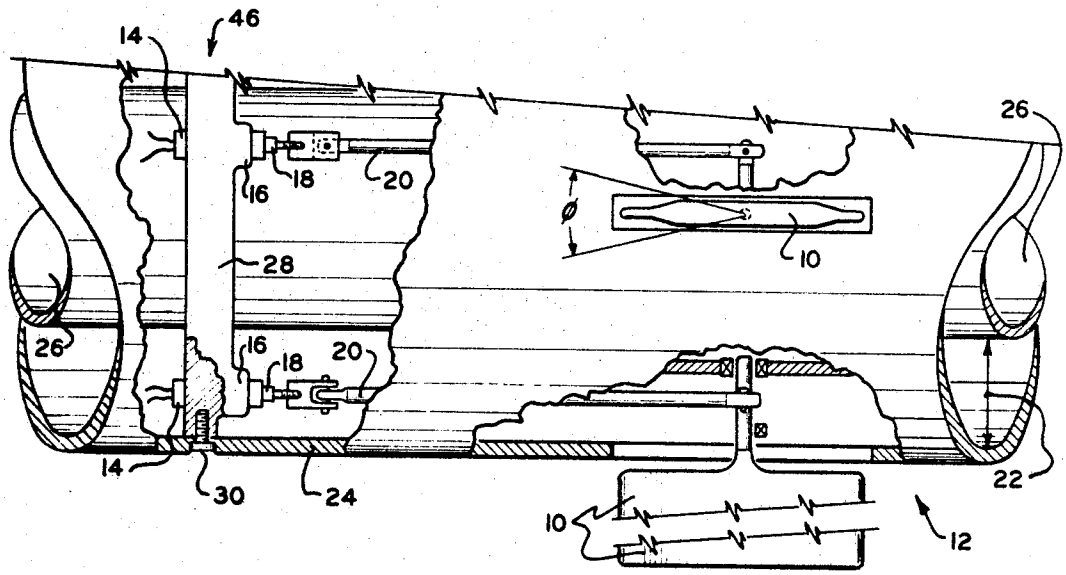

FIG. 1

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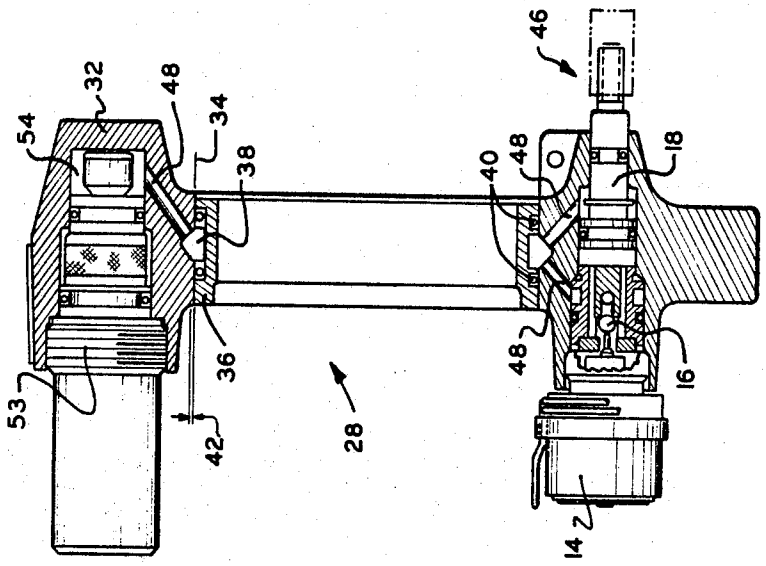

FIG. 4

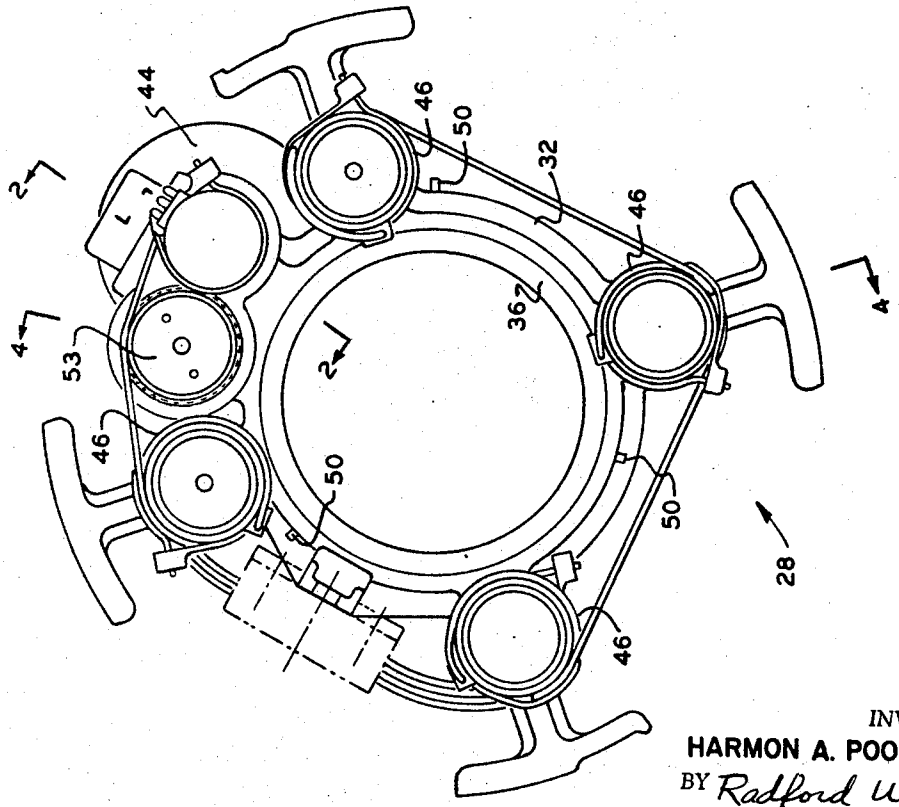

FIG. 3

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Filed May 16, 1966 3 Sheets-Sheet 3

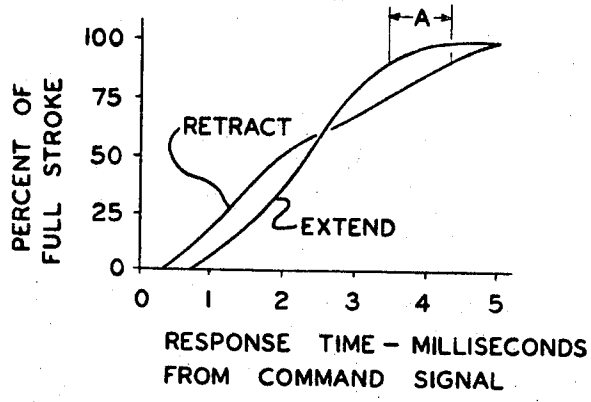

FIG. 6

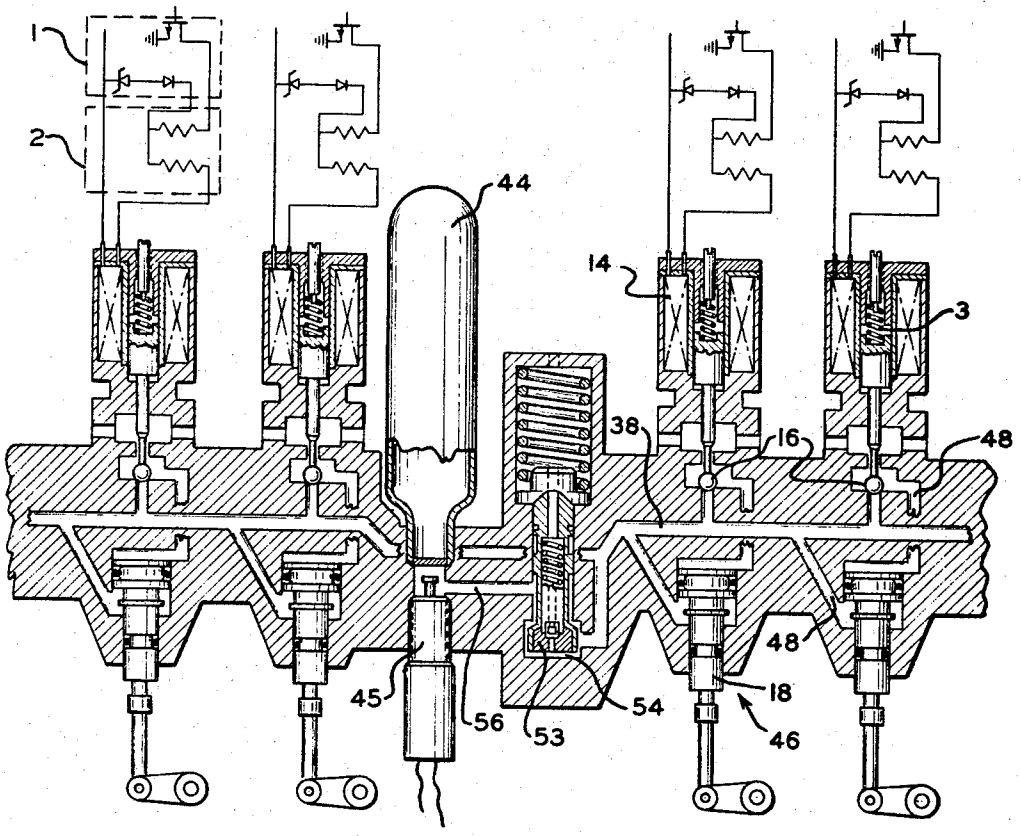

FIG. 5

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3,415,466

TIME RESPONSE MATCHING PROCESS AND PRODUCT

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Filed May 16, 1966, Ser. No. 550,331
3 Claims. (Cl. 244—3.21)

ABSTRACT OF THE DISCLOSURE

A bang-bang missile control system alters angle of attack by subjecting the missile to pure pitch or yaw moment influences produced by paired control surfaces disposed on opposite sides of a missile and separately actuated in time-mismatched limited concert, such that roll moments cancel out despite actuator hysteresis and one control surface is driven by a first actuator in an extend mode while the control surface paired therewith is driven by a second actuator in a retract mode.

This invention relates to missile flight control systems and has particular reference to a process and structure whereby the response mismatch among a plurality of aerodynamic fins is limited to a narrow absolute time response tolerance band regardless of fin position. Application No. 550,459 for Circular Manifold, filed by Alexander M. Wright in May 1966, now U.S. Patent No. 3,347,494, discloses and claims the manifold structure which serves the actuator assemblies disclosed and claimed in this application.

An object of this invention is to provide a process and product whereby a plurality of bang-bang type actuator assemblies and supporting structure will co-act to exhibit within narrow limits similar response times associated with similar load positions irrespective of the limit position from which the load position is approached.

A further object is to provide synchronized equal total effective operation of separate control members having driving means operating out of phase with each other.

Further objects and advantages of this invention will become evident upon examination of the drawings and specifications.

FIGURE 1 is a cutaway side elevation of a portion of a missile incorporating the invention.

FIGURE 2 is a fragmentary view, partly in section, taken along lines 2—2 of FIGURE 3.

FIGURES 3 and 4 are respectively plan and sectional views of the manifold.

FIGURE 5 is a schematic representation of a section taken along line 5—5 of FIGURE 3.

FIGURE 6 is a plot of Stroke versus Time in the "Extend" and "Retract" modes of actuator stroke.

FIGURE 1 shows two of the four fins **10** which protrude from the missile aft section **12**. Solenoids **14** operate ball valves **16** which control fluid flow to fin actuator pistons **18** which drive links **20** connected to fins **10**. Dither motions of fins **10** through an arc Φ are initiated by electronic control signal inputs from the missile computer (not shown) to solenoids **14**. The links **20** are longitudinally disposed in the annular space **22** between the missile skin **24** and the rocket thruster tube **26**. Manifold structure **28** is concentrically mounted in annular space **22** and attached to the missile skin **24** by screws **30**, thereby enveloping a longitudinal portion of rocket thruster tube **26**.

Pressure source **44** (see FIG. 2) is threaded into valve housing **32** and a manually controlled puncturing device **45** is threaded into valve housing **32** to effect the release of fluid from pressure source **44**. Solenoid valve-actuator

assemblies **46** (see FIG. 3) are substantially equally spaced around valve housing **32**. Pins **50** fix sleeve **36** in housing **32**.

Manifold structure **28** (see FIG. 4) comprises an annular valve housing **32** having a central bore **34**, a sleeve **36** fixed concentrically within said housing **32**, a toroidal passageway **38** formed between said sleeve **36** and said housing **32**, packing means **40** disposed outwardly of said passageway **38** to seal any annular clearance **42** between said sleeve **36** and said housing **32**, a pressure source **44** carried by said housing **32**, a plurality of solenoid valve-actuator assemblies **46** substantially equally spaced around said annular housing **32**, conduit means **48** connecting said toroidal passageway **38** to pressure chamber **54**, and to each of said plurality of assemblies **46**. Said pressure source **44** (see FIG. 5) supplies fluid to pressure regulating valve **53** via passageway **56** (see FIG. 5), the regulated fluid thence flowing into chamber **54**, thence into connecting conduit means **48**, thence into toroidal passageway **38**, and finally to a plurality of ball valves **16** and actuating pistons **18** via conduit means **48**. Pulse-width modulated signals from the missile computer (not shown) energize valve operating means such as solenoids **14** to control valve means **16** which control the position of each fin. Since the missile operates at a high velocity and the total time of flight is very short, the actuator must be fast and the unbalanced moments produced by any control action must be minimized to provide accurate stable flight. Unbalanced moments of any single pair will produce unwanted roll. The response time of each actuator unit can be matched to the response time of all of the other actuator units such that a very narrow band of response time mismatch between individual units is established by the process of summing individual elemental time response such that for a large number of assembled actuator units the overall response time of each individual assembled actuator unit will be matched to all the other assembled units to within a narrow absolute time response tolerance band such as one millisecond. Conduit means **48** direct regulated pressure directly to the rod side of the actuator pistons **18** which are constantly pressurized while the system is in operation, and also to valve assemblies **16**.

If the solenoid is in a de-energized condition, the flow will be stopped by the ball valve itself, which is then seated by spring **3** onto the lower seat. In this position the valve permits venting of the upper actuator cavity. As each individual solenoid is fully energized, the corresponding ball valve will be seated on the upper seat and regulated pressure is introduced to the large area side of the corresponding piston.

If the solenoid is de-energized, the piston **18** will snap under the influence of fluid force on the rod side of the piston **18** to the "retract" position. If the solenoid is energized, the piston **18** will snap under the influence of fluid force on the opposite side of the piston **18** to the "extend" position. The particular organization utilized for the instant actuator assembly is such that one actuator will "extend" while the diametrically opposite actuator will simultaneously "retract." However, the mechanical linkage between the actuators and the aerodynamic fins is such that the fin connected to one actuator will move in response to a "retract" signal in the same direction as the fin connected to the diametrically opposite actuator moves in response to an "extend" signal. Thus paired aerodynamic fins move in the same direction in response to an opposed actuator movement within their paired actuator assemblies. A similar operational characteristic exists between the remaining paired actuators and their respective aerodynamic fins. This operational arrangement is important in understanding the "extend" and "retract" absolute time response mismatch curve shown in FIGURE 6. The dead time and "extend" and "retract" rates depicted in FIGURE 6 can

be adjusted by individually selecting electrical means such as diodes **1** or resistors **2** to be placed in the solenoid lead wires or by mechanical means such as adjusting the spring **3** to vary the load acting on the solenoid plunger.

When the computer control signal to a solenoid is a balanced square wave, the fin will snap from the "extend" stop to the "retract" stop without producing any appreciable net control moment. Yaw or pitch control moments are produced by actuators respectively acting in pairs with the dwell time at one stop position longer than at the other stop position. The corrective moment produced by this unbalanced dwell time is related to the integral of the pair of actuator position-time traces. The significance of "mismatch" is indicated by the example shown in FIGURE 6. This shows response matching as a time function, not just an end condition. For this reason, the response time of the matched actuator units must be capable of achieving almost matched time response over a wide range of missile operating and fin loading conditions.

The total or integrated time response of the actuator unit is composed of the sum of the individual time responses of the following elements:

(1) Solenoid "rise time" (partly the function of the solenoid triggering circuit).

(2) Ball travel "transient" time.

(3) Pneumatic response time (pressurized fluid flow time through passages and orifices between ball and actuator piston inlet).

(4) Piston travel time (including time consumed to pneumatically fill piston chamber).

It is to be noted the above total time response relates to the "extend" position of the actuator piston rod. The total "retract" position response time is composed of the sum of times 2, 3 and 4, as set forth above, plus the solenoid "dropout time," which again is partly a function of the solenoid triggering circuit.

It is important to note that the total or integrated "extend" response time will not necessarily be the same as the total or integrated "retract" response time. FIGURE 6 shows a rapid "extend" rate combined with a relatively long dead time used for solenoid energization and valve travel, and a relatively slow "retract" rate combined with a relatively short dead time used for solenoid decay and valve travel.

Realistic response time limits can be established for each of the elements that contribute to each of the individual time response set forth in items 1–4 above such that a cumulative maximum response time tolerance mismatch A (see FIG. 6) of no more than one millisecond between units can be established.

By selecting and assigning a response time tolerance band to each of the elements that compose the complete actuators assembly an absolute mismatch time band of one millisecond can be established among a plurality of solenoid valve-differential actuator assemblies by the technique of matching and summing incremental time response characteristics.

While certain details have been described herein, it will be understood that other modifications and changes may be made without departing from the spirit and scope of the appended claims.

I claim:

1. A control method for missile flight steering comprising simultaneously independently moving a pair of coacting separate control members on the missile in the same direction in a continuous movement from one matched terminal position where they have one control effect to an opposite matched terminal position where they have an opposite control effect, one member having a longer travel time than the other, any mismatch of position causing an undesirable control effect, initiating starting movement of the member having the longer travel time before initiating starting movement of the other member, thus causing a first temporary mismatch in one direction, bringing the members to a simultaneous position match intermediate the control movement and then moving the members to a mismatch in the opposite direction in the remainder of the control movement to thereby cancel the effect of the first mismatch.

2. A missile control for a movable body comprising a pair of bidirectional movable control fins disposed on diametrically opposite sides of said body and having a path of bidirectional movement between opposed limiting stop positions in which positions the fins have matched cumulative control effects, unequal dwell times at the opposed stop positions causing a net control result, an individual actuator connected to each respective fin, each actuator having a slower operating rate in one direction than in the other, means connecting each fin and its respective actuator so as to move one fin at the slower rate and the other at a faster rate when moving both fins in the same direction, similar means controlling said actuators and having different operating rates in opposite directions, each of said controlling means being connected to a respective actuator so that the controlling means operation in the faster operation direction is effective to actuate said actuator in said slower actuator operating rate direction, and means for operating said controlling means, said means being so timed that the adverse control effect of a fin position mismatch in one direction in the first part of the fin movement is cancelled by an equal mismatch in the opposite direction in the later part of the fin movement.

3. Means for simultaneously independently operating a pair of control members on a missile in the same direction and over the same distance comprising, a differential piston operatively connected to each respective member for moving the respective control member bidirectionally, means continuously supplying pressure fluid to the smaller side of the piston, valve means controlling the flow of pressure fluid to and from the larger side of the piston, a solenoid controlling each valve, and having a longer energizing time than decay time, each of said pistons having a longer retract time than extend time, said solenoids being so connected that energizing a solenoid will cause extension of its respective piston, one piston operating one control member by extending and the other piston simultaneously operating the other control member in the same direction by retracting.

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