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Tucker

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[54] **GUIDANCE SYSTEM**

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[52] **U.S. Cl.** **89/1.8,** 244/3.12
[51] **Int. Cl.** **F42b 15/04**
[58] **Field of Search** 244/14, 3.12; 89/1.7, 1.8; 102/50, 49; 250/203

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EXEMPLARY CLAIM

1. Means for guiding an object along a line-of-sight path from a launching site to a target comprising an object having an aerodynamically stable shape with a front to rear axis oriented during flight to extend substantially on the line-of-sight between the launching site and the target, means at the launching site for launching the object on a course toward the target, means for causing the object to roll about its axis at a predetermined roll rate, a light source mounted on the object in position to project light rearwardly therefrom, means at the launching site for aiming and sighting on the target, other means at the launching site oriented with the aiming and sighting means for tracking the object during flight, said tracking means including light sensitive means and means for focusing light from the light source on the object into a spot on the light sensitive means, the position of said spot on the light sensitive means corresponding to the position of the object relative to the line-of-sight between launching means and the target as determined by the aiming and sighting means, means responsive to the vertical position and to changes in the vertical position of the light spot on the light sensitive means for producing first control signals, means responsive to the horizontal position of the light spot and to changes thereof for producing second control signals, means for sending commands corresponding to said first and second signals to the object, a plurality of one-shot thrust producing elements mounted at spaced locations about the surface of the object, means for sequentially exciting groups of said thrust producing elements to laterally displace the object in space, the combined thrust produced by each group of excited elements acting substantially through the center of gravity of the object, and means on the object responsive to said commands to control the frequency of excitation of succeeding groups of thruster elements and the angular orientation of the thrust produced by each group.

16 Claims, 11 Drawing Figures

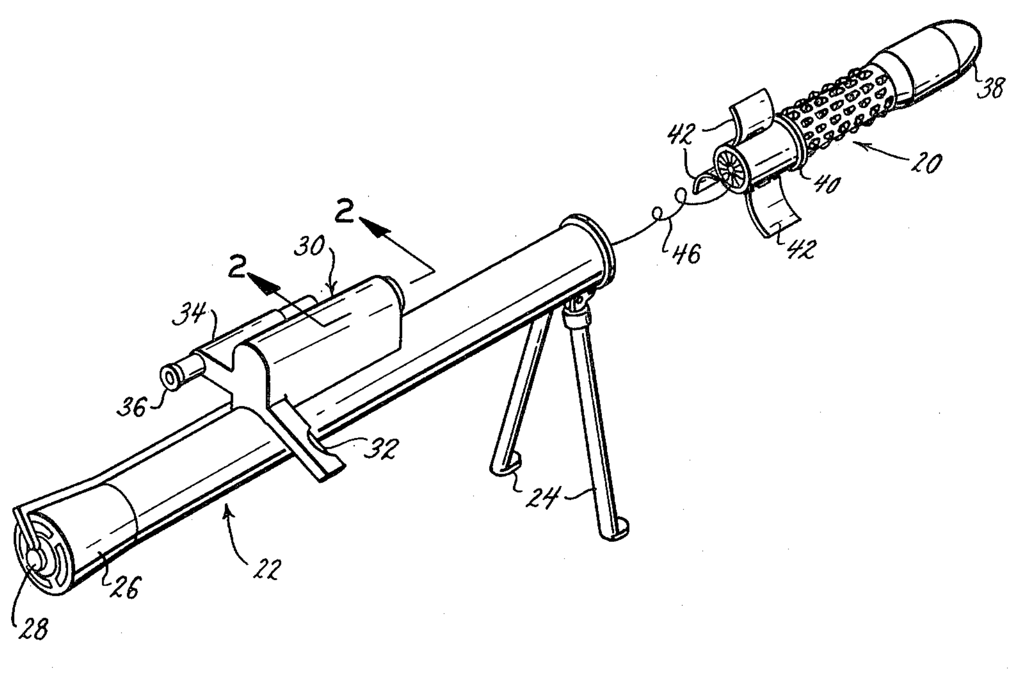


FIG. 5.

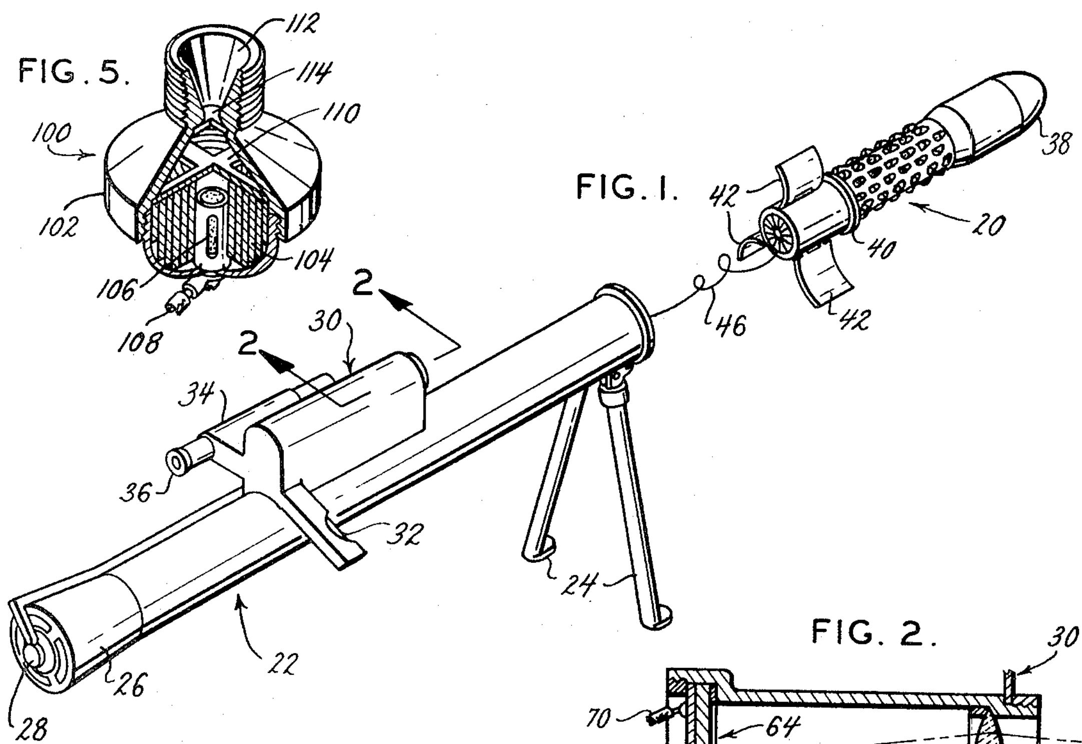
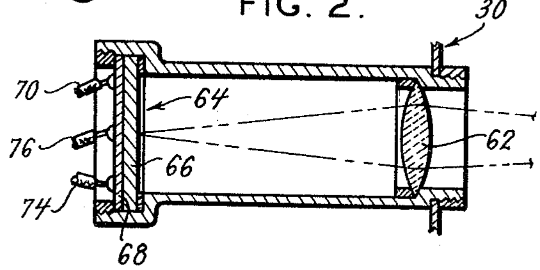


FIG. 1.

FIG. 2.



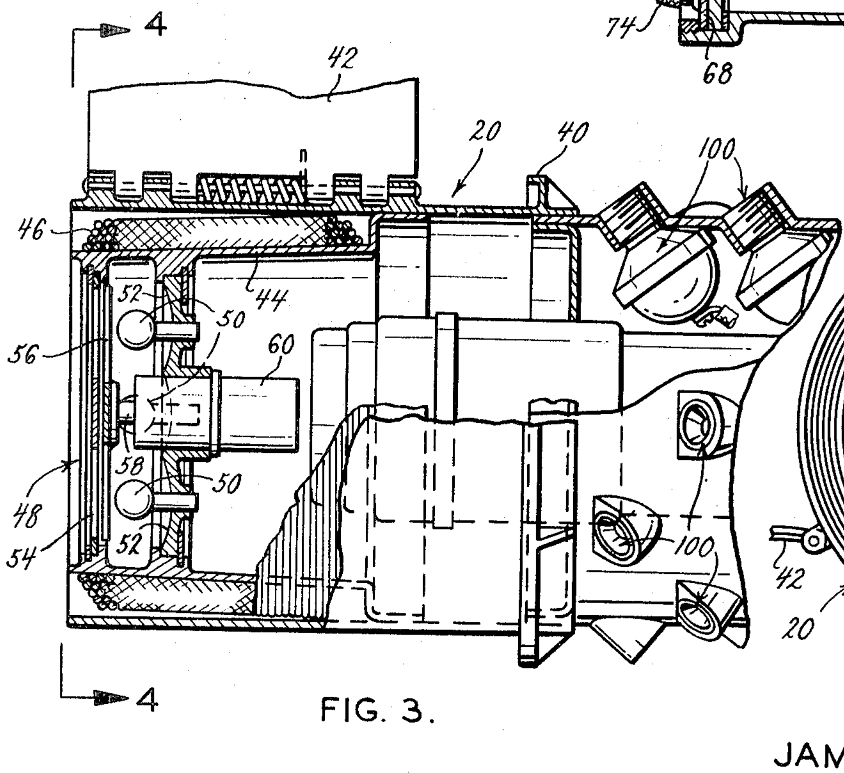


FIG. 3.

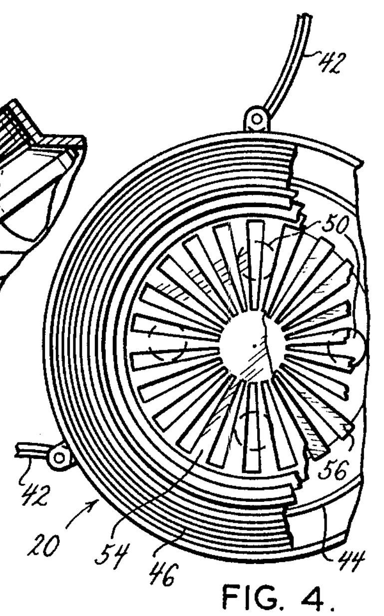


FIG. 4.

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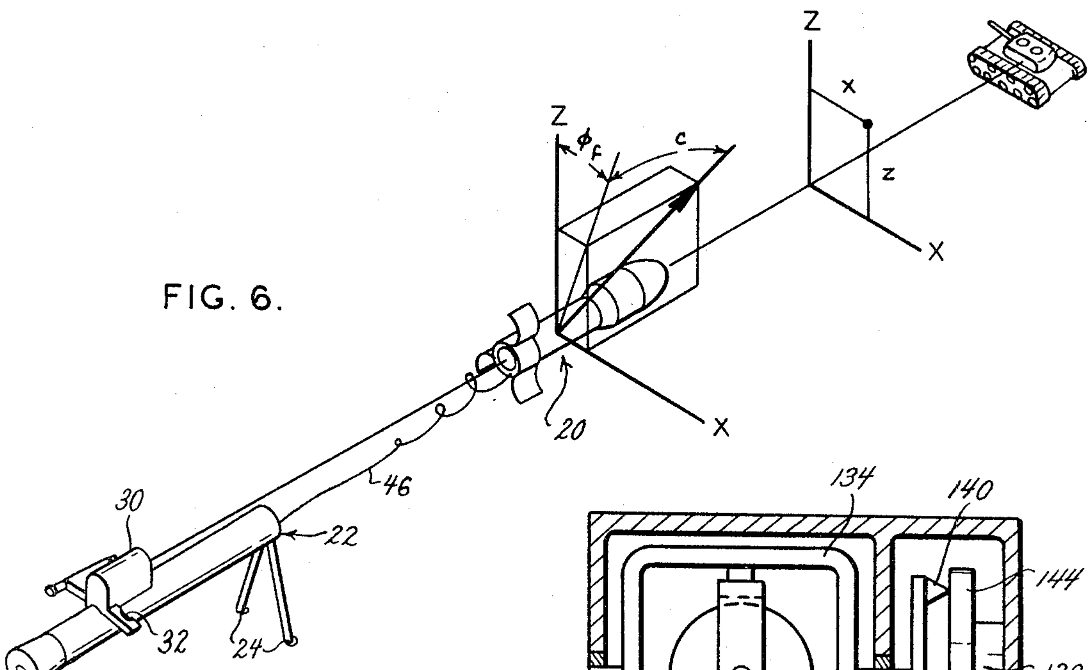

FIG. 6.

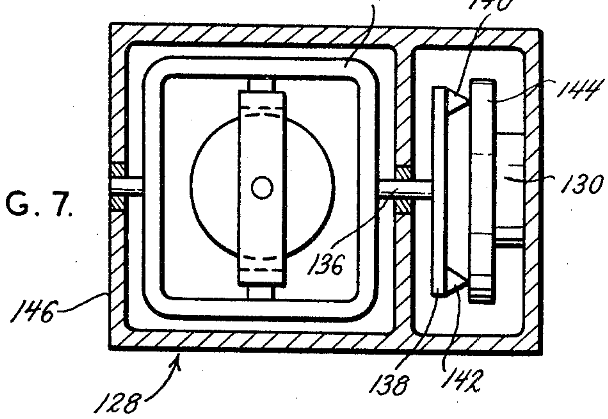

FIG. 7.

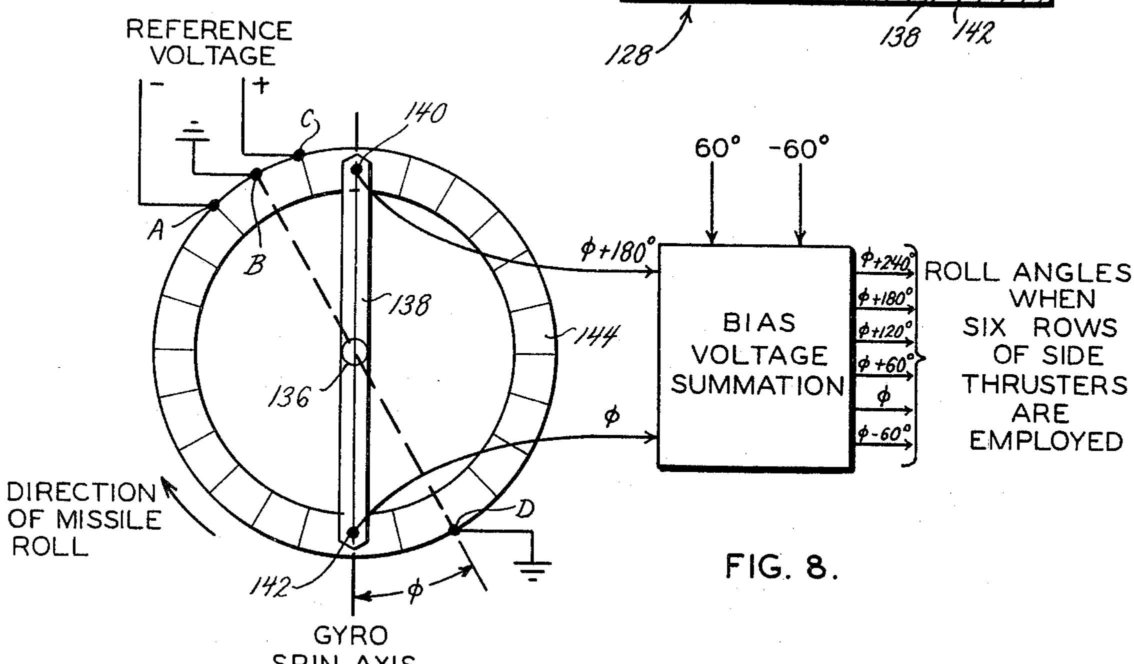

FIG. 8.

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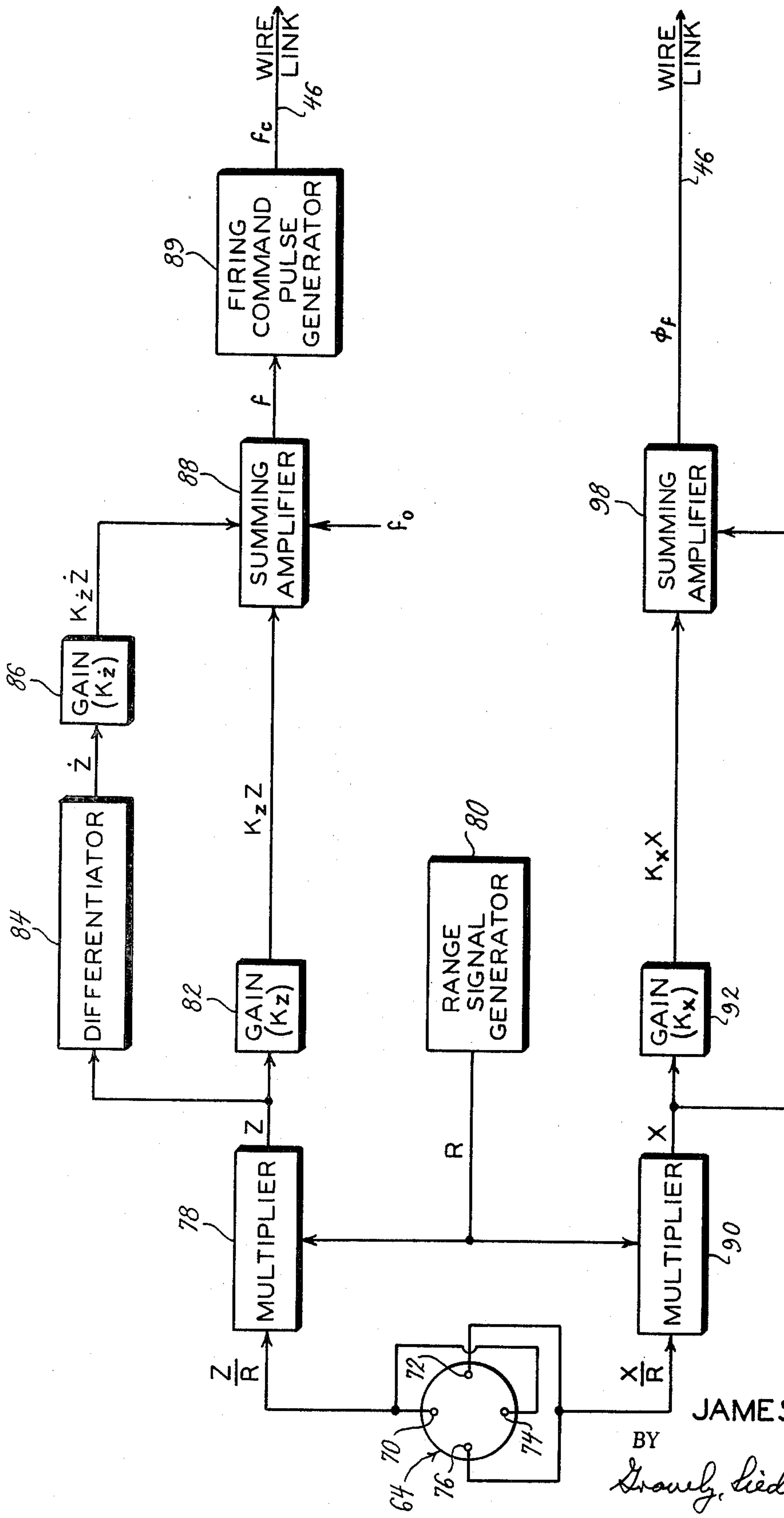

FIG. 9.

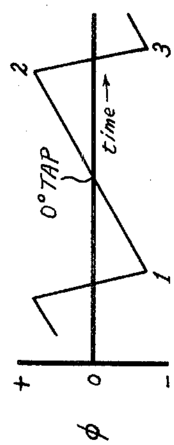

FIG. 11.

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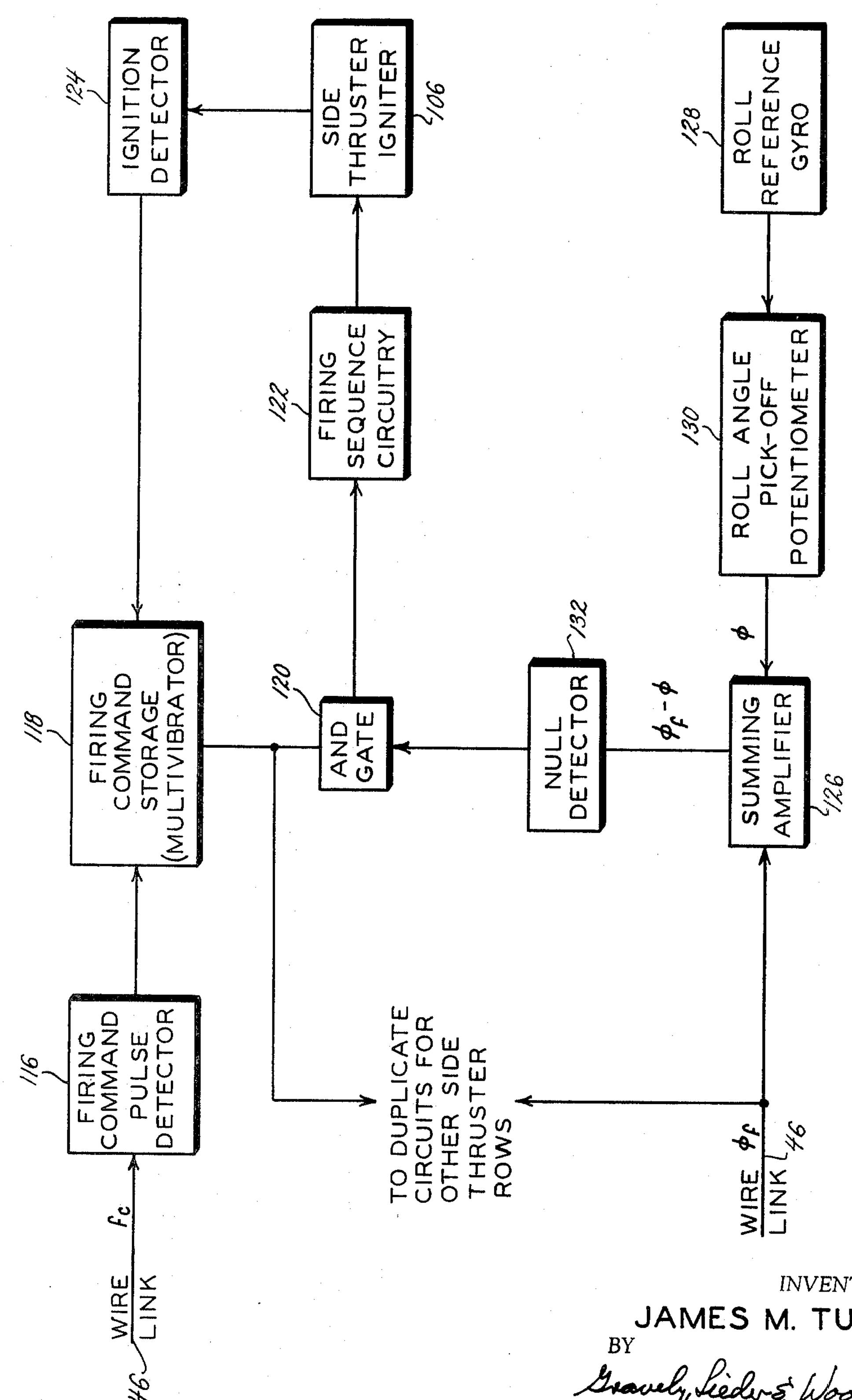

FIG. 10.

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GUIDANCE SYSTEM

The present invention relates generally to guidance systems and more specifically to a guidance system for guiding projectiles such as missiles or rockets along a line of sight path toward a target.

Various means have been devised in the past for aiming and guiding projectiles and other devices toward a target including devices which take into account movement of the target as well as atmospheric and other conditions. For the most part, however, the prior art devices have included aiming devices and remote control means having no physical connection to the projectile. It has been discovered, however, that certain advantages are obtained by maintaining a physical connection with the projectile especially in line-of-sight operation where the total flight time is only a few seconds duration. Furthermore, none of the known devices include thruster means capable of maintaining a projectile on course and at the same time increasing the forward speed and range thereof.

The present device overcomes these and other shortcomings and disadvantages of known guidance devices, particularly for line-of-sight operation, by providing means for more accurately guiding a projectile to a target during its flight. To accomplish this the present guidance means comprises guidance control means at the launching site which are connected by a wire link to a projectile during all or substantially all of its flight, which link enables the guidance control means at the launch site to more accurately guide the projectile along a line-of-sight flight path. The subject guidance means also includes means on the projectile under control of the aforesaid control means to laterally and forwardly displace the projectile during flight in a direction to maintain it on a desired flight path and to overcome or partially overcome slow down caused by gravity and friction. The subject guidance means also comprises a missile or other projectile having a body portion, means for aiming and launching the missile in a predetermined direction, a plurality of thruster devices mounted in rows adjacent to the surface of the missile, said thrusters having discharge orifices which are directed to produce lateral and forward thrust components relative to the desired direction of missile movement when energized or exploded, means for rolling the missile during flight, and guidance control means associated with the missile aiming and launching means for energizing the thrusters at predetermined times and frequencies to maintain the missile on course, said guidance control means including a source of light mounted on the missile and directed rearwardly therefrom, tracking means located at the launching means including a light sensitive element positioned to respond to the light from the light source on the missile, said tracking means producing guidance control signals that respond to the position of the light spot on the light sensitive element, said signals being responsive to the vertical and horizontal positions of the missile relative to the desired line-of-sight course therefor, and means responsive to said control signals for energizing preselected ones of the missile thruster elements to laterally and forwardly displace the missile in fight in a direction to maintain the missile on the desired flight path.

It is a major object of the present invention to provide means for guiding a missile or other projectile along a predetermined line-of-sight flight path.

Another object is to provide improved means for controlling the flight of a projectile.

Another object is to increase the accuracy of guided missiles and the like.

Another object is to provide means for simultaneously producing lateral and forward thrust to a missile during flight.

Another object is to provide means for maintaining physical connection between a fixed control station and a missile in flight.

Another object is to provide means for producing controlled thrust for guiding a rolling missile during flight.

Another object is to provide a line-of-sight missile guidance system which is relatively inexpensive, lightweight, portable, and requires little or no special skill or training to operate.

Another object is to provide means for developing missile control impulses which take into account the roll of the missile and the position of the missile relative to a desired flight path.

These and other objects and advantages of the present invention will become apparent after considering the following detailed specification of a preferred embodiment thereof in conjunction with the accompanying drawings which form a part thereof.

In the drawings:

FIG. 1 is a perspective view of a missile and missile launching and tracking means therefor constructed according to the present invention;

FIG. 2 is an enlarged cross-sectional view of a light sensitive device employed in the tracking means of the subject device;

FIG. 3 is an enlarged fragmentary view partially in section of the aft end portion of a missile constructed according to the present invention;

FIG. 4 is a fragmentary rear end view of the same missile as seen on line 4—4 of FIG. 3;

FIG. 5 is an enlarged perspective view partially in section showing a typical thruster element employed on the subject missile;

FIG. 6 is a perspective view showing the relative inflight positions of the missile guidance and tracking means, the missile, and the target, said view illustrating vectorially the direction and magnitude of thrust required to restore the missile to a desired flight path;

FIG. 7 is a top plan view of a gyro and associated commutator employed on the subject missile;

FIG. 8 is an enlarged view of the commutator and associated circuits of FIG. 7;

FIG. 9 is a block diagram of a typical electronic circuit capable of producing command signals for controlling the subject missile;

FIG. 10 is a block diagram of a typical control circuit employed on the subject missile for controlling the firing of the side thruster elements; and

FIG. 11 is a graph of one firing angle command output plotted as a function of time.

Referring to the drawings more particularly by reference numbers, the number **20** refers to a missile which is launched from a launching tube **22.** The forward end of the launch tube **22** is preferably stabilized and supported during firing on a pair of bipod legs **24** or the like, and the rear end of the launch tube **22** has a propellant canister **26** attached thereto. The canister **26** contains an explosive charge which provides the force for firing the missile in a recoilless or near recoilless manner and includes an igniter **28** which is energized to ignite the charge.

A tracking assembly **30** is mounted on the launching tube **22** and includes a pistol grip and trigger assembly **32** for initiating a firing operation and a telescopic sight **34.** The telescopic sight **34** has an eye-piece **36** with a crosshair which the operator aims at and holds on a target during launching and travel of the missile. The success of the subject device depends in large measure on the ability of the operator to keep the crosshairs on the target. The tracking assembly **30** including the telescopic sight **34** and the pistol grip assembly **32** is preferably constructed as a unit which is reusable and can be installed quickly and accurately on the launching tubes **22.** The launching tubes, on the other hand, are preferably constructed of relatively inexpensive disposable materials and are discarded after the missiles are fired. The launching tubes do, however, form convenient containers for handling and transporting the missiles as well as for launching them.

Each missile **20** has a warhead **38** on the forward end and each missile is also provided with an annular ring **40** near the rear end. The ring **40** rides on the inner surface of the launching tube **22** and provides a seal between the missile and the launching tube to prevent the launch gases produced when the explosive charge is ignited for escaping past the missile during launching. The missile **20** also has a plurality of fins **42** (three being shown in FIGS. **1** and **6**) which are hingedly connected to the rear outer surface of the missile. The fins **42** are spring loaded to move outwardly to their extended positions after launching, but during launching when the missile is in the launch tube **22** the fins are folded against the body of the missile so that the launch tube will accommodate them. The fins **42** provide aerodynamic stability and are installed at a predetermined cant angle, normally about 2° to cause the missile to roll in flight at a predetermined roll rate. The roll rate is important to the operation and control of the missile and is essentially proportional to the missile's forward velocity and to the cant angle of the fins **42.** The roll rate should be high enough to avoid long delays between successive applications of corrective thrust force. The roll rate is also effected to some extent by the physical characteristics and weight of the missile itself and by a roll torque which is produced during flight by trailing a wire link which will be described later. It has been found that the roll rate increases as the missile's forward velocity increases from an initial rate which developes shortly after launching to a final higher roll rate which occurs at or near the end of flight. It is not necessary, however, that the roll rate increase or even change so long as the approximate roll rate is known.

The rear end of the missile **20** carries a bobbin **44** which has a thin multi-strand wire **46** wound thereon. Each wire strand is also insulated. The bobbin **44** preferably has a slight taper front to rear of approximately 2° to enable the wire **46** to easily unwind therefrom during flight. The first few feet of the wire is also more heavily protected by a coating because of its exposure to the gases produced by the canister during launching. The length of the wire **46** depends on the range of the missile, and the wire is preferably lightweight so as not to unduly increase the weight of the missile. A physical connection such as a wire link is not an essential feature of the subject device but it is essential to have

some communication to transient guidance commands such as by radio or by laser communication.

One end of the wire link **46** is connected to the output of the tracker electronic circuit shown in FIG. **9** and the opposite ends of the wire link **46** is connected to the missile control circuit shown in FIG. **10.** The tracker electronic circuit is in the tracking assembly **30** mounted on the launching tube **22,** and the missile control circuit is positioned inside the missile **20** near the rear end.

A flare or light source **48** is mounted inside the bobbin **44** adjacent to the rear end of the missile and includes means for producing light which is directed rearwardly therefrom. The flare **48** includes a plurality of lights **50** each of which is provided with its own reflector **52.** Tungsten or xenon lamps or even an invisible ultra-violet or infra-red light source can be used for the lights **50.** The flare **48** also includes a chopper assembly which is positioned behind the lights **50** and which includes a slotted chopper shade **54** fixedly attached to the bobbin **44** and a rotatable chopper blade **56** which is driven by a shaft **58** and a chopper motor **60.** The chopping rate depends on the speed of the chopper motor **60** and the missile roll rate.

The light from the light elements **50** passes through the slots of the members **54** and **56** and is directed rearwardly from the missile by the reflectors **52.** This light is received at the tracking assembly through a tracker lens **62** (FIG. **2**). The lens **62** focuses the light thus received in a spot on the surface of a light sensitive detector device **64** which may be constructed along the lines of the device covered by copending James E. Dueker application Ser. No. 284,092, field May 29, 1963 entitled Light Sensitive Device and assigned to the same assignee.

The light sensitive detector **64** is constructed of a plurality of layers of materials such as semi-conductor materials **66** and **68** which are capable of responding to light impinging thereon to produce electrical signals that represent the location on the detector surface where the light impinges. The detector element **64** also has a plurality of electrical terminals **70–76** attached at spaced locations to one side of the device. For example, the terminals **70** and **74** as shown in FIG. **9** are positioned on opposite ends of the vertical diameter of the element **64,** and the terminals **72** and **76** are located on opposite ends of the horizontal diameter thereof. This means that as the light from the flare **48** moves about on the surface of the detector **64** it will produce voltage changes between the pairs of opposite terminals **70–76,** which changes vary with the position of the light spot on the detector. These voltages or signals are also representative of the position of the missile relative to its desired flight path and are used as will be shown for control and guidance purposes. The signals thus produced are fed to two different channels of the tracker circuit shown in FIG. **9** and develop command signals which are then sent to the control circuits in the missile over the wire link **46** or other communication link. The missile control circuits in turn ignite or fire the thruster elements mounted on the surface of the missile to move the missile in space in a direction to restore it to the desired flight path.

Two command signals are produced by the circuit of FIG. **9.** One of the command signals determines the frequency at which the thruster elements will be fixed or the firing rate thereof, and the other signal controls the angle of direction in which the thrusters are facing at the time they are fired. Both of these signals are effected by the amount the missile is off course and also by the rapidity at which the missile is moving away from its intended course. The accuracy of these signals also depends on the ability of the operator to keep the target in the crosshairs. In other words, the two signals are dependent upon the horizontal and vertical distance the missile is off course, and both of these distance errors are detected by where the light from the flare falls on the detector **64.**

The amount of vertical correction required to maintain the missile on course involves adding three components including; (1) a component which represents the amount of thrust required to overcome the constant effect of gravity on the missile (2) a component which represents the distance the missile is vertically off (above or below) its intended flight path, and (3) a component which has to do with the rate of change of the vertical position of the missile. All of the above components can be represented as voltages.

The gravity component is a relatively constant component and is provided by a predetermined biasing signal. The second component is determined by instantaneous values of the voltage between the upper and lower terminals **70** and **74** of the detector **64** and is a measure of the amount of vertical error only in the location of the missile relative to the intended flight path. This signal is fed from the upper and lower terminals **70** and **74** of the detector **64** to a multiplier circuit **78** which multiplies the signal by a range factor R. This is necessary because the range R of the missile has a definite effect both on the magnitude and also to some extent on the position of the light spot on the detector **64.** The output of the multiplier circuit is fed to another amplifier circuit **82** and to a differentiating circuit **84** which generates a component which represents the time rate of change of the vertical component. The differentiated signal is also amplified by amplifier **86,** and the outputs of the amplifiers **82** and **86** are added together in a summing circuit **88** which also receives a constant input representing the gravity correction factor. The output of the summing amplifier **88** is a signal (f) which represents the frequency at which the thrust producing means on the missile should be fired to maintain the missile on course vertically. The three signal components which are added together to produce the vertical correction or firing command are represented symbolically in FIG. **9** by symbol f_o which is the constant firing frequency rate necessary to overcome gravity; $K_z Z$ which is proportional to the instantaneous value of the vertical distance error at each instant of time; and $K_{\dot z}\dot Z$ which is proportional to the instantaneous rate of change of the vertical error. The symbols K_z and $K_{\dot z}$ denotes constant amplification factors referred to as the position and rate gains respectively. Preferred values of the position and rate gains depend on the specific application of the guidance concept and are generally selected to provide stable control system operation with specified guidance accuracy under specified conditions of target motion, manual tracking error and atmospheric winds and visibility. Many variations in providing the firing frequency command are possible, for example, variable gains during flight, firing frequency signal limiting, and filter circuits to reduce effects of noise. The firing frequency or rate f can be expressed by the equation: $f = f_o - K_z Z - K_{\dot z}\dot Z$. The firing frequency command signal (f) at the output of the amplifier **88** is then fed, as a frequency command input, to the circuitry of a variable frequency electronic pulse generator **89.** The output of the pulse generator **89** is represented by symbol (f_c) and includes a sequence of direct firing signals consisting of fixed amplitude, fixed pulsewidth pulses whose frequency of occurrence is controlled by the firing frequency command signal (f).

A second command impulse is also produced in the circuit of FIG. **9** and is sent to the missile on the wire link **46.** The second command is the firing angle command and controls the angle at which the thruster elements are to be facing at the time they are ignited. This command takes into account the roll of the missile. The firing angle command ϕ_f is proportional to the horizontal displacement and rate of displacement of the missile in space relative to its intended flight path as determined by the operator sighting on a target.

The firing angle command ϕ_f is produced by voltage differences in the detector between the detector terminals **72** and **76.** The signals thus produced are fed to a multiplier circuit **90** and are there multiplied by the range signal R from the range signal generator **80** in a manner similar to the multiplier circuit **78.** The output of the multiplier **90** is then fed to an amplifier circuit **92** and also to a differentiating circuit **94.** The amplifier circuit **92** produces an output signal component $K_x X$. The output of the differentiating circuit **94** is the time derivative of the azimuth or horizontal component and this signal is fed to an amplifier circuit **96** which produces an output $K_{\dot x}\dot X$. A summing circuit **98** receives the above two components and adds them together to produce the firing angle command which can be expressed by the equation: $\phi_f = K_x X + K_{\dot x}\dot X$. The firing angle command is sent to the missile controls on one of the strands of the wire link **46.**

The firing command (f) and the firing angle command (ϕ_f) are both continuously available and continuously updated during the flight of a missile and are constantly used to control the means on the missile that produces thrust to maintain the missile on course. They may also be used to change the course of the missile so that the missile can be accurately guided even to a moving target or to overcome atmospheric and other conditions that may effect the flight path.

The means on the missile which are controlled by the above named signal commands include a plurality of side thruster elements or cartridges **100** such as the element shown in FIG. **5.** The thruster elements **100** are mounted adjacent to the surface of the missile and they are preferably arranged in rows extending in a front to rear direction.

The element **100** shown in FIG. **5** is a typical thruster element and includes a housing **102** with a propellant **104** positioned therein. An igniter element **106** is also positioned in the housing **102** adjacent to the propellant **104** and is connected by lead **108** to the missile control circuit shown in FIG. **10.** The propellant is contained in the housing **102** by means of a retainer member **110** and the housing also has a nozzle portion **112** which is closed by a burst disc **114.** Each thruster element **100** is actuated to produce thrust by electrically exciting its igniter **106** which in turn ignites or explodes its propellant. When this happens, the burst disc **114** breaks to allow the gases produced by the explosion to escape through the nozzle **112** to produce the thrust.

In the subject device the nozzles **112** of the thruster elements are shown positioned to direct the escaping gases in a sideward and rearward direction so that they produce forward as well as sideward thrust components for moving the missile. This enables the missile to maintain itself in flight and also to be steered or guided. In an actual missile the thrusters **100** in each row are preferably fired in pairs, one of each pair being located ahead and the other behind the center gravity of the missile. This minimizes any tendency for the missile to be turned in flight due to the torquing action of the thrusters.

The firing command signal (f_c) and the firing angle command (ϕ_f) are transmitted to the missile **10** on different strands of the wire link **46.** The frequency of occurrence of of the pulses of signal (f_c), as already noted, is controlled by the signal (f) and each pulse thereof energizes circuits which causes a pair of side thruster elements **100** to be fired as will be described.

The arrival of a pulse of the signal (f_c) at the missile is detected by a pulse detector **116** in the form of a trigger circuit. The trigger circuit **116** is actuated whenever the voltage at the leading edge of a pulse attains a predetermined minimum threshold value. Thereafter the trigger circuit **116** is reset in readiness to receive the next succeeding pulse when the voltage at the trailing edge of the pulse is less than a preset value. Trigger circuits capable of performing this function such as the well known Schmitt trigger can be used for the circuit **116.** Detection of a firing command pulse by the pulse detector **116** causes a firing command to be stored in a storage device **118** in the form of an enabling signal. This enabling signal is thereafter made available to each of several "and" gates **120.** For illustrative purposes only one "and" gate **120** is shown in FIG. **10** although it is contemplated to have a similar "and" gate for each row of thruster elements. It is necessary in the subject device to provide storage means **118** which are capable of storing the incoming firing commands long enough to allow the missile to roll into a proper orientation required by the firing angle command as will be shown. The stored signal therefore will not be able to actuate their associated thruster elements **100** until the thruster elements are in the desired orientation position which depends upon the the roll rate and the firing angle command. When the proper missile orientation is obtained, however, the stored firing command is removed from the storage means **118** by means of a feed back signal from an ignition detector **124** to indicate that a pair of thruster elements **100** has been ignited. At this time, the storage unit **118** will be reset in preparation to receive and store a subsequent firing command impulse.

The storage device **118** may be in the form of a two state multi-vibrator circuit which is able to produce one of the two output conditions depending upon its state at a particular time. For example, the multi-vibrator circuit may be able to produce an output representing a 1 or a 0 state, and an associated "and" gate is provided to pass a command signal only when the multivibrator is in state 1, for example. This condition of the "and" gate exists only when the state 1 condition exists in both the firing command and the firing angle command channels.

The corresponding input signals from the firing angle channel are in the form of enabling pulses of fixed pulsewidth. These pulses occur each time the associated row of side thruster elements **100** passes through a roll orientation angle corresponding to the instantaneously commanded firing angle ϕ_f. Each row of thruster elements will pass through the commanded firing angle once during every revolution of the missile and there will therefore be an enabling pulse (a state 1 condition) fed to the corresponding and gates **120** connected with the firing circuit in that row. In order for a pair of thruster elements to be fired, however, there must be a simultaneous occurrence of a stored firing command impulse and also an enabling pulse indicating proper orientation. When these conditions occur simultaneously the particular and gate **120** will pass a firing signal to the appropriate firing circuits.

The generation of the enabling pulses to the and gates associated with each of the rows of thruster elements is under control of the horizontal signal produced by the light sensitive device **64** as described above. The firing angle command ϕ_f is preferably in the form of direct current signal the amplitude of which is proportional to the desired roll orientation relative to the local downward vertical which is the angle at which the thrust should be effective to overcome gravity only. The polarity of the firing angle command determines whether the resulting horizontal displacement of the missile due to the side thruster elements will be to the left or to the right. A firing angle command of 0 which indicates that the missile is on course horizontally corresponds therefore to the effective vertical downward firing with no resulting lateral displacement of the missile. In all other conditions, some sideward lateral displacement of the missile will take place. The firing angle command signal (ϕ_f) received by the missile electronics is therefore compared with each of the roll angle signals derived from the outputs of a roll gyro which will be described later, which gyro has an output associated with each individual row of thruster elements. This comparison is achieved by a summing amplifier, one of which is provided for each row of thruster elements. The outputs of the summing amplifiers go through zero when the indicated roll angle signal becomes equal to the commanded roll angle. The output of each summing amplifier is also connected to a null sensing device or detector **132** which may also be a trigger circuit such as a Schmitt trigger, and the trigger circuit in turn generates enabling pulses to the associated and gate **120** whenever it detects a zero output condition from its associated summing amplifier. The simultaneous occurrence of an enabling pulse on the null detector and the presence of a stored firing command in the storage circuit **118** results in the passing of a firing command signal through the associated and gate **120.**

Referring to FIG. **7**, there is shown a roll reference gyro **128** which is mounted on the missile. The gyro **128** is coupled to a roll angle commutator **130** and the combination thereof provides roll angle signals which are associated with each row of thruster elements **100** as aforesaid. The roll reference gyro **128** is stabilized and oriented in a particular direction prior to launching to establish a true angle reference which remains relatively uneffected by the missile roll. The gyro includes a gimbal **134** which is connected to a shaft **136** that carries a commutator wiper member **138.** The wiper **138** has two contacts **140** and **142** which ride on a potentiometer element **144** that is part of the commutator **130,** and relative movement between the contacts **140** and 142 and the potentiometer 144 will effect the output of the potentiometer 144 which in turn supplies signals to the summing amplifier circuit 126. The details of the construction and circuit of the gryo-commutator pick-off are shown in FIGS. 7 and 8. FIG. 8 also shows how the roll angles for the various rows of thruster elements are obtained.

The gyro and pick-off means are mounted in a housing 146 which is fixedly attached to the body of the missile so that the housing 146 cannot move relative to the missile body. Before the missile is launched the rotational element of the gyro is caged so that the spin axis of the gyro is in a downward vertical direction prior to launching. When the launch command signal is produced by actuating the trigger 32 it causes the rotational element in the gyro to spin and subsequently become uncaged from the gyro case of housing 146 prior to forward motion of the missile. The gimbal 134 thereafter permits the spin axis to be maintained inertially fixed during flight except for a small drift. The pick-off elements 140 and 142 maintain a fixed relation to the spin axis and therefore provide a fixed roll reference. The missile roll angles are then detected from the relationships between the essentially fixed pick-offs 140 and 142, and the rotating commutator-potentiometer device associated therewith.

The commutator device is fixed relative to the gyro housing 146 and therefore rotates with the missile and relative to the pick-offs 140 and 142. The commutator device 130 includes a linearly wound torus shaped potentiometer 144 which is attached to the commutator and oriented such that the axis of the torus coincides with the roll axis of the missile. In FIG. 8, four spaced electrical taps are shown positioned around the potentiometer and are identified by letters A, B, C and D. Taps B and D are electrically grounded and are located 180° apart, and taps A and C are located approximately 15° on opposite sides of the grounded tap B. Positive and negative reference voltages are applied to the taps C and A respectively. The taps A, B, C and D might be located differently for a different roll rate or for an opposite missile roll direction.

As the missile rolls during flight, the potentiometer 144 and the fixed tap points attached thereto rotate relative to the essentially fixed pick-up points 140 and 142. The voltage at the pick-off 142 is a measure of the angle ϕ which can be defined as the angle of the zero degree tap relative to the local vertical axis. This voltage is positive when the zero degree tap 142 is to the right of the local vertical looking forward along the missile roll axis in FIG. 8, and negative when the zero degree tap is to the left of the local vertical. As noted above, a zero degree firing angle command and the simultaneous presence of a stored firing command in the storage means 118 will result in a firing signal being supplied to the row of thrusters connected to the pick-off 142 whenever the angle ϕ goes through zero, that is to say, whenever the zero degree path reaches the vertical position of the pick-off 142.

In order that the effective thrust be delivered in the desired vertical direction, the angular location of the zero degree pick-off (tap D) is in advance by a predetermined fixed amount of the angular location of its associated row of thruster elements 100. This angular advance is achieved by appropriate orientation of the tap pattern relative to the gyro case. The magnitude of the advance angle is preset to a predetermined value by the known nominal missile roll rate and the known side thruster ignition delays. Similarly, the voltage from the pick-off 140 represents the angle $\phi + 180°$ and is associated with the row of thruster elements located 180° from the row associated with the pick-off 142. Roll angle signals associated with the additional row of thrusters are obtained by appropriately biasing the voltages from the pick-offs 140 and 142.

In the preferred construction, six rows of thrusters are +and constant bias voltages corresponding to 60° rotation angles are added and subtracted from the firing angle ϕ and from the firing angle ϕ+ 180° to provide the required six row angles separate by 60° intervals. The reason for employing two pick-offs 140 and 142 instead of just one is evident from considerations of the roll angle output ϕ for a typical row of side thruster elements. The time history of ϕ, assuming a constant missile roll rate, can be represented graphically by the saw tooth wave shown in FIG. 11. The interval between the points 1 and 2 on the graph represent the true measure of the roll angle of the missile, and the small interval from 2 to 3 represents the voltage when it is reversed to reset the roll reference during each revolution. During this brief reset time there is no available time measure of the roll angle. Therefore, the provision of the second pick-off 140 located 180° from the first pick-off 142 is included to provide continuous 360° roll information which would not otherwise be obtainable. Furthermore, because of the lack of roll information during the interval from 2 to 3 an inhibit circuit is provided which disables the and gates 120 whenever a negative value of the time derivatives of the angles ϕ or ϕ + 180° or other angles derived therefrom exist.

There are other ways of exciting the thruster elements to accomplish the same or similar results, and it is not intended that the particular means and methods described above are the only way the invention can operate. It can be seen, however, that the command signals which control the firing and the firing angle of the thruster elements 100 are produced in response to the position on a detector such as the detector 64 at which the light spot from the flare 48 impinges. These signals will in turn excite the thruster at a frequency depending on the amount of correction required, and they will also determine the angle they should face when excited taking into account the missile roll rate and the ignition delay thereof.

The actual circuits for energizing the igniters 106 for the various thruster elements 100 is from the circuit 118, through a particular and gate 120, through a firing sequence circuit 122 which determines the order of firing the igniters in each row, to the selected igniters 106 and ignition detector circuit 124, and back to reset the storage circuit 118. Similar circuits are provided for energizing the igniters associated with each row of thrusters.

As already noted, the nozzles 112 of the thruster elements 100 are canted rearwardly as well as sidewardly to provide forward thrust as well as lateral thrust to increase or maintain the speed of the missile and to extend its range. If desired, the nozzles 112 can also be canted at an angle relative to the missile radius to increase or decrease the roll rate as required. It should be apparent that the subject guidance means can also be used to steer the missile during flight to follow a moving target or to overcome environmental or other conditions which may cause it to depart from its intended flight path. When the operator is following a moving target with his crosshairs, the desired line-of-flight or flight path will change and this in turn may effect the horizontal as well as the vertical components read by the detector **64,** and will change the firing and firing angle commands.

Heretofore, projectiles such as missiles and the like have had relatively unchangeable trajectories after launching and to a large extent this has limited their usefulness and accuracy and it has not been possible to correct their flight path after launching. The subject guidance means overcomes this and other shortcomings and limitations of the known devices in the manner disclosed and provides means for controlling and guiding the missile even after it is launched. The ability of the operator to guide and steer the missile in flight also greatly increases the accuracy and utility of the subject device and enables it to be used even in the destruction of movable targets such as tanks, ships, airplanes and other moving vehicles and devices. It is not intended, however, to limit the invention to any particular use or application or even to a particular construction or circuit since it is apparent that numerous changes, variations and modifications are possible. It is also a particular advantage to have the explosive canister which launches the missile attached to the launching tube rather than to the missile because of the substantial reduction in missile weight and complexity which is thereby obtained. Missile weight reduction also means that the forward thrust produced by canting the thruster elements will have greater effect in producing sustained flight thereby increasing the range and accuracy of the missile.

The chopper means included with the flare **48** are an optional feature which are provided to make it possible for the light sensitive means **64** and the associated circuits in the tracker to distinguish between light coming from the missile and other light that may be present such as sun light. It is clearly within the scope of the invention, however, to use many other different kinds of light and light sources including visible and invisible light sources such as ultraviolet and infra-red light sources. Selection of a light source may also take into account whether the device is to be operated in daylight or at night.

The subject tracking and guiding means have other distinct advantages over known remote control guidance means because they provide more information than is usually available or obtainable and they provide more positive means to cope with certain relatively difficult guidance problems including problems relating to missile instability. The subject device is also readily adaptable to being constructed for use as a mobile field weapon because it can be relatively lightweight and portable and can be constructed to produce little or no recoil. It can also be constructed for operation on fixed platforms as well as on weapon carriers, and it can be made in many different sizes and ranges as required. Furthermore, the subject device is ready for firing as soon as a target is sighted in the telescopic sight **34** and no prelaunch operation or procedure is required. The operator instead simply has to maintain the sight on target for the relatively few seconds required to complete the missile flight, and the operator does not have to do anything to the controls themselves, except to operate the trigger mechanism.

In an actual operation, the missile is usually relatively unguided by the subject control means for a brief period immediately following launching to allow time for the missile roll rate to build up, and to allow time for the launcher and tracker to settle after launching due to transients that may occur. This usually takes less than a second. Thereafter, the electronic circuits begin to function to transmit control impulses over the wire link **46** and this continues until impact.

The roll rate of the missile during fight, as already noted, should preferably be high enough to avoid long delays between the firing of adjacent thruster elements **100** even when the firing frequency is high. Roll rate variations in the preferred application are primarily dependent upon the missile velocity and are relatively accurately predictable. Therefore, the assumption of a relatively constant or average roll rate does not usually result in significant performance penalty. For applications in which the roll rate variations are significant, however, actual roll rate measurements can be made available from the gyro and used to compensate for errors that occur.

The thruster elements in each row are preferably arranged to fire sequentially until all of the thrusters in a row have been fired. This is accomplished by having the firing of each thruster activate means which enables a circuit for exciting the next succeeding thruster. After a row of thrusters has been exhausted a firing signal to that row cannot ignite a thruster, therefore, the firing command will remain in storage until an unexhausted row of thrusters are in position to fire. This permits all thrusters to eventially be fired in attaining maximum range flight.

The launcher employed in the subject device is designed so that after each operation, the tracker, the pistol grip and the telescopic sight can be removed as a unit from the launching tube and mounted on another unfired launching tube with a missile therein. The launching tubes themselves are preferably disposable and are discarded after use. By having the telescope, the trigger assembly, and the tracker constructed as a unit, however, considerable saving is obtained and relative orientation of the sighting and tracking means is not lost and does not require field adjustment. Other forms of communication links can also be used in place of the wire link **46** described hereinabove. For example, the link can be replaced by radio, laser, maser and other forms of communication links.

Thus there has been shown and described a novel guidance system which fulfills all of the objects and advantages sought therefor. Many changes, modifications, variations and other adaptations and uses of the subject device, however, will become apparent to those skilled in the art after considering this specification and the accompanying drawings. All such changes, modifications, alterations, other uses and applications thereof which do not depart from the spirit and scope of the invention are deemed to be covered by the invention which is limited only by the claims which follow.

What is claimed is:

1. Means for guiding an object along a line-of-sight path from a launching site to a target comprising an object having an aerodynamically stable shape with a front to rear axis oriented during flight to extend substantially on the line-of-sight between the launching site and the target, means at the launching site for launching the object on a course toward the target, means for causing the object to roll about its axis at a predetermined roll rate, a light source mounted on the object in position to project light rearwardly therefrom, means at the launching site for aiming and sighting on the target, other means at the launching site oriented with the aiming and sighting means for tracking the object during flight, said tracking means including light sensitive means and means for focusing light from the light source on the object into a spot on the light sensitive means, the position of said spot on the light sensitive means corresponding to the position of the object relative to the line-of-sight between launching means and the target as determined by the aiming and sighting means, means responsive to the vertical position and to changes in the vertical position of the light spot on the light sensitive means for producing first control signals, means responsive to the horizontal position of the light spot and to changes thereof for producing second control signals, means for sending commands corresponding to said first and second signals to the object, a plurality of one-shot thrust producing elements mounted at spaced locations about the surface of the object, means for sequentially exciting groups of said thrust producing elements to laterally displace the object in space, the combined thrust produced by each group of excited elements acting substantially through the center of gravity of the object, and means on the object responsive to said commands to control the frequency of excitation of succeeding groups of thruster elements and the angular orientation of the thrust produced by each group.

2. The means for guiding an object to a target defined in claim 1 including means for converting said first control signals into firing frequency commands which control the frequency at which the thrust producing elements are excited.

3. The means for guiding an object to a target defined in claim 1 including means for converting the second control signals into firing angle commands which control the direction in which the thrust producing elements are facing when excited.

4. The means for guiding an object to a target defined in claim 1 including means for producing third control signals based on a predetermined thruster excitation frequency sufficient to overcome the effects of gravity and air friction on the object, and means for combining said third control signals with the firing frequency commands.

5. In a line-of-sight guided missile system including a missile and a launching station, said launching station comprising means for aiming and firing the missile in a predetermined direction toward a target, means at the launching station for aiming and sighting on the target, said aiming and sighting means being movable to follow the target, means oriented with the aiming and sighting means for tracking the missile during flight to maintain the missile on the line-of-sight course as determined by the aiming and sighting means, said tracking means including a light source located on the missile in position to project light rearwardly therefrom, and means at the launching station responsive to said light including a light sensitive element, and means positioned to receive and focus said light into a spot on the light sensitive element, the location of the light spot on the light sensitive element corresponding to the location of the missile relative to the line-of-sight, means responsive to the vertical position of the light spot and to changes therein for producing first control signals, other means responsive to the horizontal position of the light spot and to changes in the position thereof for producing second control signals, means for converting said first and second signals into corresponding guidance commands, said missile including means for establishing a predetermined in flight roll rate, a plurality of thrust producing elements mounted at spaced locations about the surface of the missile, and means responsive to said guidance commands for energizing said thrust producing elements in a predetermined sequence at a frequency which is responsive to the vertical location of the light spot on the light sensitive element and at a firing angle responsive to the horizontal location of the light spot on the light sensitive element to laterally displace the missile in space in a direction to move the missile toward the desired line-of-sight course.

6. A missile guidance system comprising a missile of aerodynamically stable shape having a plurality of thrust producing elements mounted at spaced locations therearound adjacent to the surface thereof, each of said elements including a charge and means when the charge is detonated for producing thrust in a predetermined direction, means for sequentially exciting predetermined ones of said elements whereby the combined thrust force produced thereby acts through the center of gravity of the missile to laterally displace the missile in space without turning the missile, means for rotating the missile during flight, light radiating means located on the missile, and a launching station including means for launching and tracking the missile, said launching means including means for aiming and sighting on a target, means for launching a missile along an initial course toward the target, other means at the launching sight oriented with the aiming and sighting means for tracking the missile, said tracking means including a light sensitive element positioned to receive light radiated by the light radiating means on the missile, means for focusing said light into a spot on the sensitive element, the position of said spot on the sensitive element corresponding with the position of the missile relative to the desired flight path as determined by the aiming and sighting means, means responsive to the position of said spot on the sensitive means for producing first command signals corresponding to the vertical positions of the missile relative to the line-of-sight path and second command signals corresponding to the horizontal positions of the missile relative to the line-of-sight path, said means on the missile for sequentially energizing the thrust producing elements at a frequency under control of the first command signals and at a firing angle under control of the second command signals to laterally displace the missile in space in the direction of the desired flight path.

7. Missile guidance means comprising a missile having a body of aerodynamically stable shape, means for launching the missile along a predetermined line-of-sight path, said means including a launching tube containing a propellant which when ignited propels the missile therefrom in the direction the tube is facing, means at the launch site for aiming and sighting on a target, means on the missile for establishing a predetermined in flight missile roll rate, means on the missile for projecting light rearwardly therefrom toward the launch site, a plurality of rows of thruster elements positioned at spaced locations about the missile body, each of said elements including a charge capable when excited of producing outward thrust, means for controlling the excitation of said thruster elements including means for sequentially exciting predetermined ones of said elements whereby the combined thrust produced acts effectively through the center of gravity of the missile to laterally displace it in space, means at the launching site for tracking the missile during flight, said tracking means including a light sensitive element, and means for focusing light received from the missile into a spot on the light sensitive means, means connected to the light sensitive means for producing first and second signals corresponding respectively to the vertical and horizontal positions of the light spot relative to preselected spot thereon which corresponds to the location of the desired line-of-sight flight path, and means including a roll gyro and associated commutator means on the missile for energizing the thruster elements under control of said first and second signals.

8. The guidance means defined in claim **7** wherein said first signals control the firing frequency of the thruster elements and said second signals control the angular orientation of the thruster elements at the time they are fired.

9. In combination a missile and missile launching means comprising a missile having an aerodynamically stable body including means thereon for rotating said body at a predetermined roll rate, thrust producing means on the body capable when fired of producing thrust to laterally displace the missile in space relative to its forward movement, said last named means including a plurality of thruster elements arranged in substantially parallel circumferentially spaced rows about the surface of the missile, control means in the missile having a connection to each of said thruster elements, other means connected to the control means for controlling the frequency and angular orientation of the thruster elements at the time they are fired, said last named means including tracking means comprising a light source located on the missile in position to project light rearwardly therefrom, and a light sensitive element located at the launching means including means for focusing light received from said light source in a spot thereon, means associated with the light sensitive means for producing first control signals responsive to the vertical position of the light spot on the light sensitive means, other means for producing second control signals responsive to the horizontal position of the light spot on the light sensitive means, and means connecting the tracking means with the thruster element, control means including a spool mounted on the missile and a wire link wound on the spool and having one end connected to the launching means.

10. In the combination set forth in claim **9** means for determining the time rate of change of the vertical and horizontal positions of the light spot on the light sensitive elements, and means for combining said time rate changes respectively with the first and second control signals.

11. In the combination set forth in claim **9** means for producing a control signal component to compensate for the effects of gravity of the missile.

12. In the combination set forth in claim **9** each of said thruster elements is oriented on the missile to produce lateral and forward thrust components when fired.

13. In the combination set forth in claim **9** means for modifying the second control signals to compensate for the roll rate of the missile.

14. Means for guiding a missile along a line-of-sight flight path comprising a missile having an aerodynamically stable shape, means for launching the missile along a predetermined line-of-sight flight path, means for establishing a predetermined in flight missile roll rate, means associated with the launching means for sighting on a target, and means oriented with the sighting means for tracking the missile, said tracking means includng a light source on the missile and means at the launching site responsive to the light from said source, said light responsive means including a light sensitive element and means for focusing the light received from the source into a spot on said light sensitive element, means responsive to the position of the light spot on the light sensitive means relative to a predetermined position corresponding to the line-of-sight flight path established by the sighting means, said means including means for producing first control signals responsive to the vertical displacement and rate of change thereof of the missile relative to the line-of-sight flight path and second control signals responsive to the horizontal displacement and rate of change thereof of the missile relative to the line-of-sight flight path, means for transmitting said first and second control signals to the missile, and means on the missile for converting said first and second signals into commands for guidance purposes, said converting means including roll gyro means having a predetermined axial orientation and commutator means movable relative to the axis of the roll gyro means.

15. Means for guiding a missile along a line-of-sight path from a launching station to a target comprising a missile having a body of aerodynamically stable shape, means at the launching station for launching the missile along a predetermined line-of-sight path, means for establishing a predetermined in flight missile roll rate, said missile includng a plurality of thruster elements positioned at spaced locations on the missile body, each of said elements including a charge of a material capable when excited of producing thrust and each of said elements having means for directing the thrust produced thereby laterally outwardly from the missile body, a light source located at the rear of the missile, means at the launching site for sighting on a target, other means oriented with the sighting means for responding to the light from the light source on the missile, said last named means including a light sensitive element and means for focusing light received from the light source into a spot on said light sensitive element, means for producing electrical signals corresponding to the vertical and horizontal positions of the light spot on the light sensitive element relative to a predetermined position thereon corresponding to the line-of-sight established by the sighting means, means for transmitting said signals to the missile, and means for converting said signals into firing frequency commands based on the vertical position and changes thereof in the position of the light spot relative to the predetermined position on the light sensitive element and firing angle commands based on the horizontal position and changes thereof in the position of the light spot relative to the predetermined position, said commands controlling respectively the firing frequency and firing direction of the thruster elements.

16. The means for guiding an object from a launching site along a line-of-sight flight path to a target defined in claim **15** wherein means are provided on the missile for storing portions of the command impulses until they are needed.

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