HOMING SYSTEM FOR GUIDED MISSILES

Filed Dec. 6, 1961

2 Sheets-Sheet 1

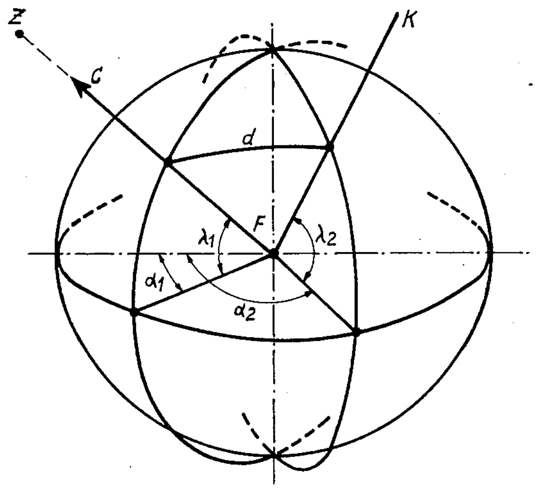

Fig. 1

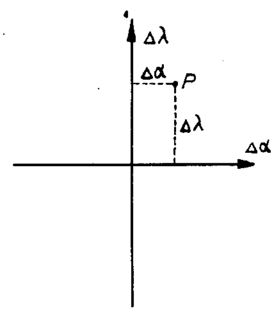

Fig.2

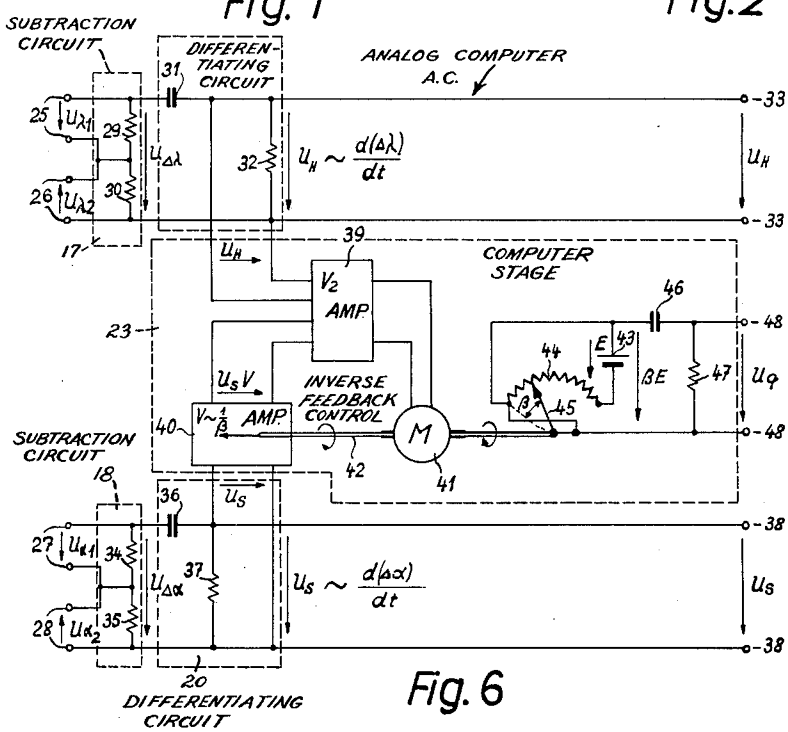

Fig. 6

Nov. 23, 1965 A. WELTI 3,219,294

HOMING SYSTEM FOR GUIDED MISSILES

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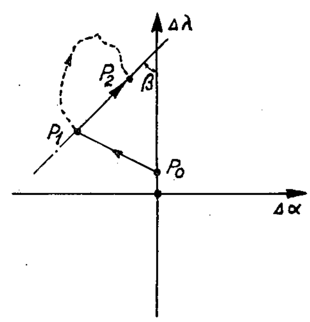

Fig. 3

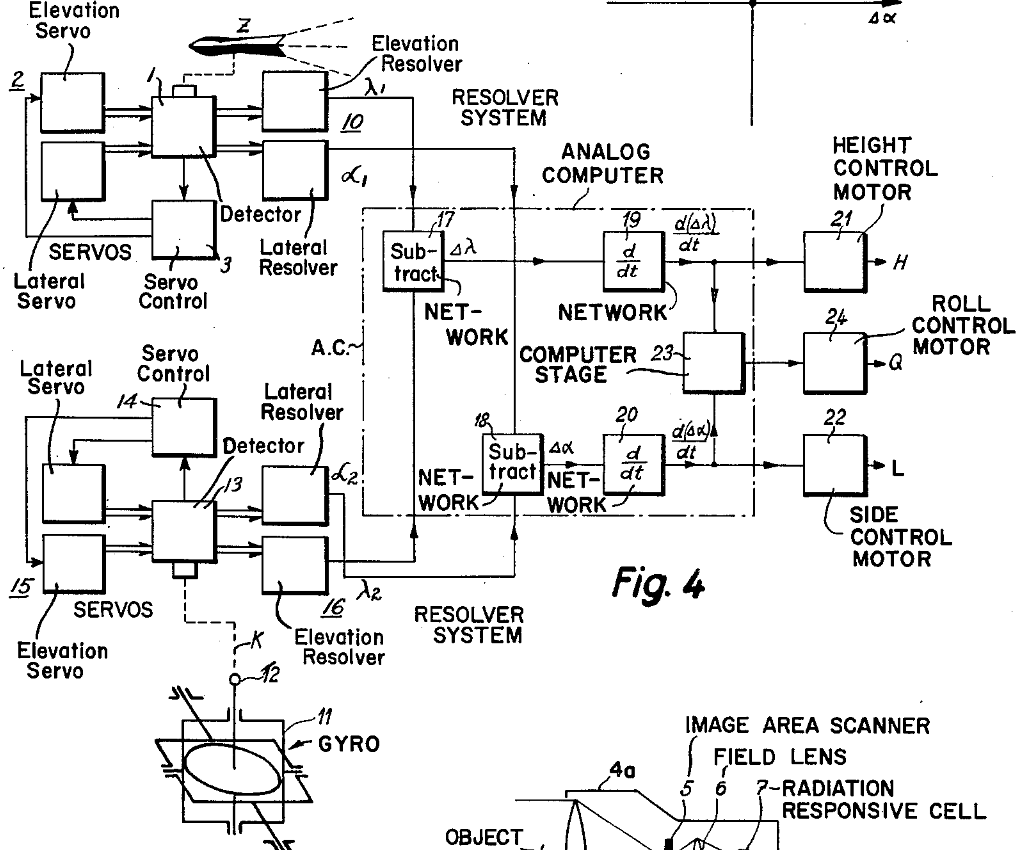

Fig. 4

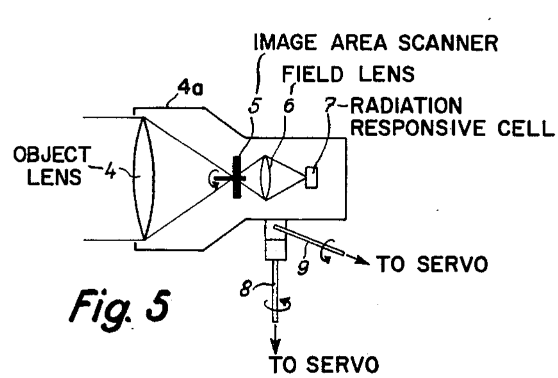

Fig. 5

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HOMING SYSTEM FOR GUIDED MISSILES

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4 Claims. (Cl. 244—14)

My invention relates to a method and system for homing guidance of missiles, according to which a missile, herein understood to denote any object travelling through space and provided with suitable directional control means such as control surfaces or control jets, guides itself toward a target, which may likewise be travelling in space, to bring about a collision or near-collision of missile and target. In a more particular aspect, my invention relates to a homing method and system of the passive type in which energy from the target itself, for example heat radiation, is sensed by suitable detectors, for example infrared sensors, in the missile, for thereby tracking the target and determining and correcting any departures from the collision course. The control signals for actuating the controls, for example a rudder, to produce the required course correction, are determined by means of computers.

Such determination of the control signals in the known homing systems is predicated upon the collision criterion that the geometric angle between the line of sight C from the missile F to the target Z on the one hand, and a spacially fixed reference axis K on the other hand must remain invariable in time. Referring to a missile-fixed polar coordinate system according to FIG. 1 of the accompanying drawings, this angle defines the so-called spherical distance d whose relation to the angular coordinates of the line of sight C and the stable axis K– – –, namely the lateral angle α_1 and the elevation λ_1 of C, and the lateral angle α_2 and elevation λ_2 of K– – –, is expressed by the equation:

$$\cos d = \sin \lambda_1 \sin \lambda_2 + \cos \lambda_1 \cos \lambda_2 \cos (\alpha_2 - \alpha_1)$$

The equipment for computing collision-course errors on the basis of this equation is intricate and space-demanding, this being a considerable disadvantage of the known homing-guidance systems. Furthermore, exacting accuracy requirements are to be met by the angle measurements, which likewise requires complicated and expensive apparatus.

It is an object of my invention to minimize or obviate these disadvantages.

My invention is based upon the following considerations:

A missile moving in space and a likewise moving target will collide under all circumstances if the target image remains at standstill on the viewing or picture area of the detector in the missile, it being only presumed that the collision has not yet occurred and that target and missile do not travel parallel to each other. The immobility of the target image is tantamount to the fact that initially the line of sight from missile to target retains its direction in space constant during the interval of time under observation. Consequently, if the missile is controlled so that the directional invariance of the line of sight is preserved at any moment, the impact condition is also satisfied at any moment.

Such directional invariance of the line of sight can be controlled after measuring its direction with the aid of target tracking, and referring it to the direction of a spacially fixed axis relative to a polar coordinate system fixed with respect to the missile. The impact condition is met, according to the basic concept of the invention, if the difference of corresponding angular coordinates of these two directions is kept constant in time. It should be understood that this is not identical with determining the above-mentioned spherical distance d between the line of sight and the stable reference axis; the above-mentioned directions are rather defined by their angular coordinates in the sense of lateral and elevational angles in the polar coordinate system of the missile, and it is only significant that the difference of the lateral angles and the difference of the height angles remain constant.

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The impact condition, thus formulated, can be graphically represented in the so-called "phase space," a diagram which represents the condition of two magnitudes in mutual correlation. According to FIG. 2 of the drawing, the angle differences $\Delta\alpha$ and $\Delta\lambda$ at an image point P are correlated as the two Cartesian coordinates of that point. The impact condition is satisfied if the image point P remains at standstill in the phase space.

Disturbances due to extraneous influences may cause the missile to depart from its collision course. In the phase such departure manifests itself in that the image point P commences to wander. However, as soon as the image point, under the action of the control performance in the missile, again comes to standstill, the impact condition is again satisfied. Although during the transition interval the direction of the line of sight in space has changed, this merely delays, but does not prevent, the collision. Consequently, the impact condition does not constitute a rigid geometrical requirement but has a temporary character. Each departure from the collision course, due to disturbance, causes a control action in the missile with the effect of slowing the image-point motion in the phase space down to standstill, and then initiates a new collision course of the missile. In other words, the collision course is reset upon each such disturbance. This flight-control principle differs fundamentally from that involved in the known systems in which the control system takes care that the collision course initially followed by the missile is retained up to impact with the target.

The impact condition upon which the control method of the invention is based, namely

$$\alpha_2 - \alpha_1 = \Delta\alpha = \text{constant}$$
$$\lambda_2 - \lambda_1 = \Delta\lambda = \text{constant}$$

does not quite fully satisfy the above-mentioned condition according to which the spherical distance d between the line of sight and the stable axis is to remain constant. Applicable is the equation:

$$\cos d = \frac{1}{2} \cos \Delta\lambda [1 + \cos \Delta\alpha] - \frac{1}{2} \cos (2\lambda_2 + \Delta\lambda)[1 - \cos \Delta\alpha]$$

Accordingly, the spherical distance d would be constant only as long as, aside from the angle difference $\Delta\alpha$ and $\Delta\lambda$, the angle λ_2 also remained constant.

Although the prerequisites $\Delta\alpha$=constant and $\Delta\lambda$=constant are sufficient as impact condition, a limitation in the freedom of motion of the missile is necessary. One reason for such limitation is the fact that the determination of the direction C and K (line of sight, and spacially fixed axis' respectively) are also subject to limitation, for example, due to the constructionally limited turning range of a radiation sensing head, or the frame or gimbal stops of a gyro system. Furthermore, the missile is supposed to take the course of most favorable impact probability. This requires roll-motion stabilization of the missile. In addition, the missile is to be so controlled as to minimize the duration of the transition interval during which the missile passes from one to another collision course upon occurrence of course disturbance. This means, relative to the phase space, that the return of the image point to a standstill position again satisfying the impact condition should always occur on a straight path.

A stability condition satisfying those requirements can be derived from the phase space shown in FIG. 3. Assume that the image point has migrated from the initial standstill point P_0 to a point P_1 due to lateral deflection of the missile. The directional regulator is now called upon to actuate the control surfaces or other control means in such a manner that the error from P_0 to P_1, after termination of a transitional interval, is corrected by placing the target image onto a new standstill point P_2. It must be taken into consideration that the components $\Delta\alpha$ and $\Delta\lambda$ of the direction regulator for a skewed position of the instantaneous missile course to the target course, are dependent upon each other, this being the reason why there is the danger of the so-called overlapping of coordinates in the regulating and control system which may lead to undesired hunting motion with respect to elevational and lateral positions of the missile. Under such conditions, a satisfactory control of the missile would be infeasible. Instabilities of this kind, as are inevitably expectable with a motion of the image point in the phase space on a curved path such as the one indicated by a broken line in FIG. 3, can be avoided by a return on a straight path. The condition for such straight return is that the directional angle β in the phase space must remain constant. Consequently, the following condition applies:

$$\tan\beta=\frac{\frac{d(\Delta\alpha)}{dt}}{\frac{d(\Delta\lambda)}{dt}}=\text{constant}$$

Therefore, a more specific feature of the homing guidance method according to the invention is to control the missile directive means by regulating the time changes of the angular differences

$$\alpha_1-\alpha_2 \text{ and } \lambda_1-\lambda_2$$

and of the ratio

$$\frac{d(\alpha_1-\alpha_2)/dt}{d(\lambda_1-\lambda_2)/dt}$$

both down to the zero value. As explained above, the terms α_1 and λ_1 denote the angular coordinates of the sighting line C from the missile to the target, and α_2 and λ_2 denote the angular coordinates of the stable axis K, these angular coordinates being continuously measured relative to a polar coordinate system fixed with respect to the missile.

The apparatus according to the invention for performing the missile-guiding method explained above, comprises a gyro to provide a stable reference axis and a radiation detector for tracking the target. These two components control respective angle transmitters or resolvers which furnish the instantaneous lateral and elevational angles of the line of sight and of the stable axis respectively with respect to a polar coordinate system fixedly related to the missile. The apparatus further comprises two networks for producing two control signals which form a measure of the time derivation (rate of change) of the difference between the lateral angles on the one hand, and of the time derivation (rate of change) of the difference between the elevational angles on the other hand; and these two signals control respective motors correlated to two coordinate axes of the flight directional control means in the sense of reducing the rate of angular change. The system further comprises a differential amplifier to which one of the above-mentioned two control signals is directly supplied and to which the other control signal is supplied through a regulating amplifier whose gain is regulated in dependence upon the output signal of the differential amplifier in the sense toward reducing this output signal, and the adjusting member for gain regulating simultaneously controls an angle transmitter (resolver system) whose output signal constitutes a measure of the instantaneous amplification factor of the regulating amplifier and, upon differentiation, controls a motor correlated to a third axis of the flight directional control means toward reducing the change of this output signal.

According to another feature of the invention, the above-described homing system is provided with another radiation detector which cooperates with the gyro for tracking a given point of the stable reference axis to thereby control the one appertaining resolver.

The invention will be further explained with reference to an embodiment of missile guidance control apparatus illustrated by way of example in the accompanying drawings in which:

FIGS. 1, 2 and 3 are explanatory diagrams already described above;

FIG. 4 is a block diagram of a missile-borne homing control apparatus, according to the invention;

FIG. 5 shows schematically the basic design of an infrared radiation detector employed in the embodiment according to FIG. 4; and

FIG. 6 is a circuit diagram of electrical equipment forming part of the same apparatus.

The guidance apparatus according to FIG. 4 is provided with a radiation detector **1** for tracking the target Z. The detector **1** is horizontally and vertically rotatable. A set of servomotors **2** is connected with the detector unit for directing the sensing axis onto the target Z. The detector **1** furnishes an error voltage which constitutes a measure for the departure of the optical axis from the line of sight C. This error voltage is impressed upon a servo-control stage **3** where it is converted to control signals for the servos **2** in the sense required for reducing the above-mentioned departure. Servo devices of this type for automatic tracking of a target are known as such. They are described for example in the 1959 Proceedings of the IRE, pages 1577–1581, in an article entitled "Servomechanisms Design Considerations for Infrared Tracking Systems," and in the June 1960 issue of Space/Aeronautics, pages 169 etc., in an article entitled "Firestreak is Guided by Advanced IR Homer." Also such systems are described in United States Patents No. 2,931,912 and No. 2,961,545. However, reference to FIG. 5 will be had for further explaining the operation of the radiation-responsive detector.

According to FIG. 5, the radiation detector comprises an object lens **4**, an image-area scanner **5**, a field lens **6**, and a radiation-responsive cell **7**. The optical and scanning components are accommodated within a housing **4a** mounted on a supporting structure which comprises two shafts **8** and **9** extending perpendicular to each other and permitting the optical axis of the detector to be turned about the respective shaft axes. The shafts **8** and **9** are connected with respective servomotors in the set **2** (FIG. 4). The scanner **5** is a rotating raster disc with a raster pattern so designed that the beam of light impinging upon the photocell **7** is modulated in dependence upon the locality of the target-image point on the image area. Hence the output voltage of the cell **7** is modulated in the same manner. This cell voltage is compared with a reference voltage indicative of the direction of the optical axis of the radiation detector and derived from the turning motion of the radiation detector. As long as the image point of the target coincides with the optical axis, the result of the comparison is zero and no error voltage is produced. When the image point of the target moves away from the optical axis, the voltage comparison results in a finite error voltage which is effective in the servo-control unit **3** to cause actuation of the servomotors in the sense of eliminating the departure of the target image point from the optical axis. More complete details can be had from the above-mentioned references.

Mechanically coupled with the radiation detector **1** is an electric angle transmitter (resolver system) **10** (FIG.

4) which has two output channels. One channel furnishes a voltage proportional to the lateral angle α_1. The other output channel furnishes a voltage proportional to the elevation angle λ_1. The angles α_1, λ_1 represent the coordinates of the line of sight C relative to a missile-fixed polar coordinate system.

The lateral angle α_1 of the missile target sighting line, the lateral angle α_2 of the stable reference axis relative to a missile-fixed polar coordinate system, the elevation angle λ_1 of the missile target sighting line and the elevation angle λ_2 of the stable reference axis relative to the missile-fixed polar coordinate system may be continuously measured in any suitable manner known. There are a number of known methods for continuously measuring the angular displacement of an axis.

The space-fixed axis K is constituted by the main axis of a gyro system **11**. The position of the gyro axis relative to the missile-fixed polar coordinate system can be determined by ascertaining a point of the gyro axis. In the illustrated embodiment, a light source **12** is used for this purpose. The source is mounted at the end of the gyro shaft and acts upon a radiation detector **13**. The detector **13** may be of the same type as the detector **1** used for tracking the target, and is likewise equipped for automatic tracking of the light source **12**. For this purpose, the detector **13** is connected with a servo-control stage **14** and a servomotor set **15** which correspond to the respective devices **3** and **2**. Any directional change of the missile axis manifests itself in a departure of the image point produced by the light source **12**, from the optical axis of the radiation detector **13**. The resulting corrective motion is transmitted to the resolver system **16** mechanically coupled with the radiation detector **13**. The resolver system **16**, operating in the same manner as the resolver system **10**, furnishes two output voltages proportional to the angular coordinates α_2, λ_2 of the stable reference axis in the missile-fixed polar coordinate system.

The described method and means for determining the position of a free gyro axis have the advantage that it requires no force or torque-demanding angle transmitters at the gyro itself. In lieu of a light source, any other electromagnetically detectable reference point (active or passive radiation source or sink) may be provided on the gyro shaft and a correspondingly sensitive cell in the radiation detector.

The portion enclosed in FIG. 4 by a dot-and-dash line and denoted by A.C. constitutes a regulating system interposed between the above-described two groups of self-tracking sensing components and the flight-direction control motors proper of the missile. In the present embodiment, the intermediate system A.C. is essentially an analog computer which determines from the measured input magnitudes α_1, α_2, λ_1 and λ_2, the control magnitudes required for flight control. The computer portion A.C. is equipped with two networks **17** and **18** for forming the angle difference $\Delta\lambda=\lambda_1-\lambda_2$ and $\Delta\alpha=\alpha_1-\alpha_2$ respectively. The computer further comprises two networks **19** and **20** for forming the differential quotients $d(\Delta\lambda)/dt$ and $d(\Delta\alpha)/dt$. The control magnitudes supplied from the networks **19** and **20** are supplied to respective control motors **21** and **22** for actuating the elevational control (H) and lateral control (L) of the missile. These two control magnitudes also pass into a computer stage **23** in which a control signal is generated proportional to the time change in the ratio of the mentioned two control magnitudes, and the latter control signal is applied to a control motor **24** for actuating the roll control (Q) of the missile.

FIG. 6 illustrates the circuit diagram of the regulating computer portion A.C. according to FIG. 4. The voltages $U\lambda_1$, $U\lambda_2$ $U\alpha_1$ and $U\alpha_2$ supplied from the resolvers **10** and **16** (FIG. 4) and impressed upon respective pairs of input terminals **25, 26, 27** and **28**, are indicative of the continuously measured angular coordinates λ_1, λ_2, α_1 and α_2 respectively. The voltages, for example, may be linearly proportional to these coordinates. Connected across the pairs of terminals are respective resistors **29, 30, 34** and **35**. The voltages $U\lambda_1$ and $U\lambda_2$, impressed across respective resistors **29** and **30** are series-opposed to each other so that the difference voltage $U\Delta\lambda=U\lambda_1-U\lambda_2$ is obtained across the series connection of the two resistors **29** and **30**. Connected to the series connection is a differentiating member consisting of a longitudinal capacitor **31** and a transverse resistor **32**. Across the resistor **32** there appears a voltage U_H proportional to the differential quotient $d(\Delta\lambda)/dt$. The voltage U_H is impressed upon output terminals **33** where it is available as control magnitude for elevational control. That is, this voltage U_H serves to control the operation of motor **21** (FIG. 4) in the event a change in elevational angle is necessary for returning the missile to a collision course.

Analogously, the resistors **34** and **35** connected across respective terminal pairs **27** and **28** are impressed by the voltages $U\alpha_1$ and $U\alpha_2$ in mutally series-opposed relation so that the series connection of the two resistors **34** and **35** furnishes the difference voltage $U\Delta\alpha=U\alpha_1-U\alpha_2$. A differentiating member is connected to the series connection and consists of a longitudinal capacitance member **36** and a transverse resistance member **37**. The voltage U_S appearing across the resistance member **37** is proportional to the differential quotient $d(\Delta\alpha)/dt$. This voltage is impressed across terminals **38** for lateral control of the motor **22** (FIG. 4).

The regulating portion A.C. of the system further comprises a differential amplifier **39** which receives the control voltage U_H directly, and which is supplied with the control voltage U_S through a variable regulating amplifier **40**. Thus, the output of the regulating amplifier **40**, and one input to the amplifier **39**, is equal to the input voltage U_S to the amplifier **40** times its amplification V; or the product U_SV. Connected to the output leads of the differential amplifier **39** is an actuator or motor **41** having a shaft **42**. The angle of rotation of the shaft **42** is designated β. The shaft **42** is coupled with a control member for varying the gain in the regulating amplifier **40** so that the amplification V of the regulating amplifier **40** is inversely proportional to the rotational angle β. This accomplishes an inverse feedback from the amplifier **39** through the motor M and the amplifier **40** so as to reduce the output voltage at the differential amplifier **39**. This equalizes the input voltages to the amplifier. Thus

$$U_SV=U_H$$

But as stated, the amplification V is controlled to be inversely proportional to β so that

$$V\sim\frac{1}{\beta}$$

Substituting for V in the equation $U_SV=U_H$ we obtain

$$U_S\frac{1}{\beta}\sim U_H$$

and

$$\beta\sim\frac{U_S}{U_H}$$

But $U_S=d(\Delta\alpha)dt$ and $U_H=d(\Delta\lambda)/dt$.

Substituting for U_S and U_H in the equation $\beta\sim/U_S/U_H$ we obtain

$$\beta\sim\frac{d(\Delta\alpha)/dt}{d(\Delta\lambda)/dt}$$

Connecting a direct-voltage source **43** furnishing a constant voltage E, is a potentiometer rheostat **44** whose slider **45** is mounted on the shaft **42** so that the slider **45** taps off the voltage βE proportional to the rotation angle β of the shaft **42**. Connected to the slider and the potentiometer is a differentiating member, consisting of a longitudinal capacitor **46** and a transverse resistor

47. This differentiating member forms the time derivation (rate of change) of the voltage βE, whereby the voltage across the output terminals **48** is proportional to the differential quotient:

$$d\frac{\frac{d(\Delta\alpha)/dt}{d(\Delta\lambda)/dt}}{dt}$$

This output voltage is applied to control motor **24** (FIG. 4) and serves as a control magnitude for the roll control of the missile.

The homing method and flight regulating system according to the invention affords a number of advantages. The means for performing the method, involving a zero principle, are relatively simple and require relatively few and rather compact components, in comparison with known homing methods and systems. Furthermore, at sufficient missile velocity, the reliability of impact with the target is considerably increased. This is because the performance of the commands issuing to the directional control means of the missile is not affected by impairment and inaccuracy or aging of the optical, mechanical or electrical components, including the sensors, as well as by any eccentrical motion of the driving means, or the occurrence of angular departures between the longitudinal missile axis and the tangent of the travel course. The trajectory or collision course of the missile is not predetermined. On each disturbance, irrespective of its character, the flight guidance system sets the missile to a new impact course, thus always providing a new definition of the path of light. The high degree of precision required for remote control operation, is not necessary, and the tolerance limits can be kept conveniently wide. All regulating, controlling and computing operations are performed with relative magnitudes only. As a result, the invention affords an adaptation of the missile flight control to the intended purpose to an extent far beyond that heretofore attainable.

I claim:

1. A missile-borne system for homing a guided missile onto a target, comprising directional control means having a lateral control motor for control about a lateral axis of the missile, a vertical control motor for control about a vertical axis of the missile and a longitudinal control motor for control about a longitudinal axis of the missile; gyroscopic reference means having a stable axis relative to space and indicating means for indicating said stable axis; a radiation sensor responsive to radiation from the target directed to receive radiation from said target for detecting departure of the sensor axis from the missile-target sighting line; detecting means directed at the indicating means of said gyroscopic reference means for detecting departure of said stable axis from a missile-fixed reference position; two servomotor means of which one is connected with said sensor for causing it to track the target and the other is connected to said detecting means for causing it to track said stable axis; two angle-transmitting revolving means connected to said respective radiation sensor and detecting means to issue respective pairs of coordinate voltages of which one voltage corresponds to a lateral angle and the other to an elevation angle in a missile-fixed polar coordinate system, one pair of coordinate voltages relating to the missile-target sighting line and the other pair to said stable axis; and a computing system comprising two electric networks connected to said two resolvers and having respective output signal voltages corresponding to the rate of change of the difference between said two lateral angles and to the rate of change of the difference between said two elevation angles, said two signal voltages being connected to said lateral control motor and to said vertical control motor for lateral and vertical control respectively in the sense required for reducing said rates of change respectively, a differential amplifier having two input circuits and an output circuit, one of said input circuits being connected to one of said signal voltages, a variable-gain regulating amplifier connecting said other signal voltage with said other input circuit, gain regulating means connected with said output circuit and in controlling connection with said regulating amplifier for controlling its gain in dependence upon the amplified output voltage of said differential amplifier and in the sense toward reducing said latter voltage, an angle transmitter connected with said gain regulating means to be controlled thereby and having an output signal indicative of the instantaneous amplification gain of said regulating amplifier, and a differential-forming network connected between said angle transmitter and said longitudinal control motor for controlling the said longitudinal control motor in the sense required to reduce said output signal.

2. A missile-homing system, as claimed in claim **1**, wherein said gain regulating means comprises an actuator electrically connected with said differential amplifier output circuit and mechanically connected with said regulating amplifier for varying its gain, said angle transmitter comprising a source of constant direct voltage, a potentiometer connected across said source and having a slide contact, said slide contact being mechanically connected with said actuator to be displaced thereby in accordance with changes in gain of said regulating amplifier, said differential-forming network being electrically connected to said slide contact and said source.

3. A missile-homing system, as claimed in claim **1**, wherein said stable axis is constituted by a shaft of said gyroscopic reference means, said means for detecting departure of said stable axis from a missile-fixed reference position comprising a radiation member on said shaft, and a sensor responsive to said member and connected to said other servomotor means for tracking said member.

4. A missile-borne system for homing a guided missile onto a target, comprising directional control means having a lateral control motor for control about a lateral axis of the missile, a vertical control motor for control about a vertical axis of the missile and a longitudinal control motor for control about a longitudinal axis of the missile; gyroscopic reference means having a stable axis relative to space and indicating means for indicating said stable axis; a radiation sensor responsive to radiation from the target directed to receive radiation from said target for detecting departure of the sensor axis from the missile-target sighting line; detecting means directed at the indicating means of said gyroscopic reference means for detecting departure of said stable axis from a missile-fixed reference position; two servomotor means of which one is connected with said sensor for causing it to track the target and the other is connected to said detecting means for causing it to track said stable axis; two angle-transmitting revolving means connected to said respective radiation sensor and detecting means to issue respective pairs of coordinate voltages of which one voltage corresponds to a lateral angle α_1 and α_2 respectively and the other to an elevation angle λ_1 and λ_2 respectively in a missile-fixed polar coordinate system, one pair of coordinate (α_1, λ_1) voltages relating to the missile-target sighting line and the other pair (α_2, λ_2) to said stable axis; and a computing system comprising two electric networks connected to said two resolvers and having respective output signal voltages corresponding to the rate of change of the difference $\Delta\alpha=\alpha_1-\alpha_2$ between said two lateral angles and to the rate of change of the difference $\Delta\lambda=\lambda_1-\lambda_2$ between said two elevation angles, said two signal voltages being connected to said lateral control motor and to said vertical control motor for lateral and vertical control respectively in the sense required for reducing said rates of change $d(\Delta\alpha)/dt$ and $d(\Delta\lambda)/dt$ respectively, a differential amplifier having two input circuits and an output circuit, one of said

input circuits being connected to one of said signal voltages, a variable-gain regulating amplifier connecting said other signal voltage with said other input circuit, gain regulating means connected with said output circuit and in controlling connection with said regulating amplifier for controlling its gain in dependence upon the amplified output voltage of said differential amplifier and in the sense toward reducing said latter voltage, an angle transmitter connected with said gain regulating means to be controlled thereby and having an output signal proportional to

$$\frac{d(\Delta\alpha)/dt}{d(\Delta\lambda)/dt}$$

indicative of the instantaneous amplification gain of

said regulating amplifier, and a differential-forming network connected between said angle transmitter and said longitudinal control motor for controlling the said longitudinal control motor in the sense required to reduce said output signal.

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