Feb. 14, 1961 H. SURTEES 2,971,437

APPARATUS FOR GUIDED MISSILES

Filed June 3, 1955 2 Sheets-Sheet 1

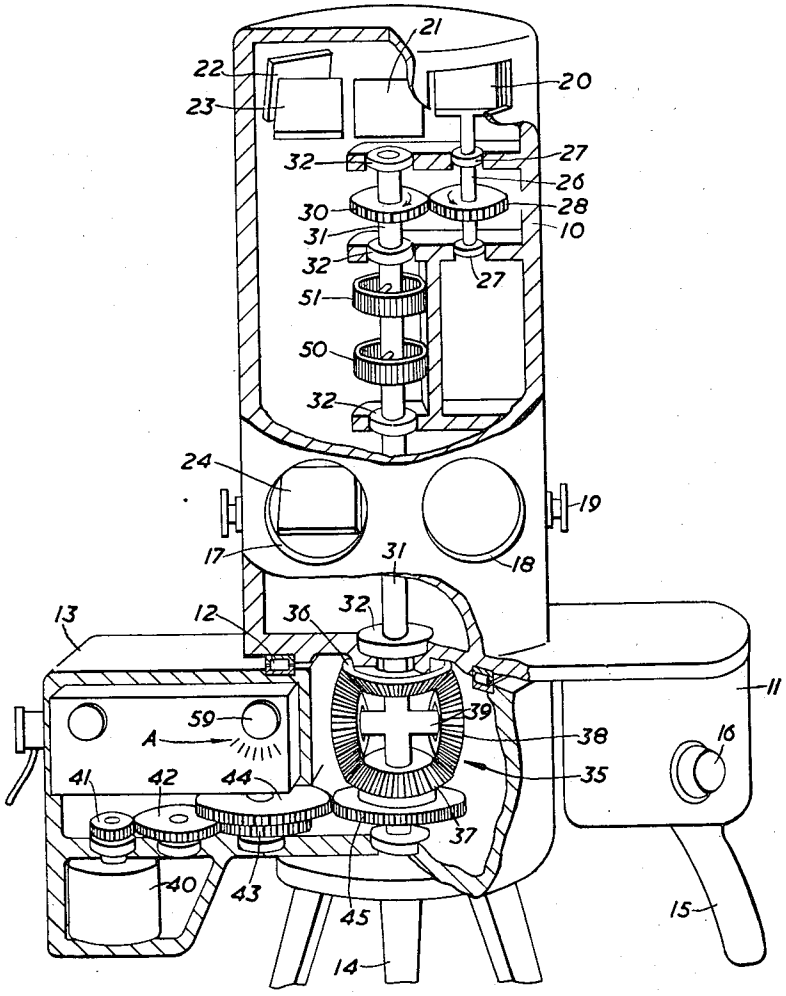


FIG. 1.

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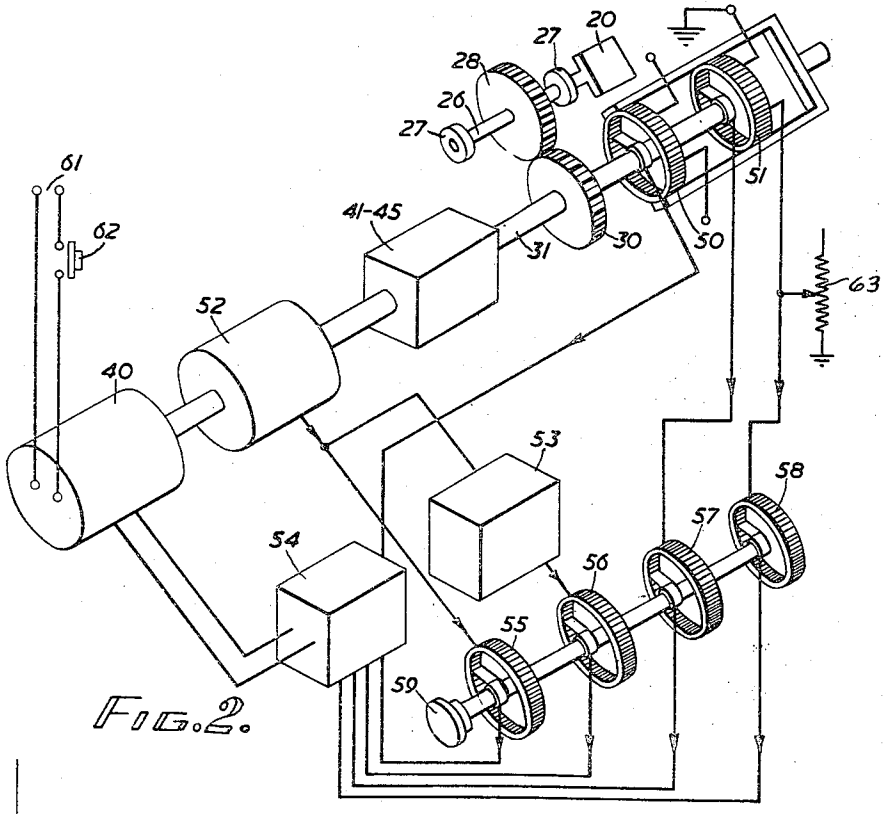


FIG. 2.

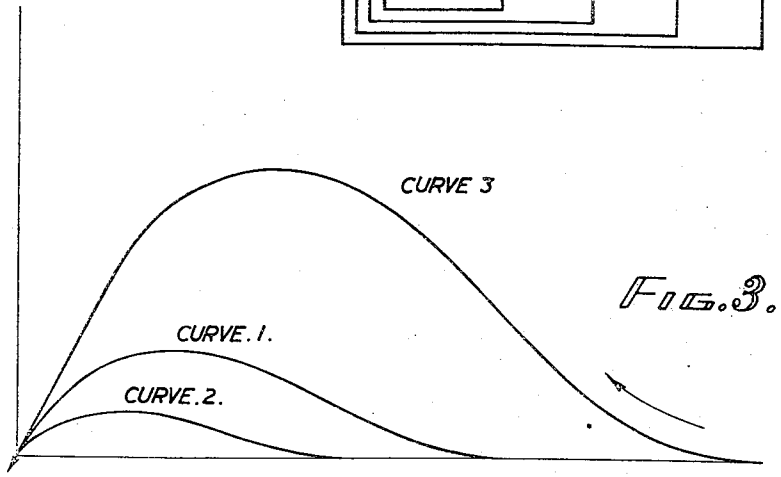


FIG. 3.

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United States Patent Office 2,971,437
Patented Feb. 14, 1961

2,971,437

APPARATUS FOR GUIDED MISSILES

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Filed June 3, 1955, Ser. No. 513,115

8 Claims. (Cl. 89—1.7)

This invention relates to apparatus for directing guided missiles, and in particular to apparatus for directing a guided missile from an aiming point nearer than the launching point to a target.

According to one form of the invention apparatus for directing a guided missile from an aiming point spaced from the launching point includes a device enabling the aimer to observe the position of the approaching missile in relation to a line of sight passing through the aiming point from the target, so that the aimer can control the missile to approach and pass over him along the said line of sight.

Conveniently the device is arranged to bring images of the approaching missile and the target simultaneously into the same apparent field of view. This phase is intended to include bringing one into the field of view of each eye.

The device may for example comprise a pair of binoculars, or other sighting device, through which the aimer observes the target, and a periscopic system of reflectors, for example including a semi reflecting surface, arranged to bring an image of the approaching missile into the field of view of the binocular, so that when it appears in the centre of the field it is in fact approaching the aimer directly along the line of sight. A limitation of this scheme is that if, for example, the line of sight may be inclined at any angle up to say 60° to the right or left of a line joining the launching point to the aiming point (referred to herein for convenience as the axis of approach), then the reflector system must have a true field of view of at least 120°. With the magnification required for the final guiding on to the target this will present difficulties.

Hence in another form of the invention a reflector is made angularly movable relatively to the binocular or other sighting device. Initially it will be directed along the axis of approach towards the launching point, so that when the missile is launched its image will appear in the middle of its field, after which it will be turned progressively to a position in which the approaching missile appears in the middle of the field when it is on the line of sight. To relieve the aimer of the task of effecting such movement, and also to ensure that the rate at which it is made varies in the most appropriate manner, it is preferably effected by automatic timing means.

Thus according to another aspect of the invention apparatus for directing a guided missile from an aiming point spaced from the launching point, includes a device enabling the aimer to observe the position of the approaching missile in relation to a datum line passing through the aiming point, and automatic programme timing means for automatically turning the datum line from the axis of approach round to the line of sight.

Preferably the arrangement is such that the datum line coincides with the line of sight before the missile passes over the aimer.

With such an arrangement the airmer focusses his sighting binocular on a target and signals for a missile to be launched. The moment the missile is launched an image of it will be produced by the reflector system in the centre of the apparent field of view, and the aimer will at once start the automatic timer. This progressively shifts the datum line of the reflector system from the

axis of approach to the line of sight. Thus the aimer has only to operate his control column to control the flight of the missile so that its image remains in the middle of his field of view, in order to bring the approaching missile on to the line of sight. The timing device should bring the datum line to the line of sight, and stop, in good time before the missile reaches the aiming point, after which the aimer has only to keep the image in the centre of his field, in order to ensure that it will pass directly overhead travelling directly towards the target. It then appears in the direct field of view of the binocular and can be followed and guided to the target with its aid.

The formula or programme of the timing device may be chosen to ensure that, for any given value of the inclination between the axis of approach and the line of sight, the missile is brought as rapidly as possible on to the line of sight without involving it in excessive turning accelerations, and indeed leaving a margin to enable the aimer to correct any errors in keeping the missile on the datum line. The programme will also be designed to enable the course of the missile to merge most readily into the sight line without hunting.

The invention may be carried into practice in various ways but one specific embodiment will be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a perspective diagram of one form of periscope for use by the aimer of a missile,

Figure 2 is a schematic circuit diagram of the driving means for the programmed mirror, and

Figure 3 is a diagram showing the form of path taken by the missile and the effect on it of errors in the moment of starting the programme.

As shown in Figure 1 the appartus employed by the aimer of a guided missile comprises a periscope tower **10** rigidly connected to a control box **11** and mounted by means of a thrust bearing **12** to rotate about a vertical axis on a driving assembly **13**, which is rigidly secured to a tripod **14**. The control box **11** has a handgrip **15** for moving the tower, and a control column **16** arranged to control the direction of flight of the missile through radio equipment wholly or partly housed within the control box.

The housing of the periscope has in it two holes **17** and **18** to receive binocular (not shown) held in place by clamps diagrammatically shown at **19**. The right eyepiece of the binocular has a direct view through the tower while the left eyepiece views in the reverse direction through a mirror system comprising mirrors **20**, **21**, **22**, **23**, and **24**. The mirrors **20**, **21**, and **22** lie in vertical planes to reflect the entering rays respectively approximately rearwardly, forwardly and rearwardly, whilst the mirrors **23** and **24** are inclined at 45° to the horizontal to reflect the rays respectively downwardly and rearwardly to the left eyepiece of the binocular. The mirrors **21** and **22** enable the mirrow **20** to be displaced horizontally so as to command a field of view behind the aimer while having a compact instrument.

The mirror **20**, referred to herein as the programmed mirror, is arranged to be automatically turned about a vertical axis in accordance with a desired programme as referred to below. Thus the mirror is carried by a vertical shaft **26** in bearings **27** in the tower, and the shaft **26** is connected through one-to-one ratio gears **28** and **30** to a central potentiometer shaft **31** also carried in bearings **32** in the tower. The potentiometer shaft **31** is driven by means of a differential assembly **35** situated within the driving assembly **13** and comprising an upper bevel **36**, a lower bevel **37** and planet bevels **38** carried by a spider **39** integral with the potentiometer

shaft **31**. The upper bevel **36** is rigidly secured to the tower **10** so as to turn with it, whilst the lower bevel is connected to an electric motor **40**, referred to herein as a programme driving motor, through a train of reduction gearing **41**, **42**, **43**, **44**, **45**.

Accordingly if the motor, and hence the lower bevel, is stationary, turning of the turret through a given angle will move the central potentiometer shaft **31** through half that angle in the same direction in space. The potentiometer shaft therefore lags relatively to the tower by half the angle through which the tower moves. Thus the programmed mirror **20**, due to the one-to-one gears **28**, **30** moves through the same angle in the opposite direction relatively to the tower and hence also lags the tower by half the angle through which the tower is moved.

The driving motor and lower bevel have an initial or zero position in which when the binoculars are on the axis of approach, the programmed mirror will be at right angles to that axis and the launching point will appear through the mirror system in the left hand binocular. Accordingly if the motor remains stationary and the tower is turned to sight a target along some other line of sight, the programmed mirror **20** will be turned back through half the angle relatively to the tower and hence the launching point will remain in the field of the left hand eye-piece.

The electrical equipment is shown schematically in Figure 2. The potentiometer shaft **31** drives a pair of potentiometers **50** and **51**. It will be appreciated that whereas the motor and lower bevel have a zero position corresponding to the beginning of a programme, the potentiometers are brought to a zero position corresponding to the end of the programme, at which time the programmed mirror **20** is brought to its zero position at right angles to the line of sight so that the missile will appear in the field of the left hand eye-piece when it is travelling directly towards the aimer along the line of sight. These potentiometers are arranged in a manner described in detail below, to stop the motor when they reach this position. The initial position of these potentiometers at the beginning of the programme will of course depend upon the inclination between the axis of approach and the line of sight, that is to say the angle through which the tower has been turned in order to train the binocular on the target.

Built into the motor **40** (but shown separately from it in Figure 2) is a tacho-generator **52** giving a signal proportional to the speed of the motor. One output from this generator is fed to a differentiating network **53** giving a signal proportional to the acceleration of the motor.

The driving assembly also includes an amplifier **54** from which the output is fed to the motor, and four potentiometers **55**, **56**, **57**, and **58** from which the outputs are fed to, and added together in, the amplifier. These potentiometers are ganged together and are manually controllable by means of a knob **59** having a range scale **60** to adjust a number of co-efficients of the equation determining the programme, in accordance with the distance between the launcher and the aimer.

A fixed potential is supplied to the potentiometer **50** so that its output is directly proportional to the deviation of the programmed mirror from its final position. This output is also fed to the amplifier. Potentiometer **63** is connected to control column **16**. The voltage proportional to the deflection of the control column **16** with respect to a line normal to the surface of mirror **20**, and hence approximately proportional to the lateral acceleration of the missile is fed from potentiometer **63** to the potentiometer **58** whence an output proportional to control column deflection and a manually adjustable co-efficient is fed to the amplifier. A similar voltage proportional to the deflection of the control column is fed to the potentiometer **51** whence the output is fed to the potentiometer **57**, whence an output proportional to control column deflection, deflection of the programmed mirror, and a manually adjustable co-efficient, is fed to the amplifier. The output from the differentiator is fed to the potentiometer **56** whence an output proportional to acceleration of the driving motor and a manually adjustable co-efficient is fed to the amplifier. An output direct from the tacho-generator is fed to the potentiometer **55** whence an output proportional to the speed of the motor and a manually adjustable co-efficient is fed to the amplifier.

The connection of the motor to an armature supply **61** is controlled by a starting button **62**.

Operation

The apparatus is set up so that with the lower bevel in its starting position and the tower turned so that the binoculars are sighted along the axis of approach, an image of the launching point is reflected into the left hand eye-piece by means of the programmed mirror and other mirrors.

To set the programme in accordance with the distance between the launcher and the aimer, the aimer turns the knob **59** to adjust the potentiometers **55**, **56**, **57** and **58** which, in effect, speed up or slow down the programme in accordance with the time taken by the missle to reach the aimer. This knob is provided with a scale directly calibrated in range. If the distance between the launcher and the aimer is for example 2,000 yards the aimer may set the knob to 1,500 yards in order to allow himself time to observe the missile and bring it into the centre of the programmed mirror before the programme begins.

To engage a target the aimer swings the tower round until the target is visible in the centre of the right hand binocular, and locks the tower in place. As indicated above the programmed mirror turns at half the speed of the tower in space so that the launching point is held in the centre of the field of the left hand eye-piece.

An independent signal is then made to the launching point and a missile is launched. When the missle is at the predetermined range, say 1,500 yards, the aimer presses the programme starting button **62** and starts the motor. According to the range and the angle of the target from the launching axis the motor speed is regulated by the potentiometers **50** and **51**.

Broadly speaking (and subject to the more detailed discussion below) a term proportional to the speed of the motor plus a term proportional to the acceleration of the motor is proportional to the deviation of the programmed mirror from its final position. Hence the speed of the motor is initially zero and the deviation of the mirror a maximum and hence the acceleration of the motor is a maximum. As the motor speed increases its acceleration drops off and a more nearly steady speed is reached which however gradually decreases as the angular deflection of the programmed mirror from its final position gradually approaches zero. When the mirror reaches its final position the potentiometers **50** and **51** feed zero voltage to the amplifier and the motor stops.

During this programme the aimer operates his control column to keep the missile in the centre of the field of view of the left hand eye-piece. As a result when the motor comes to rest the missile is in the field of the left hand eye-piece which is along the line of sight, but in the opposite direction. Accordingly the missile is directly approaching the aimer along the line of sight and will shortly pass directly overhead and then become visible in the right hand eye-piece by means of which it can be controlled to engage the target.

The mathematical basis of the scheme will now be briefly discussed.

Considering first a simplified arrangement omitting the potentiometers **51**, **57** and **58**, a simple equation describing the motion of the mirror may be written

$$A\ddot{\theta}+B\dot{\theta}=C(\alpha-\theta) \qquad \text{Equation 1}$$

where

θ is the mirror angle at any instant
$\dot{\theta}$ is the mirror angular rate at any instant
$\ddot{\theta}$ is the mirror angular acceleration at any instant
α is the final angular position of the mirror.

The co-efficients A, B and C will depend on the forward speed of the missile, and on the range at which the programme started. Hence if the programme is not started at the specific range which the controller has chosen to determine the co-efficients A, B and C, there will be errors in the flight path according to the misestimation of the range at which the programme should be started.

To make the programme less susceptible to misestimations of range the preferred mirror programme is one in which the smoothed deflections of the control column are fed back to modify the programme, in such a manner that it is compensated to a large extent for the errors made in estimating the range.

It is for this purpose that the potentiometers 51, 57 and 58 are included.

This type of programme is described by the following equation:

$$A\ddot{\theta}+B\dot{\theta}=C(\alpha-\theta)+N\{F+E(\alpha-\theta)\} \quad \text{Equation 2}$$

where

N is the smoothed deflection of the control column at any instant, and
A, B, C, F, and E are co-efficients.

Since the smoothed control column deflections will be approximately proportional to the acceleration of the missile, then as the acceleration demanded of the missile is increased the programme is slowed down, thus resulting in a decrease of demanded acceleration.

This type of programme permits large misestimations of the range at which to start the programme, whilst still keeping the resulting flight path within the capabilities of the missile. For this reason it is the preferred programme.

The mirror programme equation:

$$A\ddot{\theta}+B\dot{\theta}=C(\alpha-\theta)+N\{F+E(\alpha-\theta)\}$$

may be transferred into a dimensionless equation

$$A'\ddot{\theta}'+B'\dot{\theta}'+C(\alpha-\theta)+N'\{F'+E'(\alpha-\theta)\}$$

where all the dashed quantities are for a missile of unit forward speed starting its manoeuvre at unit range behind the aimer. The actual quantities for a missile of forward speed U_0 with a programme set up for a range R_0 are given by

$$A'=\frac{U_0^2}{R_0^2}A \qquad B'=\frac{U_0}{R_0}B$$

$$E'=\frac{U_0^2}{R_0}E \qquad F'=\frac{U_0^2}{R_0}F$$

$$\ddot{\theta}=\frac{U_0^2}{R_0}\ddot{\theta}' \qquad \dot{\theta}=\frac{U_0}{R_0}\dot{\theta}'$$

$$N=\frac{U_0^2}{R_0}N' \qquad t=\frac{R_0}{U_0}t'$$

where

$$N'=\left[2\dot{\theta}'+\frac{r'}{\dot{r}'}\dot{\theta}'\right]$$

When this value of N' is substituted into the mirror programme equation we get

$$\ddot{\theta}\left\{A'-\frac{r'}{\dot{r}'}[F'+E'(\alpha-\theta)]\right\}$$
$$=C(\alpha-\theta)-\dot{\theta}'\{B'-2F'-2E'(\alpha-\theta)\}$$

which is the equation of motion of the rear sight line and also of the missile which is on the rear sight line for $U_0=1=R_0$.

Figure 3 shows the flight paths produced by this preferred programme, when the co-efficients are as follows:

$A'=0.15$	$F'=0.5$
$B'=3.3$	$\alpha=1.0$ radian
$C=4.125$	$U_0=1$
$E'=1.0$	$R_0=1$

Curve 1 shows the flight path produced by the programme if the controller has started the programme at the correct range. Curves 2 and 3 show the effect of starting the programme at 0.7 times and 1.5 times the correct range respectively.

What I claim as my invention and desire to secure by Letters Patent is:

1. In an aiming device, the combination comprising an optical system including an eyepiece movably mounted to aim its center line at a target, optical means for presenting a rearward field of view capable of movement with said eyepiece and also movable relative to the forward field through a substantial angle on either side of an aligned position and automatic program means including a servo-system for controlling the rotation of a portion of said optical means to control the rearward field of view, said servo-system including motor means operatively connected to said optical means, amplifier means connected in driving relationship to said motor means and programme means connected to said amplifier means and to said optical means to deliver a plurality of signals to said amplifier means.

2. Apparatus as claimed in claim 1 wherein said optical means includes a reflector controlled through a differential gear so as to maintain its field along the launching axis as it is turned to train the sighting device.

3. Apparatus as claimed in claim 2 in which the reflector is driven by a motor whereof the speed is controlled in accordance with the programme.

4. Apparatus as claimed in claim 3 in which the input to the motor corresponds to a signal proportional to its speed and a signal proportional to its acceleration balanced against a signal proportional to the deviation of the reflector from its final position.

5. Apparatus as claimed in claim 4 in which the programme of movement of the reflector is also controlled in accordance with the movement of a control column controlling the course of the missile in such manner as to slow down the programme as the acceleration of the missile is increased.

6. Apparatus as claimed in claim 5 in which the signals are also balanced against a signal proportional to the control column deflection and a signal proportional both to the control column deflection and the deviation of the reflector from its final position.

7. Apparatus as claimed in claim 1 in which the optical system includes means for retaining the rearward field presenting optical means stationary, so that it can be held centered on the launching point, while the forward field is shifted to aim it at the target.

8. Apparatus as claimed in claim 7 in which the said optical means for retaining the rearward field stationary includes a rotatably mounted reflector in which the rearward field is viewed, and differential gearing arranged to control the orientation of the reflector so as to maintain the rearward field centered on the launching point while the forward field is being shifted.

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