235-411 SR
XR 3,798,420

Kaaz

[11] 3,798,420
[45] Mar. 19, 1974

# [54] METHOD OF CONTROLLING MOTOR-DRIVEN DEVICES ADAPTED TO BE DIRECTED ONTO MOVING TARGETS AND APPARATUS FOR APPLYING THE METHOD

[75] Inventor: **Albert Kaaz,** Duisburg-Grossenbaum, Germany

[73] Assignee: **Rheinmetall GmbH,** Dusseldorf, Germany

[22] Filed: **June 2, 1970**

[21] Appl. No.: **42,769**

[30] **Foreign Application Priority Data**

June 4, 1969 Germany ..... 1928483

[52] **U.S. Cl.** ..... **235/61.5 S,** 235/61.5 E, 318/591
[51] **Int. Cl.** ..... **G06f 15/58,** G06g 7/80
[58] **Field of Search** ... 235/61.5 R, 61.5 E, 61.5 DF, 235/61.5 S; 89/41 R, 41 A, 41 B, 41 D, 41 M; 178/DIG. 21; 318/591

[56] **References Cited**

UNITED STATES PATENTS

| | | | |
|---|---|---|---|
| 3,679,825 | 7/1972 | Kuhn | 178/DIG. 21 |
| 3,575,085 | 4/1971 | McAdam | 89/41 R |
| 3,339,457 | 9/1967 | Pun | 235/61.5 R |
| 3,309,963 | 3/1967 | Salomonsson | 235/61.5 E |
| 3,288,030 | 11/1966 | Lind | 89/41 R |
| 3,277,282 | 10/1966 | Kuhlenkamp | 235/61.5 R |
| 3,064,884 | 11/1962 | Crowther et al. | 235/61.5 E |

*Primary Examiner*—Felix D. Gruber
*Attorney, Agent, or Firm*—Craig & Antonelli

[57] **ABSTRACT**

Method and apparatus for controlling motor-driven devices adapted to be directed onto a moving target, such as weapons, particularly guns, or target acquisition devices, particularly optical sighting device, radar apparatus, sound locators or infrared tracking apparatus, the target being followed by at least one of these devices and the control quantities for the drive of the devices adapted to be directed onto a moving target being calculated by computer means, wherein based on the values of the lateral angle and elevation angle which values are derived continuously from one of the devices adapted to be directed onto a moving target, and on the values of the target velocity and the angle of inclination of the target path with respect to the horizontal plane, on the basis of the geometrical relationships which hold true for a rectilinear uniform movement, the lateral angular velocity and the elevational angular velocity are calculated and fed to the drives of the devices adapted to be directed onto a moving target.

**17 Claims, 11 Drawing Figures**

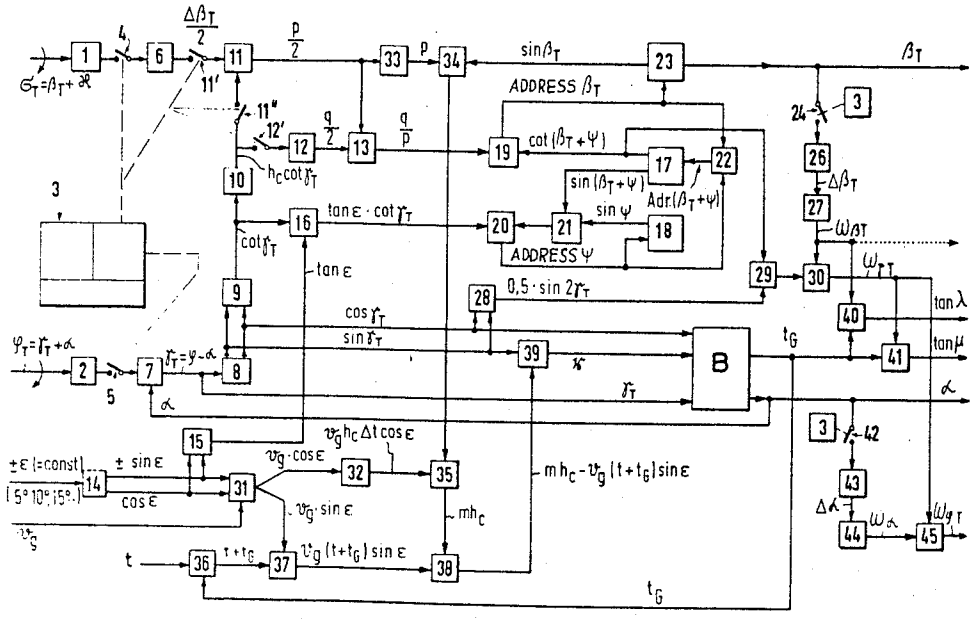


FIG.1

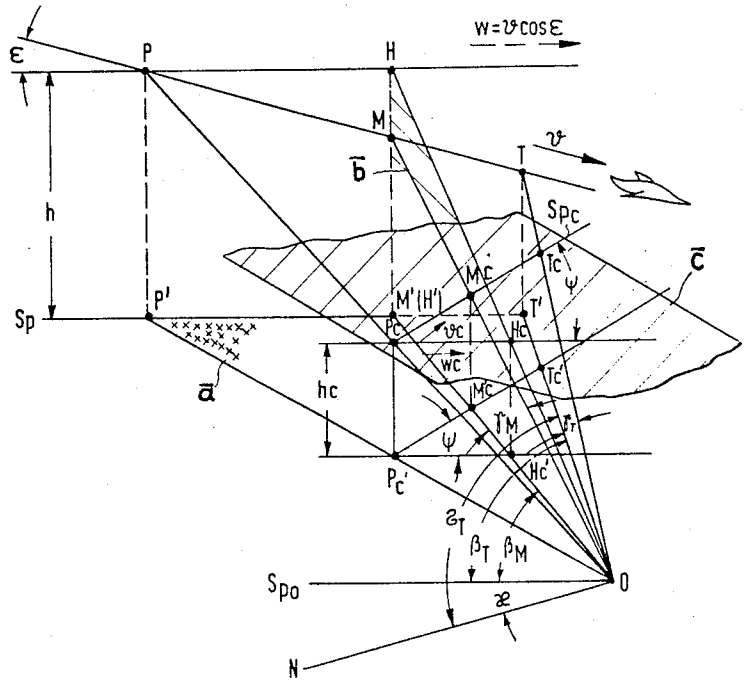
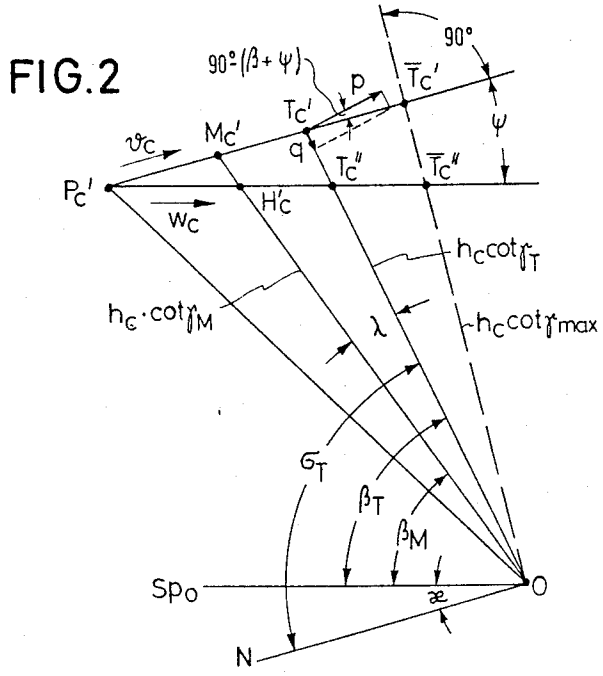



FIG.2




*INVENTOR*

ALBERT KAAZ

*BY*

*Craig, Antonelli, Stewart + Hill*

ATTORNEYS

FIG. 3

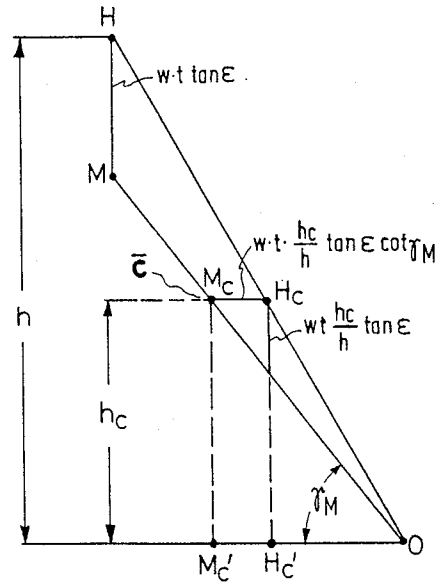
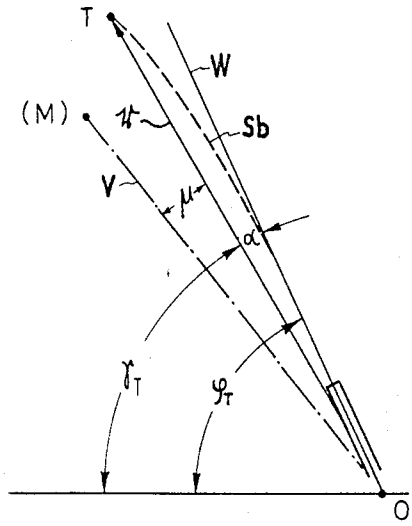



FIG. 3a



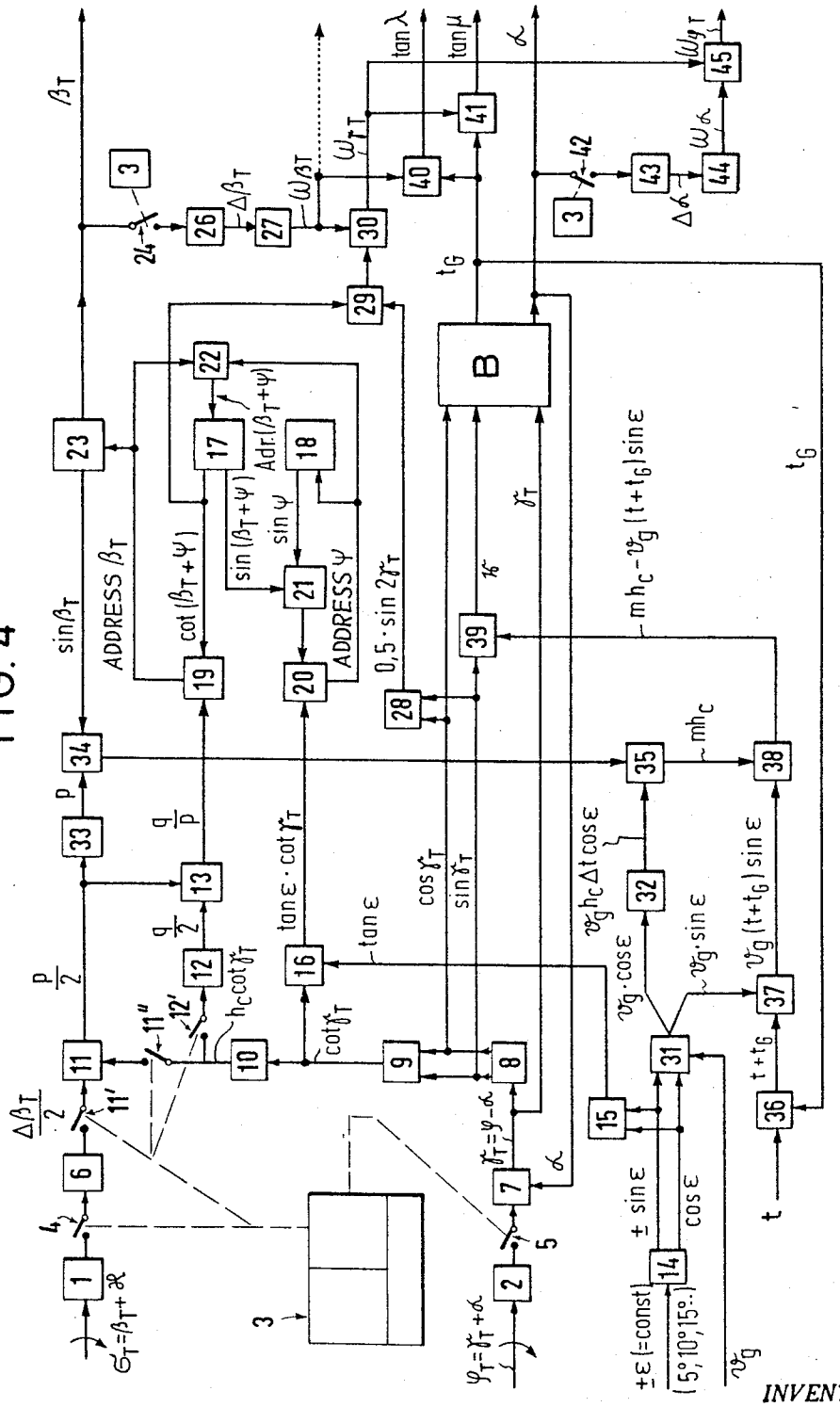

*INVENTOR*

ALBERT KAAZ

*BY* Craig, Antonelli, Stewart & Hill

ATTORNEYS

FIG. 4




*INVENTOR*

ALBERT KAAZ

*BY*

Craig, Antonelli, Stewart & Hill

ATTORNEYS

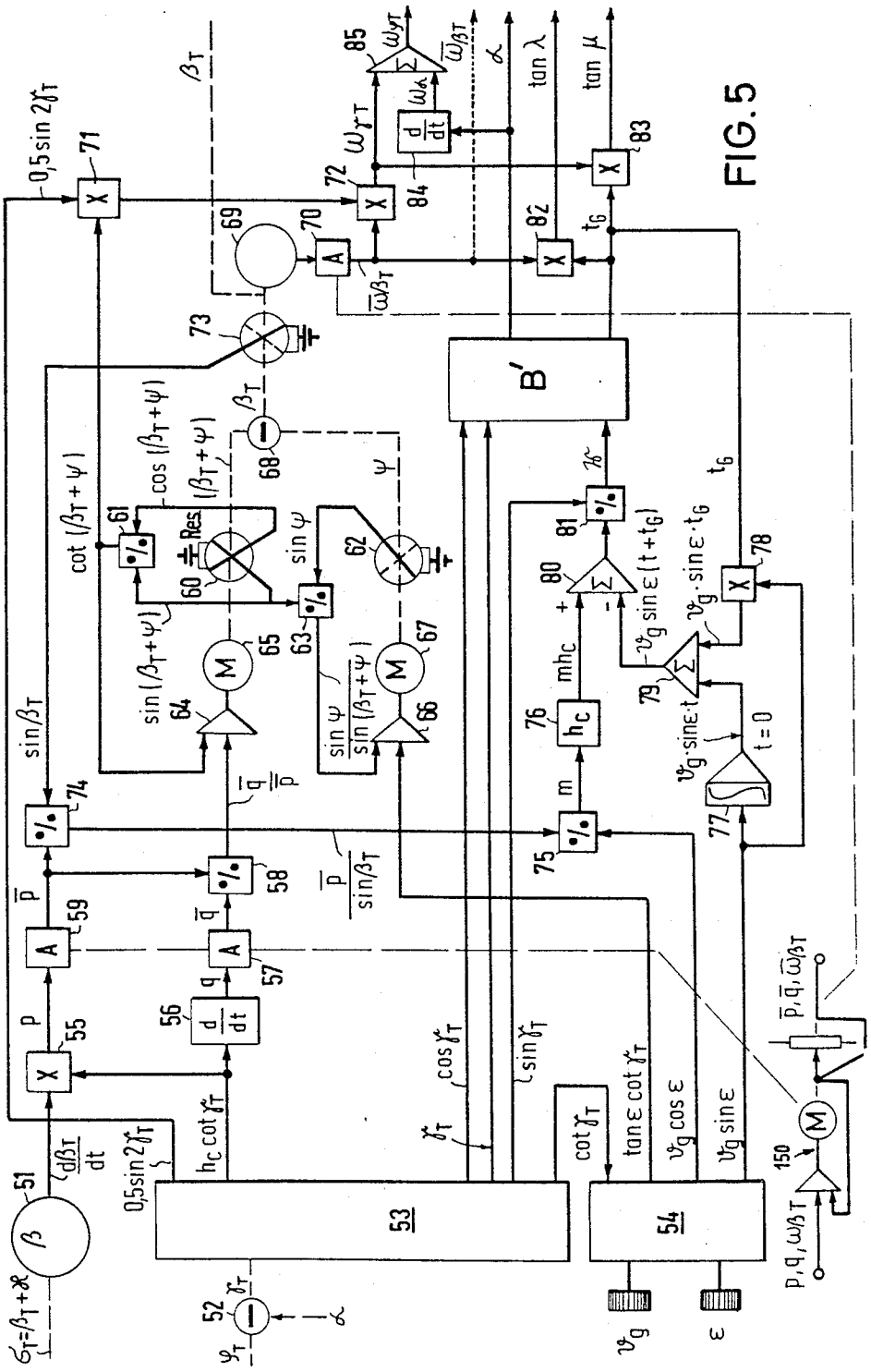


FIG. 5

*INVENTOR*

ALBERT KAAI

*BY*

Craig, Antonelli, Stewart + Hill

ATTORNEYS

FIG.8

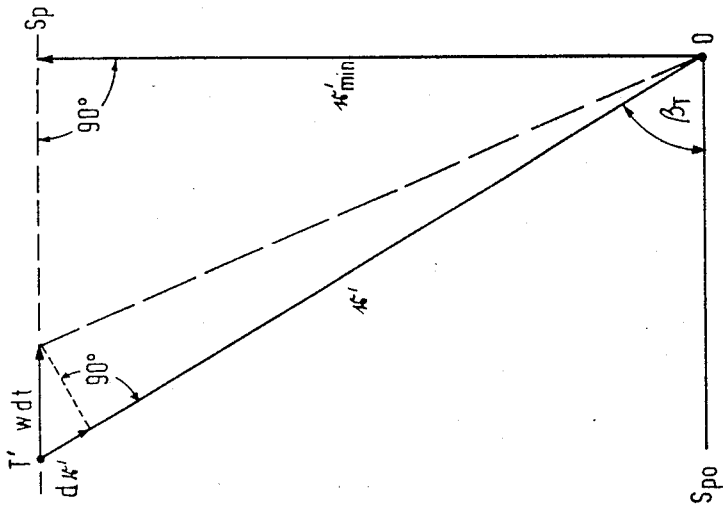
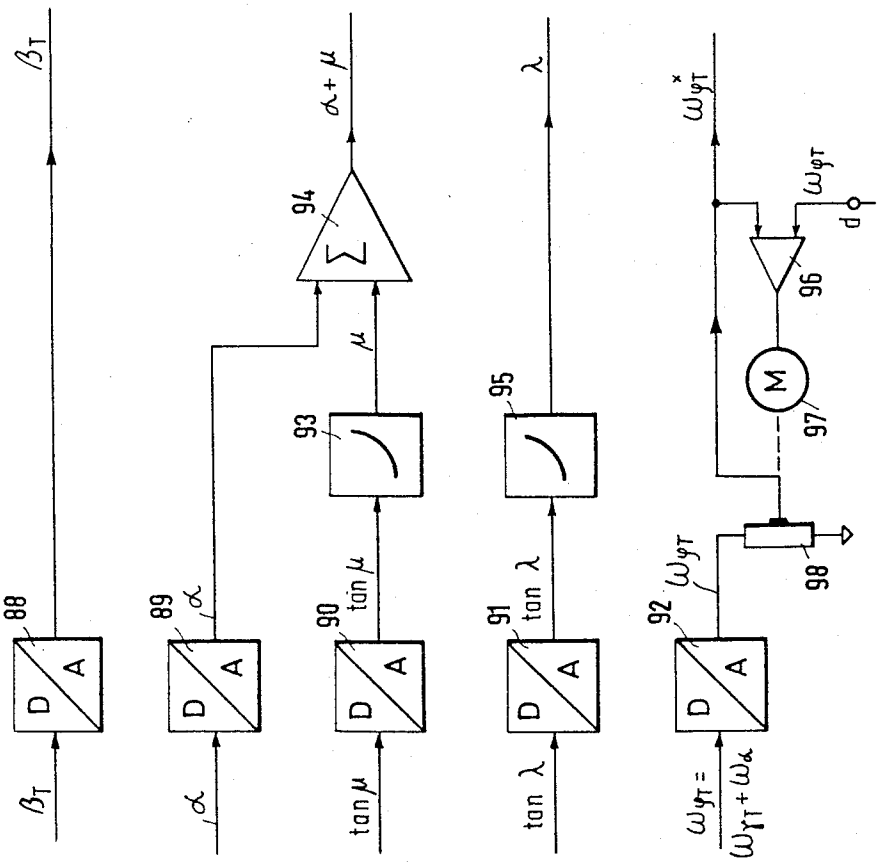



FIG.6



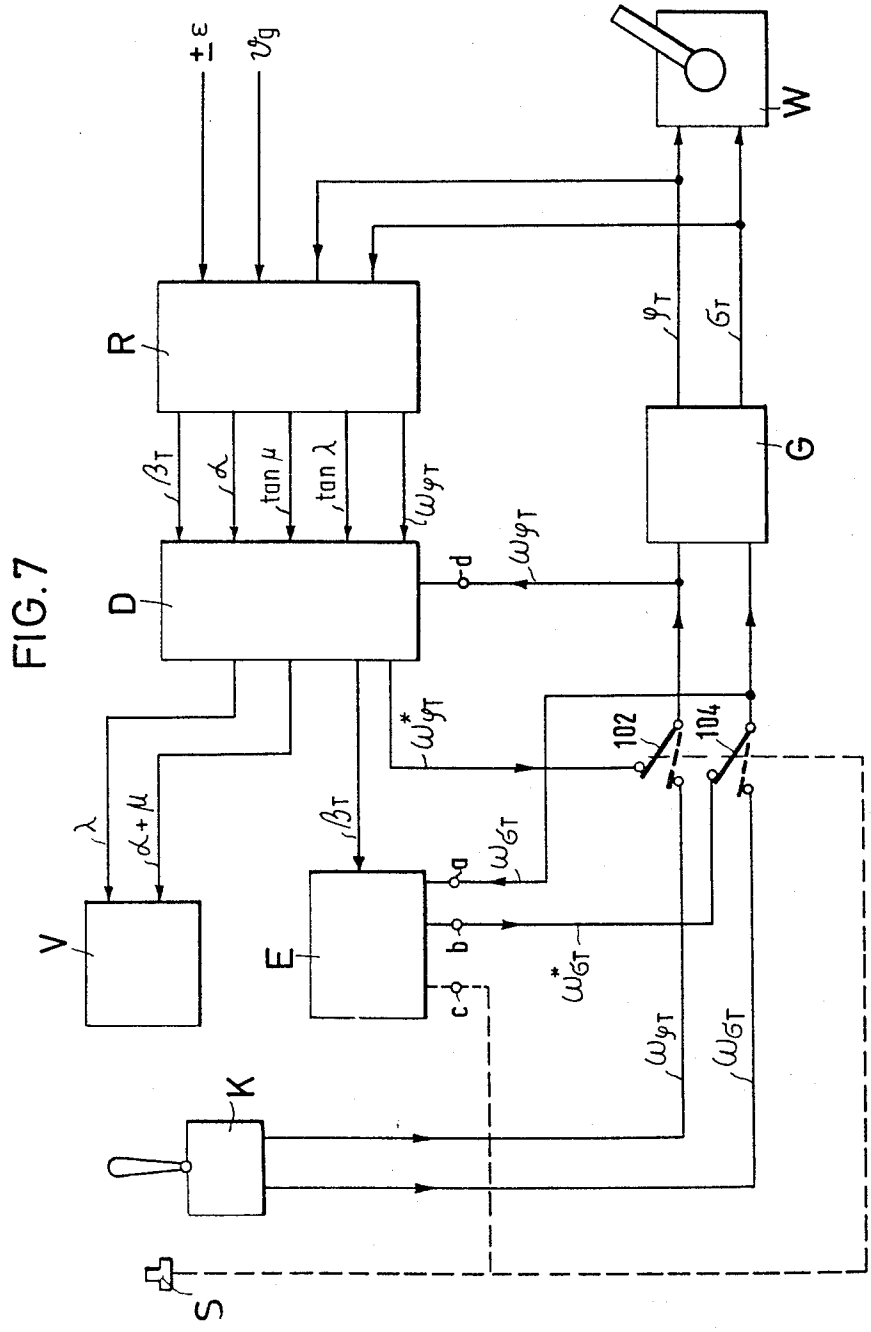

*INVENTOR*

ALBERT KAAZ

*BY* Craig, Antonelli, Stewart + Hill

ATTORNEYS

FIG. 7




*INVENTOR*

ALBERT KAAZ

*BY*

Craig, Antonelli, Stewart & Hill

ATTORNEYS

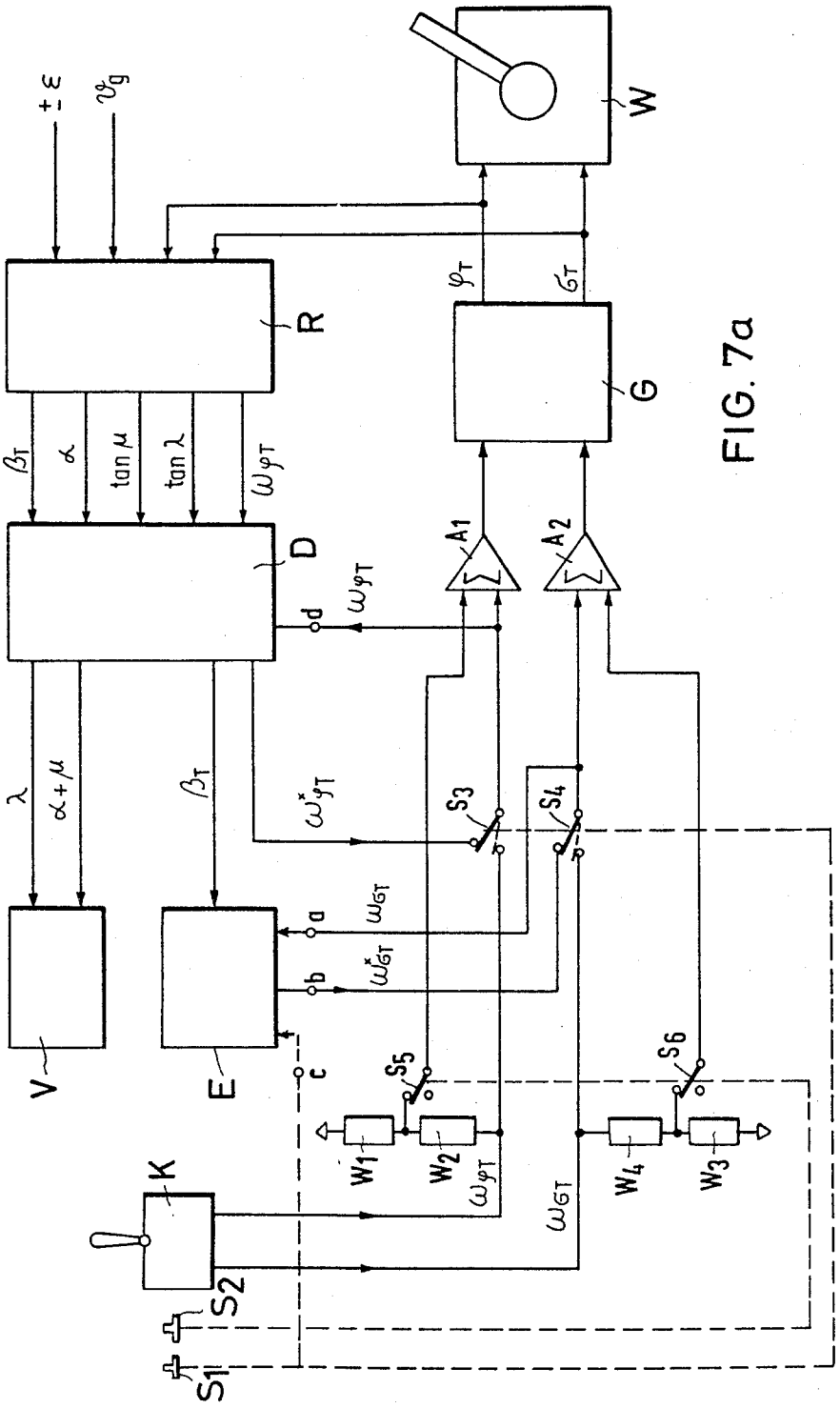



FIG. 7a

*INVENTOR*

ALBERT KAAL

*BY*

Craig, Antonelli, Stewart + Hill

ATTORNEYS

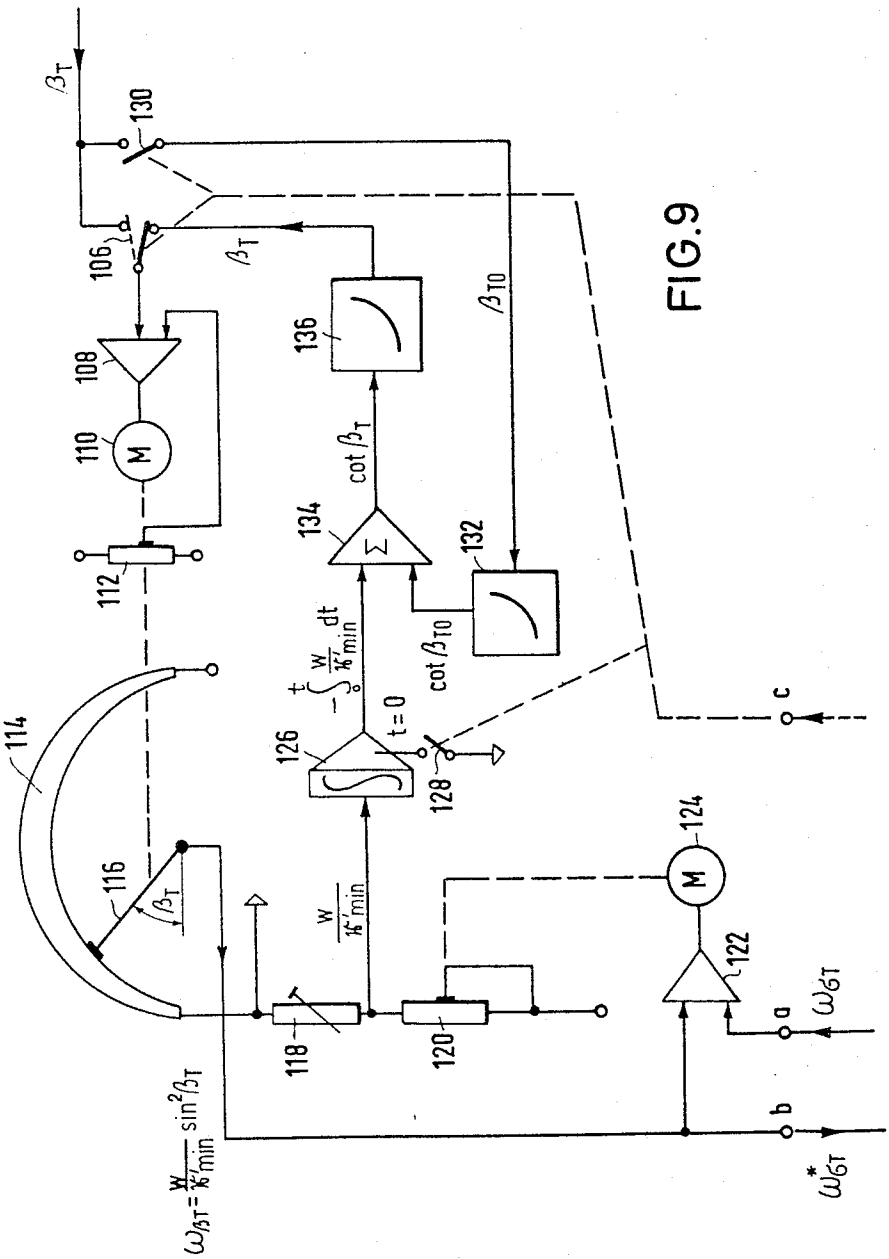



FIG.9

*INVENTOR*

ALBERT KAAZ

*BY* Craig, Antonelli, Stewart + Hill

ATTORNEYS

# METHOD OF CONTROLLING MOTOR-DRIVEN DEVICES ADAPTED TO BE DIRECTED ONTO MOVING TARGETS AND APPARATUS FOR APPLYING THE METHOD

This invention relates to a method of controlling motor-driven devices adapted to be directed onto moving targets and an appratus for applying the method.

This invention further relates to a method and an apparatus for changing from manual to automatic control of the aforementioned motor-driven devices.

Motor-driven devices such as weapons or target acquisition devices in the form of optical sighting devices, radar apparatus, sound locators or infrared tracking apparatus are mounted for pivotal movement about two axes, a vertical axis and axis at 90° to the vertical axis. In order to align such devices on moving targets, especially high-speed aerial targets, hydraulic or electrical drives are utilized which are constructed such that the operator need only perform simple operations to control the drive. For example, drives are known in which a single control lever serves for controlling both directional movements of the target acquisition device or weapon.

It has been found that in the case of fast moving targets the operation of such drives is nevertheless very difficult because due to the rapid changes in the angular velocities with which the gun or the target acquisition device must be moved about the two axes, the control lever positions also change rapidly and the operator is not always able to find the correct positions of the controls. To obviate these difficulties, an anticipatory control is already known in which operation is facilitated by restricting movement of the control lever. For this purpose, the control lever is lead in a radial guide of a rotating disc and the direction of movement of the control lever is predetermined by automatic rotation of the disc with the guide in accordance with the result of a computing process so that the operator only has the task of adjusting the magnitude of the deflection of the control lever manually in the direction predetermined by the guide.

In known apparatus an estimation of the target velocity and the distance to the change-over-point is generally necessary, the change-over-point distance being the shortest distance between the devices to be aligned on the target and the target path.

Since the weapon operator looks only at the target and the tracking operation is very short in the case of high-speed targets, the estimation of the distance to the change-over-point must be regarded as difficult and never accurate.

It is an important object of this invention to provide a method of controlling motor-driven devices adapted to be directed onto moving targets and an apparatus for applying this method in order to obviate the aforementioned disadvantages. Proceeding from a method for controlling different types of motor-driven devices mounted for movement about two axes and adapted to be directed onto moving targets, the target being followed by at least one of these devices and the control quantities for the drive of the devices adapted to be directed onto moving targets being calculated by computer means, this problem is solved according to the invention in that based on the values derived continuously from one of the devices adapted to be directed onto moving targets of the azimuth or lateral angle $\sigma$ and of the elevation angle $\phi$ and on the values, assumed constant for a given target tracking operation of the target velocity $v$ and of the angle of inclination $\epsilon$ of the target path with respect to the horizontal plane, on the basis of the geometrical relationships which hold true for a rectilinear uniform motion the azimuth angular velocity $\omega_\sigma$ and the elevational angular vellcity $\omega_\phi$ are calculated and fed to the drives of the devices adapted to be directed onto moving targets.



The invention affords the advantage of substantially simplifying and automating the tracking. The calculation of the control quantities for the drive of the target acquisition device and/or gun or rocket is advantageously based in known manner on a representation of the target movement in polar coordinates in a cotangent plane assumed at constant height. To take account of the angle of inclination $\omega$ of the target path to the horizontal plane, according to the invention the angle $\psi$ between the projection of the target path in the cotangent plane and the projection of the associated horizontal in the cotangent plane may be calculated. The angle of inclination $\omega$ and the target velocity $v$ are preferably estimated. It is of course also possible to measure these quantities and to base the calculation on the measured values.

If a target acquisition device is used which is mounted on a weapon and participates in the movement thereof, according to the invention the lateral and elevation lead angles $\lambda$ and $\mu$ and the gravity compensation angle $\alpha$ may be calculated and the target acquisition device set back by these angles with respect to the gun.

A substantially automatic tracking may be achieved according to the invention in that the quotient $w/w'\min$ formed from the horizontal component of the target velocity $v$ and the minimum value $w'\min$ of the horizontal component of the target range and being constant for agiven tracking, is determined from the formula $\omega_\sigma = w/w'\min \sin^2\beta$ by adjusting the calculated value of the lateral angular velocity $\omega_\sigma$ with the value of the lateral angular velocity supplied by a manual lever control constructed in a manner known per se, preferably during picking up and rapid homing on the target, the angle $\beta$, i.e., the lateral angle measured with respect to the direction of the track of the target path of the target acquisition device or weapon to be controlled being calculated. The value of the quotient $w/w'\min$ may then be used as a basis for the calculation of the lateral angular velocity during further tracking, for which the manual lever control may be partially or completely dispensed with.

It is another important object of the present invention to provide a method and an apparatus which substantially enable a smooth continuous transition from manual to automatic control of said motor-driven devices.

In accordance with this invention, this problem is solved in that after a short initial phase in which the operator directs a target acquisition device manually as accurately as possible onto the target the values $\omega_\sigma$ and $\omega_\phi$ of the lateral and elevational velocities supplied in form of angular velocities by the manual control are replaced at least partially by valves $\omega_\sigma{}^*$ and $\omega_\phi{}^*$ of the lateral and elevational angular velocities calculated by the computer means.

Preferably a substantially completely, smooth continuous transition from manual to automatic control is

achieved in that the values $\omega_\sigma$ and $\omega_\phi$ of the lateral and elevational angular velocities supplied by the manual control and the values of these angular velocities supplied by the computer means are adjusted to the same level before switching over from manual to automatic control.

It has been found particularly advantageous when switching from manual to automatic control not to replace the values $\omega_\sigma$ and $\omega_\phi$ of the lateral and elevational angular velocities coming from the manual control completely by the values $\omega_\sigma^*$ and $\omega_\phi^*$ of the lateral and elevational angular velocities supplied by the computer means but to leave a fraction of preferably about 3–20 percent of the values $\omega_\sigma$ and $\omega_\phi$ and to allow said fraction to be influenced by the manual control for correction purposes.

Preferably the fraction of the elevational and lateral angular velocities which remains under the influence of the manual control after switching to automatic control is infinitely variable.

Some of the objects and advantages of this invention having been stated, others will appear as the description proceeds when taken in connection with the accompanying drawings, in which:

FIG. 1 is a geometrical illustration for deriving the fundamental equations for the method according to the invention.

FIG. 2 is a separate illustration of a part of the horizontal plane.

FIG. 3 is a separate illustration of a vertical plane through a measured point.

FIG. 3*a* is an illustration of the angle of elevation.

FIG. 4 is a block circuit diagram of an example of embodiment of the computer according to the invention.

FIG. 5 is a block circuit diagram of another embodiment of the computer according to the invention.

FIG. 6 is a block circuit diagram of an adapter device which is connected between the computer and the drive of the weapon or sight.

FIG. 7 is a basic circuit diagram of a control system contructed according to the invention.

FIG. 7*a* shows a basic circuit diagram of a control system constructed according to the invention;

FIG. 8 is part of the horizontal plane showing the projection of the path of movement of the target and

FIG. 9 shows an example of embodiment of an autocontrol apparatus.

FIGS. 1 to 3 illustrate the geometrical relationships, it being assumed that the target moves with constant velocity $v$ on a straight path P M T which is inclined to the horizontal plane at an angle $\epsilon$. The point O denotes the position of a gun having a target acquisition device, in the present case an optical sighting device. A horizontal plane, the plane $\bar{a}$, is drawn through the point O. At the point P the target is picked up by the sighting device for the first time and then tracked along the straight line P M T. In the following calculations it is generally assumed that after target acquisition the operator follows the target accurately for a brief moment so that during this initial phase of the tracking accurate manually controlled values of the lateral angle and of the angle of elevation are fed to the computer means described hereinafter. The point M represents the instantaneous position of the target and is referred to hereinafter as the instantaneous measured point. The point T is the point of impact, which differs from the instantaneous measured point M by the lead, which depends substantially on the velocity of the target and the time of flight $t_G$ of the projectile until it strikes the target. The point H (FIG. 3) lies vertically above the instantaneous measured point M at the same altitude $h$ above the plane $\bar{a}$ as the point P. The horizontal P H forms with the path of flight P M T the angle of flightpath inclination $\epsilon$, which is generally assumed constant for a given tracking operation.

A vertical projection of the flightpath onto the plane $\bar{a}$ yields in the latter a line Sp on which lie the points P' and T' and the point M', which coincides with the point H' (all points projected onto the plane $\bar{a}$ are designated by a dash). A straight line $Sp_o$, parallel to the line Sp, is drawn through the gun position O and makes with a null or reference direction N, which is generally chosen as the North, a course angle $w$ which is constant for one tracking operation. For the derivation of the equations by which the computer calculates the control values for the weapon and the sighting device, the so-called cotangent plane, referred to briefly hereinafter as the plane $\bar{c}$ is introduced in known manner, extending at constant height $h_c$ above the plane $\bar{a}$. The line joining the point O to the moving point of the target passes through the plane $\bar{c}$ and traces on said plane a line $Sp_c$ through the points $P_c$ $M_c$ $T_c$, which is clearly associated with the true flight path. By projecting the straight line P H into the plane $\bar{c}$ the straight line $P_c$ $H_c$ is obtained and forms with the line $Sp_c$ of the flight path the angle $\psi$ which contains the information on the flight path inclination $\epsilon$.

On vertical projection of the aforementioned points and straight lines of the plane C onto the plane A congruent points and straight lines are obtained, since these two planes are parallel to each other. The straight lines $P'_c$ $M'_c$ $T'_c$ and $P'_c$ $H'_c$ in the plane A thus also enclose the angle $\psi$ (FIG. 2).

The position of the various points is determined in polar coordinates, proceeding from the location O of the weapon, in each case by the lateral angle $\sigma$ and the elevation angle $\phi$. The lateral angle $\sigma$ is measured in the horizontal $\bar{a}$-plane and the elevation angle in the vertical plane, e.g. the $\bar{a}$-plane M O M' (FIG. 3). The lateral angle $\sigma$ is measured in the clockwise direction starting from a null or reference direction N usually coinciding with the North.

The following symbols are also used (cf.FIGS.1–3*a*):

$\sigma_T = w + \beta_T$ Lateral angle of the point of impact or the turntable angle of the gun (measureable), $w$ being the course angle constant for one tracking operation between the line Sp or a line $Sp_o$ parallel thereto and the reference direction N.

$\beta_T = \sigma_T$ — Angle between the direction Sp or $Sp_0$ and the straight line $OT'_c$ T'.

$\beta_M = \sigma_T$ — Angle between the direction $Sp_0$ or Sp and the straight line O $M'_c$ M'.

$\phi_T = \alpha + \gamma_T$ Angle of elevation of the gun (measurable).

$\gamma_T$ Angle of elevation of the point impact T.

$\gamma_M$ Angle of elevation of the instantaneous measured point M.

$\lambda$ Lead angle increment in the lateral direction.

$\mu$ Lead angle increment in the elevational direction (not taking account of the gravity compensation angle $\alpha$).

$\alpha$ Gravity compensation angle calculated by means of a ballistic computer (FIG. 3*a*).

$\omega_{\beta T}$ and $\omega_{\gamma T}$ Lateral and elevational velocities with respect to the point of impact T.

$p$ and $q$

Components of the displacement vector on the line $P'_c\ T'_c$ in the Plane $\bar{a}$ (FIG. 2).

$v_c$

Velocity on the line $P_c\ T_c$ in the plane $\bar{c}$ and on the line $P'_c\ T'_c$ in the plane $\bar{a}$.

$w_c$

Component of $v_c$ in the direction of the straight line $P_c\ H_c$ in the plane $\bar{c}$ or in the plane $\bar{a}$.

$Sb$

Path of the projectile.

$Vr$

Direction of the sighting device.

$Wr$

Direction of the gun.

The equations derived hereinafter all relate to the gun position at the point of impact and to the four values $\beta_T$, $\gamma_T$, $\omega_{\beta T}$, $\omega_{\gamma T}$ associated with said weapon position. The relationship to the measured point which is usually tracked by means of an optical sighting device, is established by the angular increments $\lambda$ and $\mu$ of the lead. The effect of gravity on the projectile is compensated for by the gravity compensation angle $\alpha$.

Firstly, two fundamental equations for the angle and for the track velocity $v_c$ in the cotangent plane are derived. In FIG. 2 a straight line is drawn from O vertically to the straight line $P'_c\ M'_c\ T'_c$ and intersects the latter at the point $\overline{T}'_c$ and the straight line $P'_c\ H'_c$ at the point $\overline{T}''_c$ we have

$$\sin\psi = \tan\epsilon \cdot \cot\gamma_{max}$$

whereby

$$\cot\gamma_{max} = \cot\gamma_T \cdot \sin(\beta_T + \psi)$$

wherence

$$\sin\psi/\sin(\beta_T+\psi) = \tan\epsilon \cdot \cot\gamma_T \qquad (I)$$

The point of intersection of the straight line $O\ T'_c$ with the straight line $P'_c\ H'_c$ yields the point $T''_c$ in the plane $a$ as shown in FIG. 2.

The sine law for the triangle $P'_c\ T'_c\ T''_c$ leads to

$$v_c = w_c\ [\sin\beta_T/\sin(\beta_T+\psi)],\quad w_c = v\ (h_c/h)\cos\epsilon \qquad (II)$$

It is apparent from this that $v_c$ is in no way constant except in the limiting case:

$$\lim_{\psi \to 0} v_c = w_c = \text{constant}$$

in which case it is constant for a single tracking operation.

The equations for the components $p$ and $q$ of the displacement vector on the line $P'_c\ T'_c$ in the plane $\bar{a}$ (FIG. 2) are then

$$p = h_c \cdot \cot\gamma_T \Delta\beta_T = v_c \cdot \sin(\beta_T+\psi)\ \Delta t \qquad (IIa)$$

$$q = \Delta(h_c \cdot \cot\gamma_T) = v_c \cdot \cos(\beta_T+\psi)\ \Delta t \qquad (IIb)$$

Whence



$$q/p = \cot(\beta_T+\psi) \qquad (III)$$

Equations (I) and (III) determine at any instant the angles $\psi$ and $\beta_T$ for given values of $h_c$ and $\gamma_T$. As already stated above, the angle $\psi$ is constant for a given tracking operation because the flight path of the target is assumed to be a straight line. Since $\sigma_T$ is known the determination of $\beta_T$ automatically gives the course angle $w$, which is also constant for a given tracking operation.

The angular velocity $\omega_{\beta T}$ is determined in the computer from the time derivative of $\beta_T$ and the function $\sin\beta_T$ which is also generated in the computer.

The elevational velocity is obtained by differentiating the equation (I) with respect to time, i.e.,

$$\omega_{\gamma T} = 0{,}5\ \sin 2\gamma_T \cot(\beta_T+\psi) \cdot \omega_{\beta T} \qquad (VI)$$

To obtain the lead angle increments $\lambda$ and $\mu$ for the lateral and elevational direction, the result of the following publication is used:

"Ein modernes Visier für leichte Flak" by D. Schröder, Wehrtechnische Monatshefte 61, 1964, No. 10, pages 367–373,

the equation for $\lambda$ being

$$\tan\lambda = \omega_{\beta T} \cdot t_G$$

wherein $t_g$ is the projectile time of flight, which is calculated in the ballistic computer.

The following equations are then obtained

$$\tan\lambda = \omega_{\beta T} \cdot t_G \qquad (V)$$

$$\tan\mu = o{,}5\ \sin 2\gamma_T \cot(\beta_T+\psi) \cdot \tan\lambda = \omega_{\gamma T} \cdot t_G \qquad (VI)$$

Equation (VI) being based on a simplification which assumes that $\mu$ is small compared with $\lambda$.

Finally, the range of the weapon from the aerial target is to be determined. It is denoted by $w$. The following equations are true.

$$\mathfrak{W} = h - v \cdot (t+t_G) \cdot \sin\epsilon/\sin\gamma_T$$

$$\mathfrak{W} = m\,h_c - v \cdot (t+t_G)\ \sin\epsilon/\sin\gamma_T \qquad (VII)$$

wherein $m = h/h_c$ and $t$ is the time in which the target covers the distance PM. The factor $m$ is also determined from the velocity ratio $v \cdot \cos\epsilon\ \Delta t/w_c \cdot \Delta t$.

With the expression for $p$ equation (II) yields $p/\sin\beta_T = w_c\ \Delta t$,

$t$ = constant time increment. Whence:

$$m = \frac{h}{h_c} = \frac{v \cdot \cos\epsilon \Delta t}{w_c \Delta t} = \frac{v \cdot \cos\epsilon \Delta t}{\frac{p}{\sin\beta_T}} \qquad (VIII)$$

In the examples of embodiment of a computer described hereinafter the product

$$m h_c = \frac{v \cdot h_c \cdot \cos\epsilon \Delta t}{\frac{p}{\sin\beta_T}} \qquad (IX)$$

is formed directly.

The input data $w$ and $\gamma_T$ or a function of $\gamma_T$ are sufficient for the ballistic computer. In practice, the type of projectile, temperature, wind and other parameters are also taken into account. The output thereof must give the correct gravity compensation angle $\alpha$ and the projectile flight time $t_G$. The equations for providing ballistic information are calculated by means of the ballistic computer B in FIG. 4 and B' in FIG. 5, which ballistic computers are constructed to solve the equations in a manner known in the art.

FIG. 4 shows a digital computer which is based on the equations derived above. By means of the analog digital converter or pulse code converter 1 and 2 the lateral angle $\sigma_T$ and the elevation angle $\phi_T$ measured at the weapon are converted into binary form for feeding into the computer. A block 3 contains a stabilized oscillator, a counter and a timing device which closes the switches 4 and 5 at constant time intervals $\Delta t$, for example every 5 milliseconds, for a short time, i.e., for a time which is small cmpared with $\Delta t$, to scan new values of $\sigma_T$ and $\phi_T$ in each case and feed these values into the blocks 6 and 7. The block 6 contains two registers. A value of $\sigma_T$ fed into the first register at a given instant will be transferred to the second register after the time increment $\Delta t$, when a new value $\sigma_T$ is fed into the first register. $\Delta\beta/2$ appears at the output of the block 6.

The block 7 contains two registers. The value $\phi_T$ is fed into the first and the value of the gravity compensation angle $\alpha$ obtained from the output of a ballistic computer B into the second. $\gamma_T$ appears at the output of the block 7 and represents the difference between the values $\alpha$ and $\gamma_T$ fed into said block, The value $\gamma_T$ is fed into the block 8, which contains a store for associated values of $\sin\gamma_T$ und $\cos\gamma_T$. The output values $\sin\gamma_T$ and $\cos\gamma_T$ of the block 8 are fed into the block 9 in which the value $\cot\gamma_T$ is formed which is multiplied in block 10 by the constant value $h_c$, thus obtaining $h_c \cdot \cot\gamma_T$. This value is now multiplied on the one hand in the block 11 by the value $\Delta\beta/2$ from block 6 to obtain the value P/2 corresponding to equation (II*a*). On the other hand this value is fed into the block 12 containing two registers. The value fed into the first register at a certain instant is transmitted to the second register when after passage of the time increment $\Delta t$, a new value is fed into the first register. Half of the difference $\Delta(h_c \cdot \cot\gamma_T)/2$ of the values in the two registers appears at the output of the block 12 and is equal in accordance with equation (II*b*) to the half value $q/2$ of the component $q$ of the displacement vector in the plane $\pi$. The input values for the blocks 11 and 12 are supplied to the latter via switches 11', 11'' and 12', which are controlled by the timing device in block 3. The output value $q/2$ from block 12 is divided in block 13 by the output value $p/2$ of block 11 so that the value $q/p$ appears at the output of block 13.

The estimated flight path inclination $\epsilon$ will preferably be fed in discreet values, for example 5°, 10°, 15°, etc. into the block 14 which contains binary registers for its output values $\pm \sin\epsilon$ and $\cos\epsilon$. Formation of the quotient of these values in block 15 gives the value $\tan\epsilon$ which is multiplied in block 16 by the value $\cot\gamma_T$ from block 9 to obtain the value $\tan\epsilon \cdot \cot\gamma_T$.

By means of the computing unit consisting of blocks 17 to 22 and with the aid of the value $q/p$ from block 13 and the value $\tan\epsilon \cdot \cot\gamma_T$ from block 16 the values $\beta_T$ and $\cot(\beta_T + \psi)$ are obtained. The computing unit includes a block 17 in which the different possible values of $\cot(\beta_T + \psi)$ and $\sin(\beta_T + \psi)$ are stored and a block 18 which stores the different values of $\sin\psi$. In the blocks 17 and 18 tables of the desired output values are stored. The output value $\cot(\beta_T = \psi)$ of block 17, which represents the right-hand side of the equation (III), is compared in block 19 with the value $q/p$ from block 13, which represents the left-hand side of equation (III). The output value $\sin\psi$ from block 18 is divided in block 21 by the output value $\sin(\beta_T + \psi)$ from block 17. The value $\sin\psi/\sin(\beta_T + \psi)$ thus obtained, which corresponds to the left-hand side of equation (I), is compared in block 20 with the corresponding value $\tan\epsilon \cdot \cot\gamma_T$ from block 16 representing the right-hand side of equation (I).

The store address "address $\psi$" appears at the output of the block 20; this address is firstly fed directly into the store block 18 and is then added in the block 22 to the store address "address $\beta_T$" coming from block 19, thus obtaining the "address $(\beta_T + \psi)$", which is fed into block 17. The store addresses are systematically modified in the blocks 19 and 20 in accordance with the result of the comparison in said blocks, whereby new values are called up in the store blocks 17 and 18, with which the comparision operation is repeated until identity in the two blocks 19 and 20 is established. When identity obtains the conditions of the equations (I) and (III) are fulfilled and the correct output values "address $\beta_T$" and $\cot(\beta_T + \psi)$ of the computing unit consisting of the blocks 17 to 20 have been found.

The store address "address $\beta_T$" coming from the block 19 is fed into the block 23 in which the values of $\beta_T$ and $\sin\beta_T$ are stored. The output value $\sin\beta_T$ of said block 23 is used as described hereinafter to calculate the target range $w$. The output value $\beta_T$ represents an output value of the computer. In addition, the value $\beta_T$ is simultaneously fed via a switch 24 actuated by the timing device in block 3 simultaneously with the switches 4 and 5 into the block 26 which has a similar function to that of the blocks 6 and 12 and forms the value $\Delta\beta_T$, which is a measure of the angular velocity $\omega_{\beta T}$ of the lateral rotation of the gun. The value $\Delta\beta_T$ is multiplied in block 27 by the factor 200. At the output of the block 27 the value $\omega_{\beta T}$ is obtained. The value $\omega_{\beta T}$, which is equal to $\Delta\beta/\Delta t$, is obtained by multiplying $\Delta\beta$, derived from the block 26, by the factor 200, since in the presend embodiment $t = 5$ m/sec and $\Delta\beta/\Delta t = 200 \cdot \Delta\beta$/sec.

The value $\omega_{\gamma T}$ is calculated in accordance with equation (IV) in another computing unit which includes blocks 26 and 27. For this purpose the values $\sin\gamma_T$ and $\cos\gamma_T$ are fed from the outputs of the block 8 into the block 28 in which the value $0{,}5 \cdot \sin 2\gamma_T$ is calculated, which is then passed on to the block 29 where it is multiplied by the value $\cot(\beta_T + \psi)$ from block 17. The output value of the block 29 is also multiplied in the block 30 by the value $\omega_{\beta T}$ from the block 27 so that at the output of the block 30 the value $\omega_{\gamma T}$ is obtained in accordance with the equation (IV).

Now that part of the computer is still to be described which with the cooperation of the ballistic computer B calculates the functions $\tan\lambda$ and $\tan\mu$ of the lead angle increments $\lambda$ and $\mu$ and the gravity compensation angle $\alpha$. The calculation of the range $w$ between the weapon and target is first described; it is based on equations

(VII) and (IX). In block **31** the estimated flight velocity $v_g$ of the target, which is an input quantity to the computer, is multiplied by the values sin$\epsilon$ and cos$\epsilon$ from block **14**, thus obtaining at the two outputs of block **31** the values $v_g \cdot \cos\epsilon$ and $v_g \cdot \sin\epsilon$. In block **32** the value $v_g \cdot \cos\epsilon$ is multiplied by the constant value $h_c \cdot \Delta t$ the value of $h_c \cdot \Delta t$ being made equal to **1.** In block **33** the value p/2 from block **11** is multiplied by the factor **2** to obtain the value $p$, which is divided in block **34** by the value $\sin\beta_T$ from block **23.** The value $v_g \cdot h_c \cdot \Delta t \cdot \cos\epsilon$ from block **32** is divided in block **35** by the value $p/\sin\beta_T$ obtained at the output of block **34.** The quantity $mh_c$ is then obtained at the output of block **35** in accordance with equation (IX), m being equal to the ratio of the heights $h/h_c$. From a real time counter reset to zero after each tracking operation the time $t$ from the instant at which the target was picked up at the point P at an altitude $h$ is fed into block **36** where the time of flight $t_G$ of the projectile obtained from the ballistic computer is added thereto. The resetting of the real time counter may be coupled to the setting of the estimated value of the path inclination angle $\epsilon$. The value $t + t_G$ is multiplied in block **37** by the quantity $v_g \cdot \sin\epsilon$. The product from the output of the block **37** is then deducted in block **38** from the quantity $mh_c$ from block **35** and the output value of block **38** is then divided in accordance with equation (VII) in block **39** by the quantity $\sin\gamma_T$ obtained from block **8.** The value of the target range obtained at the output of the block **39** is fed into the ballistic computer B.

In addition to the calculated target range the two quantities $\cos\gamma_T$ from block **8** and $\gamma_T$ from block **7** are fed into the ballistic computer which then calculates therefrom the projectile time of flight $t_G$ and the gravity compensation angle $\alpha$, which is an output quantity of the computer.

In accordance with equation (V), in block **40** the output quantity tan$\lambda$ of the computer is calculated as a product of the quantity $t_G$ from the ballistic computer B and the angular velocity $\omega_{\beta T}$ from block **27.** The output quantity tan$\mu$ of the computer is formed in accordance with equation (VI) by multiplying $t_G$ from the ballistic computer B by the quantity $\omega_{YT}$ from block **30** in block **41.**

The value $\alpha$ from the ballistic computer is fed via a switch **42** actuated simultaneously with the switches **24, 4** and **5** by the timing device in block **3** into block **43,** which operates in the same manner as block **26** and forms the value $\Delta\alpha$. Corresponding to the procedure with $\Delta\beta$ in block **27,** in block **44** the value $\Delta\alpha$ is multiplied by the factor 200 to obtain $\omega_\alpha$, which is then added in block **45** to the value $\omega_{YT}$ from block **30.** The quantity $\omega_{YT} = \omega_{YT} + \omega_\alpha$ from block **45** is an output value of the computer.

In the digital computer described above the switches **4, 5, 11', 11'', 12', 24** and **42** (FIG. **4**) are actuated by the timing device **3.** The scanning time of these switches, i.e., the period in which the switches are closed, is small compared with the time increment $\Delta t$ between two scannings. The computing unit consisting of the blocks **17** to **22** generally requires for finding the correct values of $\beta_T$ and $\cot(\beta_T + \psi)$ a time which is greater than the scanning time of the switches but which should not be greater than $\Delta t$, so that the total computing time of the digital computer may be minimized.

FIG. **5** shows an analog computer which is equivalent to the digital computer of FIG. **4.** The lateral angle $\sigma_T$ is available as angle of rotation of the gun drive shaft and drives a tachometric dynamo **51** from which the value of the velocity $d\beta_T/dt$ is obtained in the form of an electrical quantity. The elevational angle $\phi_T$ and the gravity compensation angle $\alpha$ are also fed as shaft angles of rotation into the computer. In a mechanical substracting device **52,** which may be for example a differential gear, $\alpha$ is deducted from $\phi_T$, thus obtaining $\gamma_T$, which is fed into an electromechanical transducer **53** which may include multipliers and function generators for supplying at its outputs the following six values in the form of electrical quantities: $0.5 \cdot \sin 2\gamma_T$, $hc \cdot \cot\gamma_T$, $\cos\gamma$, $\gamma_T$, $\sin\gamma_T$ and $\cot\gamma_T$. The value $\cot\gamma_T$ is fed into a second electromechanical transducer **54** at which the estimated flight speed $v_g$ of the target and the estimated path inclination $\epsilon$ are also set. The transducer **54** may include multipliers and function generators for supplying the three values $\tan\epsilon \cdot \cot\gamma_T$, $v_g \cdot \cos\epsilon$ and $v_g \cdot \sin\epsilon$ in the form of electrical quantities. The value $h_c \cdot \cot\gamma_T$ from the transducer **53** is first multiplied in block **55** by $d\beta_T/dt$, from the tachometric dynamo **51,** thus obtaining the value $p$, in accordance with equation (II*a*). Secondly, in block **56** in accordance with equation (II*b*) the value $q$ is formed as the time derivative of said value of $h_c \cdot \cot\gamma_T$ and fed via a stabilizing circuit **57,** from which the stabilized value $\bar{q}$ is obtained, to the block **58** which forms the quotient $\bar{q}/\bar{p}$ the value p from block **55** being stabilized in a stabilizing circuit **59** and fed as the value $\bar{p}$ into the block **58.**

By means of a computing unit including two control circuits consisting of the elements **60** to **68** and with the aid of the value $\bar{q}/\bar{p}$ from block **58** and the value $\tan\epsilon \cdot \cot\gamma_T$ from the electromechanical transducer **54** the values $\beta_T$ and $\cot(\beta_T + \psi)$ are determined. The computer unit includes a resolver **60** which supplies at its outputs the values $\sin(\beta_T + \psi)$ and $\cos(\beta_T + \psi)$ as electrical quantities, the angle of rotation of the shaft of said resolver **60** corresponding to the value $\beta_T + \psi$. In the block **61** the value $\cot(\beta_T + \psi)$ is formed as a quotient of the two output values of the resolver **60.** The computer circuit also includes a second resolver **62** the angle of rotation of which corresponds to the value $\psi$ and which supplies the value $\sin\psi$ as an electrical output quantity, said value being devided in the block **63** by the value $\sin(\beta_T + \psi)$ from the first resolver. The output value $\cot(\beta_T + \psi)$ from block **61,** which represents the right-hand side of equation (III), is compared in block **64,** which is constructed as an amplifier, with the value $\bar{q}/\bar{p}$ from block **58,** which represents the left-hand side of equation (III). The value sin $\psi/\sin(\beta_T + \psi)$ from block **63,** corresponding to the left-hand side of equation (I), is compared in block **66** with the value $\tan\epsilon \cdot \cot\gamma_T$ from the electromechanical transducer **54** corresponding to the right-hand side of equation (I). The result of the comparison in the blocks **64** and **66,** constructed as amplifiers, is used to control the servomotors **65** and **67** respectively by means of which the shafts of the resolvers **60** and **62** respectively are rotated until the blocks **64** and **66** are balanced, i.e., measure identity. At balance the conditions of equations (I) and (III) are fulfilled and the correct values of $(\beta_T + \psi)$ and $\psi$ corresponding to the angle of rotation of the shafts of the resolvers and of $\cot(\beta_T + \psi)$ as electrical output quantity from block **61** are established. In a mechanical subtracting device **68,** for example a differen-

tial gear, the difference between the angles of rotation of the two resolver shafts is formed, thus obtaining the value $\beta_T$, which is an output quantity of the computer, as the angle of rotation of a shaft. Said shaft drives inter alia a tachometric dynamo **69** which via a stabilizing circuit **70** generates the value $\omega_{\gamma T}$ as an electrical quantity. The arrangement of the stabilizing circuits **58, 59** and **70** is shown at **150.**

The value cot $(\beta_T + \psi)$ from block **61** is multiplied in block **71** by the value 0.5 $\sin 2\gamma_T$ from the electromechanical transducer **53** and the product obtained from said block **71** is multiplied in block **72** by the value $\omega_{\gamma T}$ from block **70,** thus obtaining the value $\omega_{\gamma T}$ in accordance with equation (IV).

The part of the computer which with the aid of a ballistic computer B' calculates the functions $\tan\lambda$ and $\tan\mu$ of the lead angle increments $\lambda$ and $\mu$ and the gravity compensation angle $\alpha$ will be described hereinafter. As before, the calculation of the distance between gun and the target will first be described, forming the basis of equations (VII) and (IX). The output shaft of the subtraction device **68,** whose angle of rotation corresponds to the value $\beta_T$, drives a resolver **73** which supplies the value $\sin\beta_T$ in the form of an electrical quantity. In block **74** the value $\bar{p}$ from block **59** is divided by said value $\sin\beta_T$. In block **75** the value $v_g \cdot \cos\epsilon$ from the electromechanical transducer **54** is divided by the quotient thus obtained in block **74,** thus giving the value $m$ according to equation (VIII), which is multiplied in block **76** by the constant factor $h_c$ to obtain the value $mh_c$.

The value $v_g \cdot \sin\epsilon$ from the electromechanical transducer **54** is integrated in the block **77** with respect to time, $t=o$ being the instant at which the target is picked up at the point P . An the other hand, the value $v_g \cdot \sin\epsilon$ is multiplied in block **78** by the value $t_G$ of the projectile flight time calculated in the ballistic computer B'. The two products $v_g \cdot \sin\epsilon \cdot t$ from block **77** and $v_g \cdot \sin\epsilon \cdot t_G$ from block **78** are added in block **79,** which contains a summation circuit, thus obtaining the value $v_g \cdot \sin\epsilon \cdot (t+t_G)$ which is fed with a negative sign into a block **80** including a summation circuit, where it is deducted from the value $mh_c$ from block **76.** The output value of block **80** corresponding to the difference between the two input values is further divided in block **81** in accordance with equation VII by the value $\sin\gamma_T$ from the electromechanical transducer **53** to obtain the value $w$ of the target range, which is fed into the ballistic computer B'.

In addition to the calculated value of the target range $w$, the values $\cos\gamma_T$ and $\gamma_T$ from the electromechanical transducer **53** are fed into the ballistic computer B', which then calculates the projectile flight time $t_G$ and the gravity compensation angle$\alpha$, which is an output quantity of the computer.

In accordance with equation (V) in block **82** the output value $\tan\lambda$ of the computer is calculated as a product of the value $t_G$ from the ballistic computer B' and the value of the angular velocity $\omega_{\beta T}$ from block **70.** The output value $\tan\mu$ of the computer is formed in accordance with equation (VI) by multiplying in block **83** the value $t_G$ from the ballistic computer B' by the value $\omega_{\gamma T}$ from block **72.**

In block **84** the derivative $\omega_\alpha$ with respect to time of the value $\alpha$ obtained as an electrical quantity at the output of the ballistic computer B' is formed. The value $\omega_\alpha$ thus obtained is added in block **85,** which contains a summation circuit, to the value $\omega_{\gamma T}$ from block **72,** thus obtaining the output value $\omega_\gamma$ of the computer. The value of the output of the ballistic computer B' is also converted in a unit which is not illustrated in the drawings by means of an amplifier and a servomotor into the rotation of a shaft and fed in this form into the substraction unit **52** at the input of the analog computer.

Instead of the resolvers **60, 62** and **73** other suitable function generators, for example, sine-cosine potentiometers or computing capacitors may be used.

It may be convenient to construct the computer as a hybrid computer in which elements of the digital computer type and of the analog computer type are combined, in particular to obtain a rapid and accurate computer.

In the examples of embodiment described above the gun and the target acquisition device have the same location, denoted in FIGS. **1** to **3** by O. However, if the locations are different the ballistic computer may be so designed that in addition to the gravity compensation angle $\alpha$ and the lead angle components $\lambda$ and $\mu$ it calculates two further correction values $\lambda_K$ and $\mu_K$ for the elevation angle and the lateral angle of the target acquisition device, which cancel out the difference in location.

FIG. **6** shows an adapter device which converts the output quantities of the computer into the form necessary for controlling the drives of the gun and of the sighting device. The blocks **88** to **92** contain digital-analog converters and convert the digital output quantities of the digital computer into analog form. The analog value of $\beta_T$ formed in block **88** is one of the output quantities of the adapter. In block **93,** which contains a function converter, the value $\mu$ is obtained from the analog value of $\tan\mu$ formed in block **90.** The value $\mu$ thus obtained is added in block **94,** which contains a summation circuit, to the value from block **89** and the value $\alpha + \mu$ forms an output quantity of the adapter. The value $\tan\lambda$ is used to form the value$\lambda$ in a block **95** containing a function converter. The value of $\omega_{\gamma T}$ calculated by the computer is fed after conversion to analog form in block **92** to a potentiometer **98.** At the potentio-meter **98** a fraction $\omega_{\gamma T}^*$ of the calculated value of $\omega_{\gamma T}$ is tapped off. In the case of manual control the value $\omega_{\gamma T}$ set by the gun operator at the control lever K is fed into the input $d$ of the adapter and supplied as reference value to an amplifier **96,** to which $\omega_{\gamma T}^*$ is also supplied and which compares $\omega_{\gamma T}^*$ with the reference value $\omega_{\gamma T}$. During this normalizing procedure of $\omega_{\gamma T}^*$ the amplifier **96** controls a servometer **97** actuating the potentiometer **98** in such a manner that the output value $\omega_{\gamma T}^*$ of the adapter tapped from the potentiometer is equal to the value $\omega_{\gamma T}$ supplied during the manual control to the gun drives. This ensures a smooth passage from the manual control to the automatic tracking. During the automatic tracking the two inputs of block **96,** as can be seen from FIG. **7,** are short circuited and the position of the potentiometer **98** thereafter remains unchanged.

When using an analog computer as shown for example in FIG. **5,** the blocks **88** to **92** of the adapter which contain the digital-analog converter may be dispensed with.

In the block diagram illustrated in FIG. **7** a gun W is laterally and vertically pivotal and movable in these directions by means of a vertical and lateral drive G. In the initial phase of a tracking operation, in which the gunner brings the sighting device V onto the target by

means of a lever control K, the switches **102** and **104** are in their positions shown in dashed line and are controlled by the switch S. In this initial phase the values $\omega_{\gamma T}$ and $\omega_{\sigma T}$ are fed to the gun drives G from the lever control K. A computer R, which may be a digital computer in accordance with FIG. **4** or an analog computer in accordance with FIG. **5**, is continuously supplied with the lateral and elevational angular position $\phi_T$ and $\sigma_T$ of the gun measured thereat, and the estimated values of the flight path inclination $\pm\epsilon$ and the flight velocity $v_g$ are fed manually into the computer R. If the computer is a digital computer the values measured at the weapon of $\phi_T$ and $\sigma_T$ are fed to the computer in coded form as electrical signals. In the case of an analog computer these values are fed to the latter in the form of angles of rotation of the shafts.

The output quantities of the computer R are fed to an adapter D which is illustrated in detail in FIG. **6** and has already been fully described. There is also shown in FIG. **7** an autocontrol device E which is illustrated in detail in FIG. **9**, the operation of which will be described with reference to FIGS. 7a and **9**.

In FIG. *7a* a modified embodiment is illustrated which is similar to that of FIG. **7**. In the embodiment of FIG. *7a* a lever control K is provided too, which is operated by a control lever which influences both directional movements, i.e., the lateral velocity $\omega_{\sigma T}$ and the elevational velocity $\omega_{\gamma T}$ of the gun. The gun W is driven by the gun drives G. The lateral angle $\sigma_T$ and the elevational angle $\phi_T$ are taken via suitable coding means continuously from the gun and fed to a computer R. In addition to these values, the target velocity, which is generally fed in as an estimated value $v_g$, and the inclination $\epsilon$ of the target path to the horizontal are fed to the computer R. The angle of inclination $\epsilon$ of the target path to the horizontal is also generally fed in as an estimated value. The computer R provides from the input values $\sigma_T$, $\phi_T$, $v_g$ and $\epsilon$ supplied thereto the output values $\beta_T$, $\alpha$, tan $\mu$, tan $\lambda$ and $\omega_{\gamma T}$. From these values the values for the lateral lead $\lambda$ and the elevational lead $\mu$ as well as the gravity compensation angle $\alpha$ are determined in an adapter device D. It is assumed here that the sight is mounted on the gun and participates in the movements thereof so that the axis of the sight must be pivoted with respect to the barrel axis of the gun by the lead angles and the gravity compensation angle.

In addition, the adapter device D carries out an adjustment or standardization of the value of $\omega_{\gamma T}$ calculated by the computer. The adjusted value of $\omega_{\gamma T}^*$ supplied by the adapter device D is denoted in FIG. *7a* by $\omega_{\gamma T}^*$. The adjustment is made by feeding the values $\omega_{\gamma T}$ supplied during manual control by means of the control lever K in the initial phase of the target tracking, i.e., the period in which the target is followed manually as comparison values via the switch $S_3$ closed during this phase and the connection *d* to the adapter device D and adjusting these values to the calculated values $\omega_{\gamma T}$ from the computer R, as will be described in detail hereinafter. An autocontrol device E, which will also be described in detail hereinafter, supplies a lateral angular velocity $\omega_{\sigma T}^*$ which is analogously adjusted to the values $\omega_{\sigma T}$ supplied by the control lever K during manual control, these latter values being fed during the manual control via the switch $S_4$ to the gun drives G and simultaneously to the connection a of the autocontrol device E. The adjusted values $\omega_{\gamma T}^*$ and $\omega_{\sigma T}^*$ are not used during the initial phase of the target tracking, in which the switches $S_3$ and $S_4$ assume the position shown in dashed line in FIG. *7a*. However, the adjustment of these values is essential in order to ensure a smooth continuous transition of the lateral and elevational angular velocities supplied to the gun drives G when switching from manual to automatic control, when the switches $S_3$ and $S_4$ are moved from the positions shown in dashed line to the full-line positions.

In the example of embodiment according to FIG. *7a* two summation devices $A_1$ and $A_2$ are provided which each add a fraction of the values of $\omega_{\gamma T}$ and $\omega_{\sigma T}$ supplied by the control lever additionally to the values $\omega_{\gamma T}^*$ and $\omega_{\sigma T}^*$, respectively. These fractions are tapped off at voltage dividers $W_1$, $W_2$ and $W_3$, $W_4$ via switches $S_5$ and $S_6$, respectively. The ratio between the resistances $W_1$, $W_2$ and $W_3$, $W_4$, respectively, may be made for example 1:19 so that in each case one-twentieth of the values of $\omega_{\gamma T}$ and $\omega_{\sigma T}$ supplied by the control lever are additionally fed to the summation devices $A_1$ and $A_2$.

When the operator has picked up the target and exactly followed it manually for a brief moment in the initial phase of the target tracking, he operates by means of the switch $S_1$ the switches $S_3$ and $S_4$ in such a manner that the latter are moved into the full-line position shown in FIG.*7a*. The values $\omega_{\gamma T}^*$ and $\omega_{\sigma T}^*$ supplied by the computer R, i.e., the adapter device D and the autocontrol device E are then supplied to the summation devices $A_1$ and $A_2$. Since the switch $S_2$ is not actuated as this is done, the switches $S_5$ and $S_6$ remain in the full-line position shown in FIG. **1**, and consequently one-twentieth of the values of $\omega_{\gamma T}$ and $\omega_{\sigma T}$ supplied by the control lever continues to be fed to the summation devices $A_1$ and $A_2$. The control lever can thus be used in the automated control for correcting the angular velocities supplied by the computer means R, D and E and fed to the gun drives G. Consequently, in the control system according to FIG. *7a* the lever control is converted to a precision control without the need of additional provisions.

Instead of the fixed voltage dividers $W_1$, $W_2$ and $W_3$, $W_4$ variable potentiometers may be provided. The tapped-off fractions of the lateral and elevational angular velocities $\omega_{\sigma T}$ and $\omega_{\gamma T}$ may then be different from each other and can also be varied. A change in the magnitude of the tapped-off fractions of $\omega_{\sigma T}$ and $\omega_{\gamma T}$ may be particularly advantageous when the apparatus is used for low-speed objects after having been used to track high-speed objects, e.g. when going from high-speed fighter plane tracking to low-speed helicopter tracking.

The output value $\beta_T$ of the adapter is fed to an autocontrol device E. Said autocontrol device E will be explained in detail hereinafter. The equations on which the autocontrol is based may be derived from FIG. **8**. In FIG. **8** the position of the gun is denoted by O. Since it is assumed that the sight is mounted on the gun, O is also the position of the sight. The dashed line *Sp* represents the trace of the flight path in the horizontal plane and *w'* the horizontal projection of the distance *w* at impact *w'* forming with the line *Sp* and also with the straight line $Sp_o$, parallel to said line the angle $\beta_T$. The horizontal component of the distance to the change-over-point is denoted in FIG. **8** by *w'* min, the distance to the change-over-point being the shortest

distance between the position of the gun or the target acquisition device respectively and the target path.

According to FIG. 8 the equation

$$w' \cdot \sin\beta_T = w_{min}$$

is true, wherein $v_{min}$ is constant for a given tracking operation. Differentiation of the above equation with respect to time yields

$$(dw'/dt) \cdot \sin\beta_T + w' \cdot (d\beta_T/dt) \cdot \cos\beta_T = 0$$

As is apparent from FIG. 8

$$dw'/dt = w \cdot \cos\beta_T$$

wherein $w$ is the horizontal component of the velocity $v$ of the target or the velocity with which the point T' moves along the line S$p$. With

$$w' = w'_{min}/\sin\beta_T$$

it is then possible to write

$$\omega_{\beta T} = (d\beta_T/dt) = (w/w'_{min}) \cdot \sin^2\beta_T \qquad (X)$$

wherein the value $w/w'_{min}$ is constant for a given tracking operation. Equation (X) may also be written in the form

$$d\beta_T/\sin^2\beta_T = (w/w'_{min}) \cdot dt$$

the integration of which leads to

$$-\cot\beta_T = (w/w'_{min}) \cdot t + C$$

with $t = o$ ist $C = -\cot\beta$ To
It is thus possible to write

$$\beta_T(t) = \text{arc cot}\,[\cot\beta_{To} - (w/w'_{min}) \cdot t] \qquad (XI)$$

The autocontrol device illustrated in FIG. 9 includes a switch **106** which during the initial phase of the target tracking, in which the operator brings the sight to bear on the target manually, takes up the position shown in dashed line. The value $\beta_T$ calculated in the computer R and fed via the adapter D (FIG. 7) as an electrical quantity is supplied in this case to a positioning device which comprises an amplifier **108**, a servomotor **110** and a potentiometer **112** and in accordance with the value $\beta_T$ turns the shaft shown in dotted lines of the servomotor **110**, said shaft in turn pivoting the slider **116** of a potentiometer **114**. The resistance of the potentiometer **114** is proportional to $\sin^2\beta_T$. The potentiometer **114** is connected in series with a resistance **118** which is variable for adjustment purposes and a potentiometer **120** to a voltage source which supplies a constant direct or alternating voltage. The voltage tapped by the slider **116** from the potentiometer **114** is fed to the output b of the autocontrol device and to an amplifier **122**. Also supplied to the amplifier **122** is the value $\omega_{\sigma T}$ which is provided via the input a by the lever control K in the initial phase of the tracking (FIG. 7). A servomotor **124** controlled by the amplifier **122** actuates the potentiometer **120**, which is thus adjusted so that the voltage tapped at the potentiometer **114** coincides with the value $\omega_{\sigma T}$ supplied by the lever control. The value $w/w'$ min, which is constant for a given tracking operation, is thus determined. Said value $w/w'_{min}$ corresponds to the current flowing through the potentiometer **114**, which is set by adjusting the potentiometer **120**.

In accordance with equation (X) the product of $(w/w'_{min}) \cdot \sin^2\beta_T = \omega_{\beta T}$, i.e., the voltage tapped from the potentiometer **114**, is equal to $\omega_{\beta T}$. Since the angles $\sigma_T$ and $\beta_T$ differ only by a constant angle $w$, their angular velocities are identical. The value of $\omega_{\beta T}$ adjusted by the value $\omega_{\sigma T}$ supplied by the control lever K is denoted by $\omega_{\sigma T}^*$ to indicate that this is an adjusted value which when switching from manual control to automatic tracking ensures a smooth transition.

If during the initial phase of the tracking the operator has followed the target by means of the manual control accurately for a short distance, he can then switch to automatic tracking by actuating the switch S (FIG. 7). Actuation of the switch S simultaneously results in switching over of the switch **106** (FIG. 9) into the position shown in full line via the input c of the autocontrol device. The autocontrol device then no longer obtains the value $\beta_T$ from the computer but forms it in accordance with equation (XI) with the aid of the circuit including the blocks **126, 132, 134** and **136.** During automatic tracking the two inputs of the amplifier **122**, as shown in FIG. 7 are short circuited so that the position of the potentiometer **120** and thus the current flowing through the resistances **114, 118** and **120** and the value of $w/w'_{min}$ then remain constant.

On switching over to automatic tracking the switch **128** is also actuated, thus initiating in a block **126** the integration overtime $t$ of the value $w/w'$ min taken off the resistance **118.** Furthermore, on switching over the switch **130** is closed for a brief instant in order to scan the value $\beta_T$ supplied at the instant of the switching-over operation by the computer via the adapter, said value representing the value $\beta_{TO}$ for calculating $\beta_T$ from equation (XI). The value $\beta_{TO}$ is converted in block **132**, which contains a function member, into the value cot $\beta_{TO}$ and stored in this form, being fed during the automatic tracking constantly into the block **134** containing a summation circuit, where it is added to the value

$$-\int_0^t \frac{w}{w'\,\text{min}} \cdot dt$$

supplied by the integrator, thus obtaining the value cot $\beta_T$ which is converted in the block **136** containing a function converter into the value $\beta_T$. The block **136** may for example comprise a diode network for converting cos $\beta_T$ to $\beta_T$.

The value of $\beta_T$ thus produced is supplied, as was previously the value $\beta_T$ calculated by the computer, to the positioning device including the elements **108, 110** and **112,** said device actuating the slider **116** of the potentiometer **114.**

The output value $\omega_{\sigma T}^*$ of the autocontrol is fed via the output b to the lateral drive of the gun.

By integration in block **126** a continuous variation of the position of the slider **116** on the potentiometer **114** is effected and corresponds to the variation of $\beta_T$, which corresponds to a rectilinear continued motion of the target at constant velocity. After switching from manual control to automatic target tracking the value $\omega_{\beta T}$ tapped from the potentiometer **114** and leaving the autocontrol device E as $\omega_{\sigma T}^*$ is fed to the gun drives G via the switch **104** in case of the control system according to FIG. 7 and via the swtich $S_4$ and the summation device $A_2$ in case of the control system ac-

cording to FIG. 7a. Fruthermore, on switching from manual control to automatic tracking the value $\omega_{\gamma T}^*$ is fed to the gun drives via the switch **102** in case of the control system according to FIG. **7** and via the switch $S_3$ and the summation device $A_1$ in case of the control system according to FIG. *7a*. As described in connection with the adapter according to FIG. **6**, the value $\omega_{\gamma T}^*$ is adjusted in the initial phase, in which the tracking is done manually, to the value $\omega_{\gamma T}$ supplied by the control lever K via the connection *d* and consequently on switching from manual control to automatic control the value of the angular velocity of $\phi_T$ fed to the gun drives G does not exhibit a jump.

In the examples of embodiment described herein it is assumed that the sighting device is mounted on the gun W and participates in the pivot movements of the latter.

To take account of the lead and of the gravity compensation angle the values $\lambda$ and $\alpha + \mu$ from the adapter device D are fed to the sighting device V and control the position of the sighting device and gun with respect to each other. During the initial phase of the tracking, in which the operator brings the sight and the gun to bear on the target manually, the computer R supports this manual control by calculating the lead angle and the comepnsation angle.

The autocontrol device E, which after switching from manual control to automatic control automatically produces the lateral angle velocity $\omega_{\sigma T}^*$ on the basis of equations (X) and (XI), is not absolutely essential to automatic tracking. The lateral angle velocity $\omega_{\beta T}$ may also be supplied to the gun drives G from the outputs shown in dotted line in the computer. In this case, analogously to the calculated elevational angular velocity $\omega_{\gamma T}$, the calculated lateral angular velocity $\omega_{\beta T}$ is also adjusted to the lateral angular velocity $\omega_{\sigma T}$ supplied by the manual control K so that a normalized value of $\omega_{\beta T}$ is available on switching over and a smooth transition is thus ensured. In such a control arrangement without autocontrol E a continuous tracking is ensured, enhanced due to the inertia of the gun drives.

Particularly in the last-described control system without autocontrol device the possibility according to this invention of correcting the calculated values of the angular veocties after switching from manual to automatic control is very advantageous. It may be convenient to correct only the lateral angular velocity and to dispense with a correction of the elevational angular velocity which is calculated in the computer in accordance with equation (IV). This may be done in the control system according to FIG. *7a* by opening the switch $S_5$ before commencement of a target tracking. It may also be expedient for certain high speed aerial targets to dispense with the possibility of making a correction from the start. In this case, the switches $S_5$ and $S_6$ are opened before commencement of the target tracking by actuating the so-called autoswitch $S_2$.

In the drawings and specification, there have been set forth preferred embodiments of the invention and although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation. It will be apparent to those skilled in the art, to whom the disclosure is directed, that variations and modifications may be made without departing from the essence of the invention which should be broadly construed in view of the valuable technological development disclosed.

What is claimed is:

**1.** A method of controlling motor-driven devices mounted on two axes and adapted to be directed onto a moving target, the motion of which is assumed to be rectilinear uniform, and wherein the target is manually tracked at least during initial tracking of the target by controlling at least one of the devices to follow the target, comprising the steps of continuously deriving signals of the lateral angle $\sigma$ and of the elevation angle $\phi$ from the device to the target in accordance with the manual tracking, supplying the derived signals to computer means, supplying the computer means with signals corresponding to the target velocity $v$ and the angle of inclination $\epsilon$ of the target path with respect to the horizontal plane, and processing by the computer means of the supplied signals to calculate control quantities for each axis which quantities are to be supplied to the motor-driven devices for substantially automatically controlling the drive thereof.

**2.** A method according to claim **1**, wherein the step of processing includes representing the target motion in polar coordinate form in a cotangent plane, and representing the angle of inclination $\epsilon$ by an angle $\psi$ arranged in the cotangent plane and lying between the projection of the target path on the cotangent plane and the projection on the cotangent plane of the projection of the target path in the horizontal plane.

**3.** A method according to claim **2**, including the step of estimating the target velocity $v$.

**4.** A method according to claim **2**, including the step of estimating the angle of inclination $\epsilon$ of the target path.

**5.** A method for changing from manual to automatic control of motor-driven devices adapted to be directed onto moving targets, comprising the steps of manually tracking the target and manually controlling the generation of signal values in the form of control quantities of the lateral angular velocity $\omega_\sigma$ and the elevational angular velocity $\omega_\gamma$, supplying the control quantities to the drive of the device adapted to be directed onto the target, generating signals in a computer means on the basis of the manually generated signal values of the angular velocities of control quantities of the lateral angular velocity $\omega_\sigma^*$ and of the elevational angular velocity $\omega_\gamma$ to obtain an anticipatory control function for at least one of facilitating and automating the target tracking, and after accurately manually directing the motor-driven device onto the target changing from manual to automatic control by at least partially replacing the manually generated control quantity signal values supplied to the device by the computer generated control quantity signal values.

**6.** A method according to claim **5**, including the step of adjusting the computer generated signal values $\omega_\sigma^*$ and $\omega_\gamma$ of the lateral and elevational angular velocities to the manually generatd signal values of such angular velocities prior to changing from manual to automatic control.

**7.** A method according to claim **5**, wherein the step of replacing the manually generated control quantities by the computer generated control quantities includes only partially replacing the manually generated control quantities such that a fraction of about 3–20 percent of the manually generated control quantities are supplied

to the drive of the device for manual correction of the tracking.

8. A method according to claim 7, including the step of continuously adjusting the fraction of the lateral and elevational angular velocities which are supplied to the drive of the device after changing to automatic control.

9. A method according to claim 5, wherein the motor-driven device is a gun having a target acquisition device mounted thereon and participating in the movements thereof, durther including the steps of generating signals in the computer means of lead angles $\lambda$ and $\mu$ and gravity compensation angle $\alpha$ for the gun, moving the target acquisition device with respect to the barrel axis of the gun by the lead angles $\lambda$ and $\mu$ and the gravity compensation angle $\alpha$, and accounting for the variation with time $\omega_\alpha$ of the gravity compensation angle $\alpha$ in generating the computer signal values of the lateral and elevational angular velocities for the gun.

10. An apparatus for controlling motor-driven devices mounted on two axes and adapted to be directed onto a moving target, the target being followed by at least one of the devices, comprising means for deriving signal values of the lateral angle $\sigma$ and the elevation angle $\phi$ from the device to the target, first means for supplying the derived signal values to computer means, second means for supplying the computer means with signals corresponding to the target velocity $v$ and the angle of inclination $\epsilon$ of the target path with respect to the horizontal plane, said computer means including a first computer unit for processing the supplied signal values in accordance with the equations

$\sin \psi / \sin (\beta + \psi) = \tan \epsilon \cdot \cot \gamma$;

$h_c \cdot \cot \gamma \, \Delta \beta / \Delta (h_c \cdot \cot \gamma) = \cot (\beta + \psi)$

to provide signal values of at least one of the angles $\psi$ and $\beta$ and trigonometrical functions thereof, and a second computer unit means responsive to the output signal values of the first computing unit for generating signal values in accordance with the equation

$$\omega_\gamma = 0.5 \sin 2\gamma, \cot (\beta + \psi) \cdot \omega_\beta$$

to provide a signal value of the elevational angular velocity $\omega\gamma$, said second computer unit further including means for at least one of differentiating the output signal value $\beta$ of the lateral angle and forming differences between the output signal values of $\beta$ to provide a signal value of the lateral angular velocity $\omega_\beta$.

11. An apparatus according to claim 10, wherein said computer means generates a signal of the distance to the target in accordance with the equation

$$w = m\, h_c - \omega \cdot (t + t_G) \cdot \sin \epsilon / \sin \gamma.$$

and ballistic computer means responsive to the output signal of the range for generating signal values of the gravity compensation angle $\alpha$ and the projectile flight time $t_G$.

12. An apparatus according to claim 11, wherein said computer means further includes multiplying computer unit means responsive to the output of said second computer unit means and said ballistic computer means for generating signal values of the tangent of the elevational lead angle $\mu$ and of the lateral lead angle $\lambda$ in accordance with the equations

$\tan \mu = \omega_\gamma \cdot t_G$ and

$\tan \lambda = \omega_\beta \cdot t_G$, and

and function converter means responsive to the output signal values of said multiplying computer unit means for obtaining the inverse function of the output signal values to provide signal values of $\mu$ and $\lambda$.

13. An apparatus according to claim 12, further comprising autocontrol means including a sine squared potentiometer whose resistance varies with the rotation of a slider in accordance with the square of the sine of the angle of rotation and a first self-balancing control circuit responsive to the output of the computer means for swinging the slider of the sine squared potentiometer in accordance with the signal value generated by the computer means of the lateral angle $\beta$ to provide a resistance value of $\sin^2 \beta$, a second control circuit for adjusting the slider of a current regulating potentiometer for setting the current flowing through the sine squared potentiometer to a value, constant for a given tracking operation, of the quotient $w/w'_{min}$ formed from the horizontal component $w$ of the target velocity $v$ and the minimum value $w'_{min}$ of the horizontal component of the target range, the setting being effected by adjusting the voltage tapped from the sine squared potentiometer in accordance with the equation

$$\omega_\beta = -w/w'_{min} \cdot \sin^2 \beta$$

and corresponding to the lateral angular velocity $\omega_\beta$ by the voltage signal value $\omega_\sigma$ of the lateral angular velocity supplied by a control lever for effecting manual tracking, an integrator for generating a signal of cot $\beta$ in accordance with the equation

$$\cot \beta = -\int_0^t \frac{w}{w'_{\min}} dt,$$

a function converter for converting the signal cot $\beta$ to the signal value $\beta$, and a switch means being operated to change from manual control to automatic control to replace the signal value of $\beta$ generated by the computer means by the signal value $\beta$ generated by said function converter.

14. A method of tracking a target by an operator directing a motor-driven device onto a moving target wherein the motor-driven device is a target acquisition device, comprising the steps of manually tracking the target and manually generating signal values in accordance with the manual tracking, supplying the manually generated values to the drive for the device and to a computer means, generating signal values in the computer means on the basis of the manually generated signal values, the computer generated signal values being adapted to be supplied to the drive of the device, and supplying the computer generated signal values to the drive of the device in place of the manually generated signal values at a time selected by the operator when the manual tracking of the traget has been determined to be of approximately the greatest possible accuracy.

15. A method according to claim 14, wherein the step of manually tracking the target and manually generating signal values for controlling the drive of the device includes tracking the target for a period of time sufficient to ensure that the motion of the target acquisition device corresponds to the motion of the target.

16. A method according to claim 14, wherein the step of manually tracking the target and manually generating signal values for controlling the drive of the device includes manually directing the target acquisition device along the path of the target such that the motion

of the target acquisition device corresponds to the motion of the target.

17. An apparatus for changing from manual to automatic control of motor-driven devices adapted to be directed onto moving targets, comprising a manual control for supplying signal values of the lateral angular velocity and of the elevational angular velocity for controlling the motor-driven devices, computer means responsive to the signal values of the lateral and elevational angles from the manual control for generating signal values $\omega_\sigma^*$ and $\omega_\gamma^*$ of the lateral and elevational angular velocities for the drive of the devices, two summation devices, said computer means including an anticipatory control means, the generated signals of control quantities being fed to the anticipatory control means for at least one of the functions of facilitating and automating the target tracking, the signal values $\omega_\sigma$ and $\omega_\gamma$ of the lateral and elevational angular velocities from the manual control being fed directly to the first input of said two summation devices whose output signal values are fed to the drives of the devices, and a fraction of about 5 – 20 percent of the signal values $\omega_\sigma$ and $\omega_\gamma$ of the lateral and elevational angular velocities supplied by the manual control being fed via voltage divider means to a second input of said two summation devices, and a change-over switch means being provided in the connection between the manual control and the summation devices for supplying the signal values $\omega_\sigma^*$ and $\omega_\gamma^*$ of the lateral and elevational angular velocities generated by the computer means to the first input of the summation devices.

* * * * *