June 8, 1948. G. E. WHITE ET AL 2,442,792

APPARATUS FOR DETERMINING FUSE SETTING DATA

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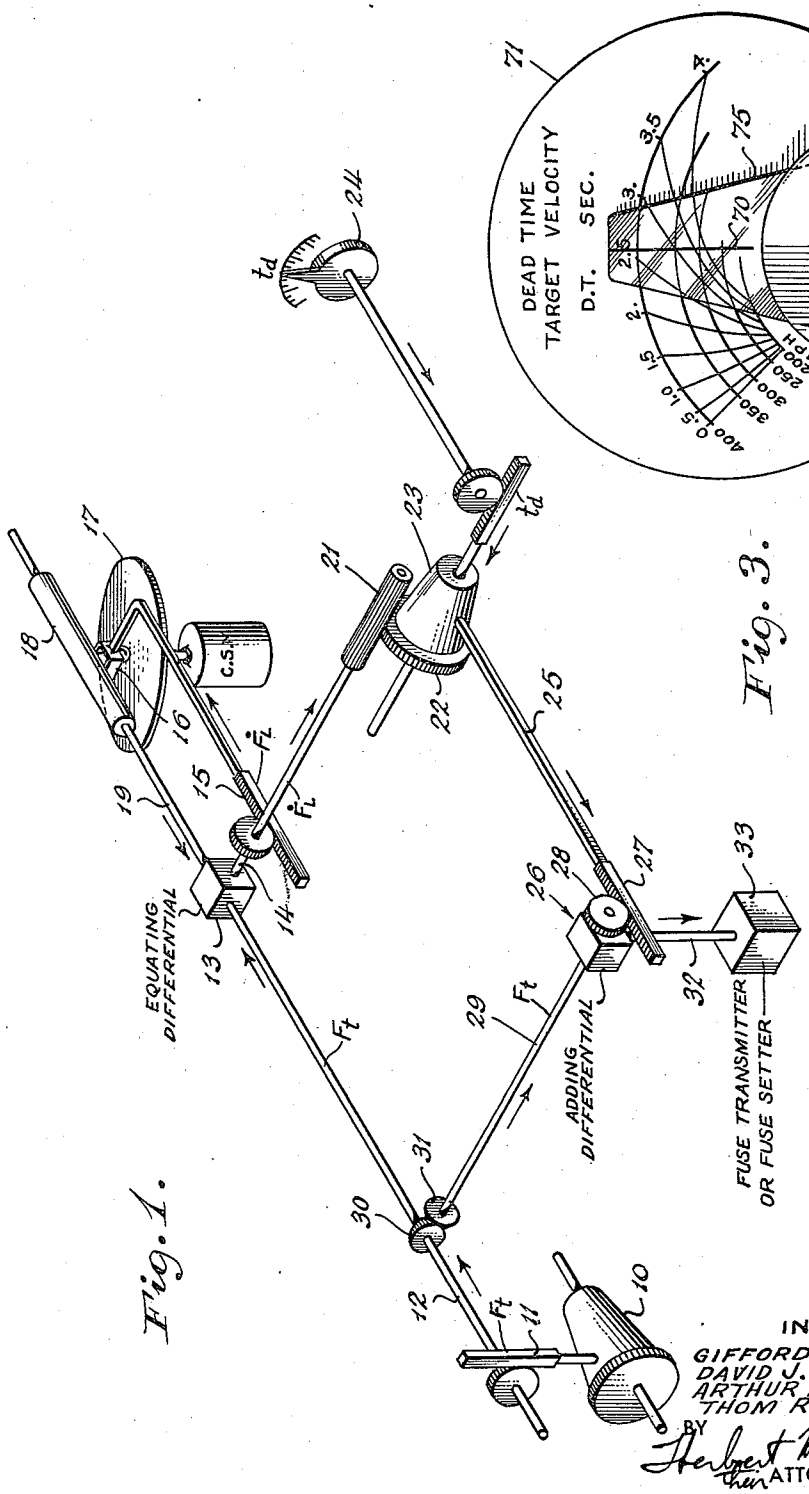


Fig. 1.

Fig. 3.

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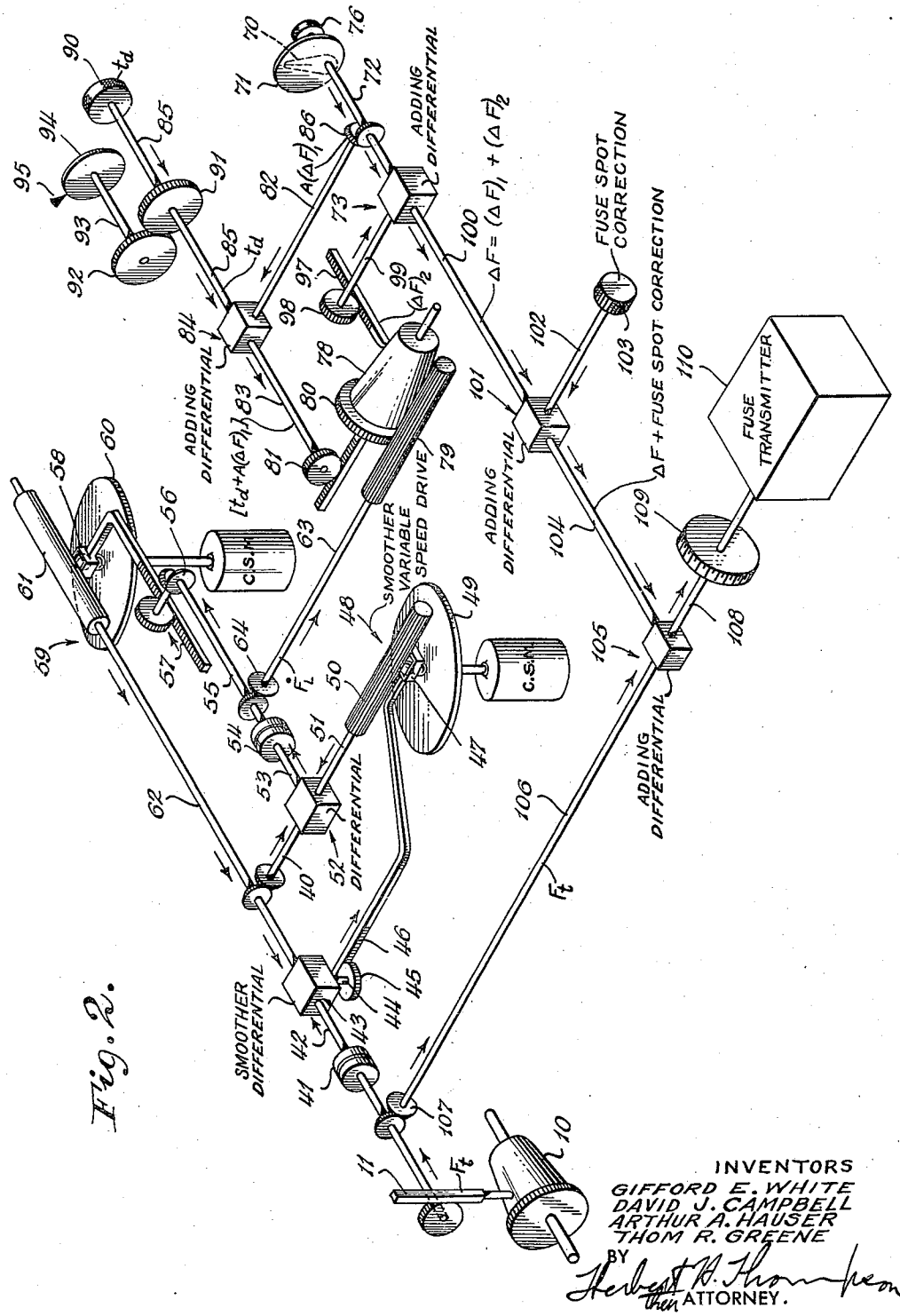


Fig. 2.

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APPARATUS FOR DETERMINING FUSE SETTING DATA

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12 Claims. (Cl. 235—61.5)

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This invention relates to a fuze dead time prediction circuit for gun directors.

An object of the invention is to provide a simplified fuze dead time computing device which will give a more accurate solution than existing devices.

Another object of the invention is to provide an improved fuze dead time computing device which may be installed in existing gun directors.

Known gun directors when computing gun aiming angles also compute the fuze setting required to cause the projectile to explode at some predetermined point in its trajectory. In the process of firing an anti-aircraft gun, for example, the fuze of the projectile must be set before the instant of firing. The computing apparatus of the director accordingly must predict at each instant of time, t, the aiming coordinates of the gun for a shot fired at time, t, and also the fuze setting for a short fired at time, $t+t_d$, where t_d is used to indicate the fuze dead time period between the setting of the fuze and the firing of the shot. The two predictions, correspond to two future positions on the path of the target and hence an exact solution to this problem is to construct the equivalent of two directors, which procedure, however, is too complex to merit serious consideration. The alternative is to construct a fuze prediction circuit which utilizes measures which are correct at time t in order to anticipate or generate a fuze setting for time $t+t_d$.

In known directors such as the "M7" and "T20," fuze rate is obtained and multiplied by dead time to obtain prediction. This solution is almost adequate, but the residual systematic errors are still large enough to cause a search for a better approximation. These directors, now used by the armed forces, are well known to artillery officers and are described in various manuals published by the War Department. The "M7" director is described in Technical Manual No. 9–2658 published by the War Department. The "T20" is described in manual No. 14–8085B published by the Sperry Gyroscope Company, Inc., which is available to authorized persons.

Certain directors, have a shaft actuated according to fuze time (F_t). The mechanism for actuating this shaft is not a part of the present invention and therefore is not shown in detail. In the case of the "M–7" director, the shaft is displaced by a lift pin which cooperates with a fuze cam displaced in rotation according to future range and translated according to future altitude. The cam is constructed so that the lift imparted thereby to the lift pin is proportional to the fuze time (F_t) required for all points governed by the

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two factors by which the cam is displaced. However, the fuze of the projectile must be set before it is inserted into the breach of the gun and the operation of setting the fuze and loading may take two to four seconds for manual loading, and around one second or less for automatic ramming. This time interval between setting the fuze and firing the gun is known as fuze dead time (t_d).

If no correction were made for the fuze dead time, the fuze would be set according to the fuze time (F_t) that was correct, say about two seconds before the projectile was fired, and could amount to a difference in shell burst position and target position up to three hundred yards. To prevent this error, a correction or a prediction (ΔF) is computed by the present invention and added to (F_t). In connection with the description of the invention, the specification will refer to a quantity (F_L) which is a lagging measure of fuze rate computed by a rate measuring mechanism. The output of this mechanism has an inherent lag with respect to instantaneous fuze time (F_t) and therefore is referred to as a lagging measure of fuze rate (F_L).

The invention will now be described with the aid of the accompanying drawings, of which

Figs. 1 and 2 show schematically two different embodiments of the invention; and

Fig. 3 shows a dial arrangement used with the second embodiment of the invention.

A first embodiment of the invention is a rather simple mechanism which is shown in Fig. 1 where fuze cam 10 is a part of a cam assembly of a director, the cam being displaceable in rotation and translation by suitable mechanism, usually in accordance with future range and altitude. Cam 10 is laid out so as to displace its lift pin 11 in accordance with fuze time F_t.

In the present invention, lift pin 11 turns shaft 12 connected with an input of differential 13. An output shaft 14, through a rack and pinion arrangement 15 controls the displacement of the ball carriage 16 of a variable speed drive having a disc 17 driven at constant speed and a cylinder 18 which drives shaft 19 connected to a second input of differential 13. This arrangement is well known. Initial displacement of shaft 12 effects a displacement of shaft 14 and ball carriage 16 from the center of the disc causing cylinder 18 to turn. The rotary movement of the cylinder at some position of the ball carriage will balance that of shaft 12 and in this position of equilibrium, the displacement of the ball carriage and shaft 14 is a lagging measure of fuze rate (F_L),

since the positioning of shaft 14 will always lag somewhat any change in position of cam pin 11.

Shaft 14 turns long pinion 21 meshing with gear 22 on cam 23. The cam is moved in translation in accordance with fuze dead time t_d by fuze dead time knob 24. The cam actuates a lift pin 25 which displaces one input of a differential 26 by means of a rack 27 and a gear 28.

The second input of differential 26 is displaced according to F_t by shaft 29 which is driven from shaft 12 by gears 30 and 31.

These displacements are added in the differential 26 whose output shaft 32 furnishes the data for the operation of a fuze setter or fuze transmitter indicated diagrammatically by the box 33.

The lagging measure of fuze rate ($\dot{F}_L$), represented by the displacement of shaft 14 is slightly in error due to neglect of terms of higher order than the rate term in a fuze curve. The cam 23 is laid out empirically to approximately compensate for such errors and at the same time to multiply its input displacements, thus making the fuze prediction more nearly correct than in the former rate multiplied by time method.

The method of laying out a cam such as cam 23 is well known to those skilled in ballistics. Ballistic tables furnished by the Government, among other information, give accurate data for the position of a projectile at each unit time of flight. From this information, curves may be drawn representing the trajectory of the projectile as compared with the fuze curve for a suitable range of fuze dead time values.

Generally speaking, there will be a discrepancy between the true fuze curve and a fuze curve computed on the basis of the rate of change of fuze multiplied by fuze dead time, due principally to neglect of terms higher than the rate term in the latter curve.

By similar graphic procedure, it is not difficult to lay out a cam 23 according to the present invention, actuated according to the lagging measure of fuze rate $\dot{F}_L$ in one dimension and by fuze dead time in another dimension, whose output closely follows the true fuze curve.

The solution obtained by the circuit of Fig. 2 is made more accurate than that of Fig. 1 by taking target speed into account. The mechanism which is shown schematically, for greater clearness, is actually so designed as to fit into existing directors to replace the present fuze rate multiplied by time type of computer.

Any suitable means providing a lagging measure of fuze rate ($\dot{F}_L$) may be used with the invention, such as the known circuit which will now be described briefly. This circuit includes a known smoothing mechanism by which spurious perturbations on the input shaft, usually due to inaccurate tracking, are smoothed out.

As in the previous embodiment, fuze cam 10 of the director displaces lift pin 11 which actuates shaft 12 in accordance with fuze time F_t. Shaft 12 is coupled by slip clutch 41 to an input 42 of a smoother differential 43. Output shaft 44 of differential 43 is coupled by gear 45 and rack 46 to ball carriage 47 of a smoother variable speed drive 48. The disc 49 of the variable speed drive is driven at constant speed and cylinder 50 is driven thereby. Cylinder 50 turns an input shaft 51 of an equating differential 52 having an output shaft 53 coupled by slip clutch 54 to shaft 55 carrying gear 56 which displaces through suitable gearing a rack 57 connected to ball carriage 58 of a rate measuring variable speed drive 59. This variable speed drive is provided with a disc 60 driven at constant speed and a cylinder 61. The latter is connected to an input shaft 62 of differential 43 and also to an input shaft 40 of differential 52. The output member of the assembly of mechanism just described is a shaft 63 connected to shaft 55 by bevel gears 64. The displacement of shaft 63 is controlled by the position of ball carriage 58 and represents a lagging measure of fuze rate ($\dot{F}_L$). Because of the delays in the mechanical circuits just described, the generated measure of fuze rate will be lagging the exact rate. The ball carriage 58 of the rate measuring variable speed drive 59 will be displaced in such a direction as to tend to make the rate of the rate measuring variable speed cylinder 61 equal to the rate of the smoothing variable speed drive cylinder 50. Under these conditions, the displacement of output shaft 53 of the differential which displaces ball carriage 58 represents a lagging measure of fuze rate, $\dot{F}_L$.

Generally speaking, the smoothing mechanism is used to average out errors in fuze time F_t due primarily to faulty tracking. The output of smoother differential 43 effects corresponding changes in the rate of the smoother variable speed drive 48. This variable speed drive is designed so that a change in the output of differential 43 will cause a relatively slow change in the rate of its cylinder 50. This is accomplished by choosing suitable gear ratios in all gear trains and also by selecting the proper disc speeds of the variable speed drives. Thus, if the input rate is subject to occasional brief perturbations, such perturbations will have little effect on the smoother cylinder rate before the input rate has returned to its true value. By judiciously selecting all gear ratios and disc speeds, the smoothing circuit can be designed to effect a relatively smooth measure of fuze rate, $\dot{F}_L$.

The fuze dead time circuit of the second embodiment of the invention effects total fuze dead time prediction ΔF by differentially adding two components of prediction $(\Delta F)_1$ and $(\Delta F)_2$. The first of these quantities is a quantity dependent upon fuze dead time, t_d and target velocity (V_T), only. An angular displacement proportional to $(\Delta F)_1$ is introduced by positioning the index 70 of the $(\Delta F)_1$ dial 71, Fig. 3, according to fuze dead time, t_d, and an estimate of target velocity (V_T).

Dial 71 is so laid out that when index 70 is positioned according to the appropriate values of target velocity and dead time engraved on the dial, shaft 72 on which the index is mounted will be displaced in proportion to $(\Delta F)_1$. Shaft 72 is connected to one input of adding differential 73.

A preferred form of dial and index is shown in Fig. 3. The index 70 is marked on a transparent arm 75 attached to knob 76 which is mounted on shaft 72. The $(\Delta F)_1$ dial 71 is preferably laid out as shown in the drawing with a number of spaced curved lines approximately concentrically disposed with respect to the center of rotation of the index arm representing respectively different target velocities in miles per hour. These lines are intersected by others calibrated according to fuze dead time in fractions of seconds. The layout of the dial is empirical and is based on a study of ballistic curves for the particular ammunition used, to give at each intersection of the curves the displacement of shaft 72 proportional to $(\Delta F)_1$ required for the particular operating conditions.

The second component of fuze dead time pre-

diction $(\Delta F)_2$ is a quantity which is dependent upon the generated measure of the time rate of change of fuze $\dot{F}_L$, and the quantity t_d plus $A(\Delta F)_1$, where "A" is an empirical constant. An angular displacement proportional to $(\Delta F)_2$ is effected by the $(\Delta F)_2$ three dimension cam **78**.

Cam **78** is rotated in proportion to $\dot{F}_L$, the output lagging measure of fuze rate, by means of a long pinion **79** on shaft **63** which meshes with gear **80** formed at one end of the cam.

The cam is translated proportionately to $[t_d+A(\Delta F)_1]$ by means of a gear **81** which meshes with a rack attached to the cam. Gear **81** is driven by output shaft **83** of differential **84**. One input to this differential is a shaft **82** connected by gears **86** to shaft **72**. Gears **86** multiply the displacement of shaft **72** by an empirical constant "A" whereby this input to differential **84** is $A(\Delta F)_1$. The other input to differential **84** is a shaft **85** displaced in proportion to fuze dead time. A t_d knob **90** is mounted on shaft **85** which is connected by gears **91**, **92** and shaft **93** to t_d dial **94** which cooperates with stationary index **95**. Displacement of shaft **85** takes place when knob **90** is moved to position the appropriate fuze dead time value on dial **94** opposite index **95**.

When cam **78** is displaced in rotation and translation as described, the lift of its lift pin **97** represents $(\Delta F)_2$. A rack on the lift pin meshes with gear **98** which turns shaft **99** connected to an input of adding differential **73**. The displacement of output shaft **100** of differential **73** is proportional to total prediction ΔF, or $\Delta F=(\Delta F)_1+(\Delta F)_2$.

Shaft **102** is an input for a fuze spot correction differential **101** having a second input **102** operated by fuze spot knob **103**. Output shaft **104** of the differential whose displacement is equal to ΔF plus fuze spot correction is connected to an input of differential **105** which adds the displacement of shaft **104** with that of shaft **106** which is proportional to fuze time F_t. Shaft **106** is connected by gears **107** to shaft **12**. The output shaft **108** of differential **105** operates fuze dial **109** and a fuze transmitter, indicated by the box **110**, which usually is used to operate an automatic fuze setting device at the gun location.

Cam **78** is laid out empirically in accordance with a suitable function of $\dot{F}_L$ so that the lift pin will be displaced in accordance with the product of the function and $[t_d+A(\Delta F)_1]$. For example, the cam may be constructed according to the following equation:

$$(\Delta F)_2=\dot{F}_L(1.025+.05\dot{F}_L)[t_d+A(\Delta F)_1]$$

As already pointed out, A is an empirical constant, and the functions $(\Delta F)_1$ and $(\Delta F)_2$ may also be expressed by empirical equations. The optimum value of A and the mathematical expressions which are used to represent $(\Delta F)_1$ and $(\Delta F)_2$ are dependent upon (1) the sensitivity conconstant (or constants) of the differentiating circuit, and (2) the ballistics of the ammunition. These empirical expressions can be determined by studying ballistic tables for the particular problem to give accurate corrections for targets which are flying straight line constant velocity courses.

The solution just described requires but two initial settings, one of which is a setting of dead time and a second setting which refines fuze dead time prediction according to an estimate of target velocity. After these settings have been made, the device will generate a relatively smooth

measure of fuze dead time prediction more accurately than former devices and with a comparatively simple mechanism.

As many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. In a fuze dead time prediction circuit, a shaft displaced according to fuze time, a rate measuring means controlled by said shaft for obtaining a measure of fuze rate, a three dimension cam displaced in one dimension by the rate measuring means in accordance with fuze rate, means for displacing the cam in a second dimension according to fuze dead time, a lift pin for the cam, the cam being so laid out as to displace the lift pin in proportion to the product of a function of fuze rate and fuze dead time which represents a corrected prediction value, differential means having input members controlled by said shaft and said lift pin and having an output member displaced in proportion to the sum of the displacements of the input members, and a fuze transmitter controlled by the output member.

2. In a fuze dead time prediction circuit, means for deriving a first prediction component which is dependent on fuze dead time and target velocity, means for obtaining a second component of prediction comprising a three dimension cam, means for positioning the cam in one dimension according to fuze rate, means for positioning the cam in another dimension in accordance to fuze dead time and the first prediction component, a lift pin for the cam, the cam being so laid out as to displace the lift pin in proportion to a second prediction component, and means for producing a measure of total fuze dead time prediction which comprises a differential having one input controlled by the first mentioned means in proportion to the first prediction component and the other input controlled by the lift pin in proportion to the displacement thereof, and an output member for the differential, the displacement of which is proportional to total fuze dead time prediction.

3. In a fuze dead time prediction circuit, means providing a measure of fuze time, a shaft displaced thereby, a rate measuring device controlled by the shaft for obtaining a measure of fuze rate, a three dimension cam, a lift pin therefor, means controlled by the rate measuring device for displacing the cam in one dimension, a differential mechanism provided with a pair of inputs having an output shaft mechanically coupled with the cam for displacing the same in another dimension, means for operating one input of the differential mechanism in accordance with fuze dead time, means for operating the other input of the differential mechanism in accordance with target velocity and fuze dead time, the cam being laid out to displace the lift pin in proportion to the product of a function of fuze rate and fuze dead time which product represents a corrected prediction value, and fuze data transmission means jointly controlled by the first mentioned shaft and the lift pin in accordance with the sum of their displacements.

4. In a fuze dead time prediction circuit, means providing a measure of fuze time, a shaft

displaced thereby, a rate measuring device controlled by the shaft for obtaining a measure of fuze rate, a three dimension cam, a lift pin therefor, means controlled by the rate measuring device for displacing the cam in one dimension, a differential mechanism provided with a pair of input members, respective means for actuating the members manually in accordance with fuze dead time, and fuze dead time and target velocity, an output member for the differential mechanism coupled with the cam for displacing the same in a second dimension, the cam being laid out to displace the lift pin in accordance with the product of predetermined functions of fuze dead time and fuze rate which product represents a corrected prediction value, and fuze data transmission means jointly controlled by the first-mentioned shaft and the lift pin in accordance with the sum of their respective displacements.

5. In a fuze dead time prediction circuit, means providing a measure of fuze time, a shaft displaced thereby, a rate measuring device controlled by the shaft for providing a measure of fuze rate, a three dimension cam, a lift pin therefor, means controlled by the rate measuring device for displacing the cam about its axis, a differential mechanism having a pair of input members and an output member coupled with the cam for displacing the same in translation, manual means for displacing a first of the inputs in accordance with fuze dead time, other manual means for actuating the second of the inputs in accordance with target volecity and fuze dead time, the cam being laid out to displace the lift pin in accordance with the product of predetermined functions of fuze dead time and fuse rate which represents a corrected prediction value, adding differential means jointly controlled by the first mentioned shaft and the lift pin, and means for transmitting fuze data controlled by the output of the last mentioned differential means.

6. In a fuze dead time prediction circuit, means providing a measure of fuze time, a shaft displaced thereby, a rate measuring device controlled by the shaft for providing a measure of fuze rate, a three dimension cam, a lift pin therefor, means controlled by the rate measuring device for displacing the cam on its axis, a pair of manually operable knobs respectively provided with cooperating dials and shaft, a differential mechanism operable by the shaft of a first of the knobs according to a predetermined function of fuze dead time, a mechanical connection between the shaft of the second of the knobs and the differential mechanism for operating the differential mechanism in accordance with a predetermined function of fuze dead time and target velocity, an output number for the differential mechanism operatively connected with the cam for displacing the same in translation, the cam being laid out to displace the lift pin in accordance with the product of predetermined functions of fuze dead time and fuze rate which represents a prediction value, adding differential means jointly controlled by the first mentioned shaft, the shaft of the second knob of the pair and the lift pin, and means for transmitting fuze data controlled by the output of the last-mentioned differential means.

7. In a fuze dead time prediction circuit, means providing a measure of fuze time, a shaft displaced thereby, a rate measuring device controlled by the shaft for providing a measure of fuze rate, a three dimension cam, a lift pin therefor, means controlled by the rate measuring device for displacing the cam on its axis, a pair of shafts, a differential mechanism having one input actuated by a first shaft of the pair, a second input for the differential, means including multiplying gearing for actuating the latter input from the second shaft of the pair, manual means for actuating the first shaft of the pair in accordance with fuze dead time, a knob having a cooperating scale for actuating the second shaft in accordance with target velocity and fuze dead time, an output member for the differential mechanism operatively connected with the cam for displacing the same in translation, the cam being laid out to displace the lift pin in accordance with the product of predetermined functions of fuze dead time and fuze rate which represents a prediction value, adding differential means jointly controlled by the first mentioned shaft, the shaft of the second knob of the pair and the lift pin, and means for transmitting fuze data controlled by the output of the last mentioned differential means.

8. In a fuze dead time prediction circuit, means providing a measure of fuze time, a shaft displaced thereby, a rate measuring device controlled by the shaft for providing a measure of fuze rate, a three dimension cam, a lift pin therefor, means controlled by the rate measuring device for displacing the cam about its axis, a pair of manually controlled shafts, a differential mechanism having a plurality of inputs, one being actuated by a first shaft of the pair in accordance with fuze dead time, means for displacing the second shaft of the pair in accordance with fuze dead time and target velocity which represents a first prediction component, means including multiplying gear means operatively connecting the second shaft with a second input of the differential mechanism for displacing the same in accordance with the product of the first prediction component and a predetermined constant, an output member for the differential mechanism operatively connected with the cam for displacing the same in translation, the cam being laid out to displace its lift pin in accordance with a second prediction component, and means for adding the first and second components to obtain total fuze dead time prediction which comprises a differential mechanism jointly controlled by the lift pin and the second shaft.

9. In a fuze dead time prediction circuit, means providing a measure of fuze time, a shaft displaced thereby, a rate measuring device controlled by the shaft for providing a measure of fuze rate, a three dimension cam, a lift pin therefor, means controlled by the rate measuring device for displacing the cam about its axis, a pair of manually controlled shafts, a differential mechanism having a plurality of inputs, one being actuated by a first shaft of the pair in accordance with fuze dead time, means for displacing the second shaft of the pair in accordance with fuze dead time and target velocity which represents a first prediction component, means including multiplying gear means operatively connecting the second shaft with a second input of the differential mechanism for displacing the same in accordance with the product of the first prediction component and a predetermined constant, an output member for the differential mechanism operatively connected with the cam for displacing the same in translation, the cam being laid out to displace its lift pin in accordance

with a second prediction component, means for adding the first and second components to obtain total fuze dead time prediction which comprises a differential mechanism jointly controlled by the lift pin and the second shaft, means for adding total fuze dead time to fuze time comprising a differential mechanism actuated by the output of the last mentioned differential mechanism and by the first mentioned shaft, and fuze data transmission means controlled by the output of the last mentioned differential mechanism.

10. A fuse dead time prediction circuit according to claim 4 in which the rate measuring device comprises a pair of cooperating variable speed mechanisms, one being for the purpose of smoothing the fuze time data of the first mentioned shaft and the other being for the purpose of measuring fuze rate.

11. A fuze dead time prediction circuit according to claim 7 in which the rate measuring device comprises a pair of variable speed mechanisms, one being for the purpose of smoothing the fuze time data from the first mentioned shaft and the other being jointly controlled by said shaft and the smoothing variable speed mechanism for the purpose of measuring fuze rate.

12. A fuze dead time prediction circuit according to claim 8 in which the rate measuring device comprises a pair of cooperating variable speed mechanisms, one for the purpose of smoothing fuze time data from the first mentioned shaft and the other for measuring the rate of change of the data.

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