March 14, 1967 J. PETERS 3,308,760

PASSIVE MAGNETIC PROXIMITY FUSE

Filed Nov. 29, 1962

4 Sheets-Sheet 1

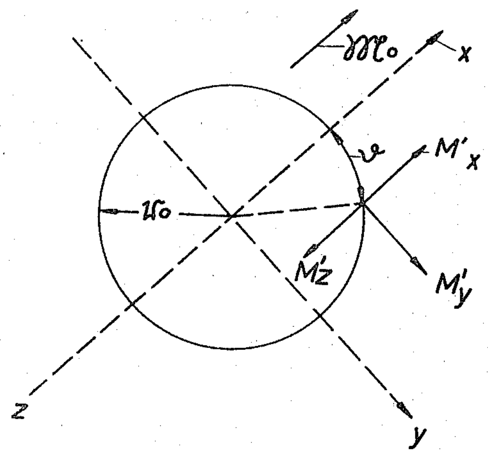
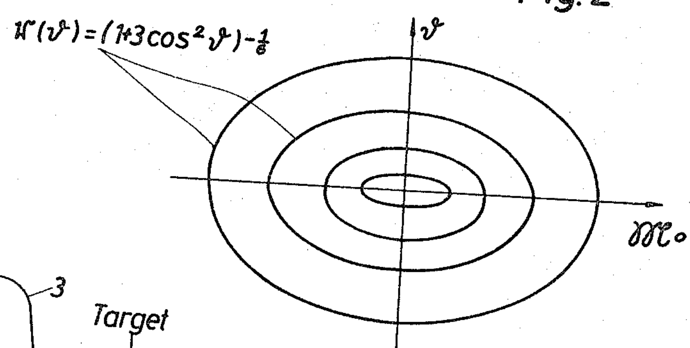


Fig.1

Fig. 2



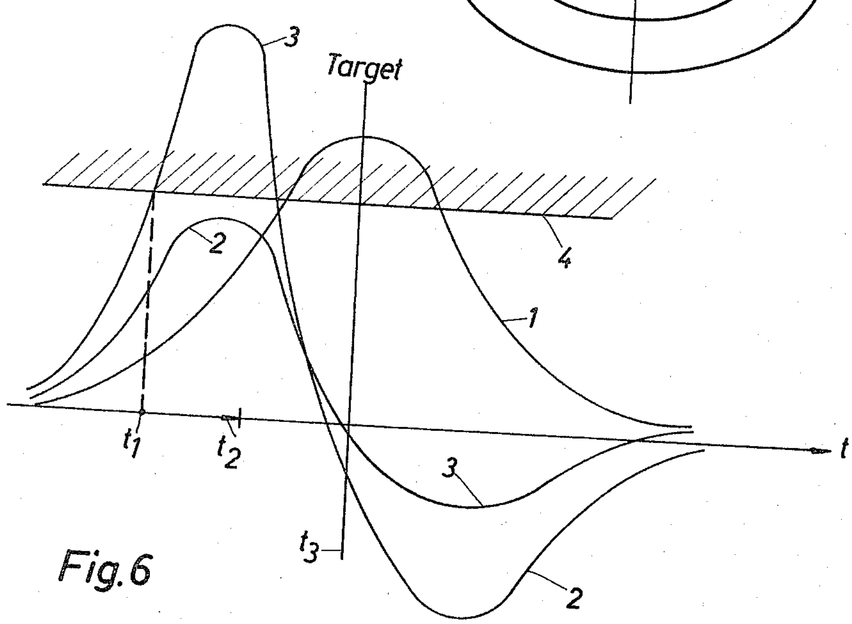


Fig.6

INVENTOR

Johannes Peters

By McGlew and Toren

ATTORNEYS

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Fig. 3

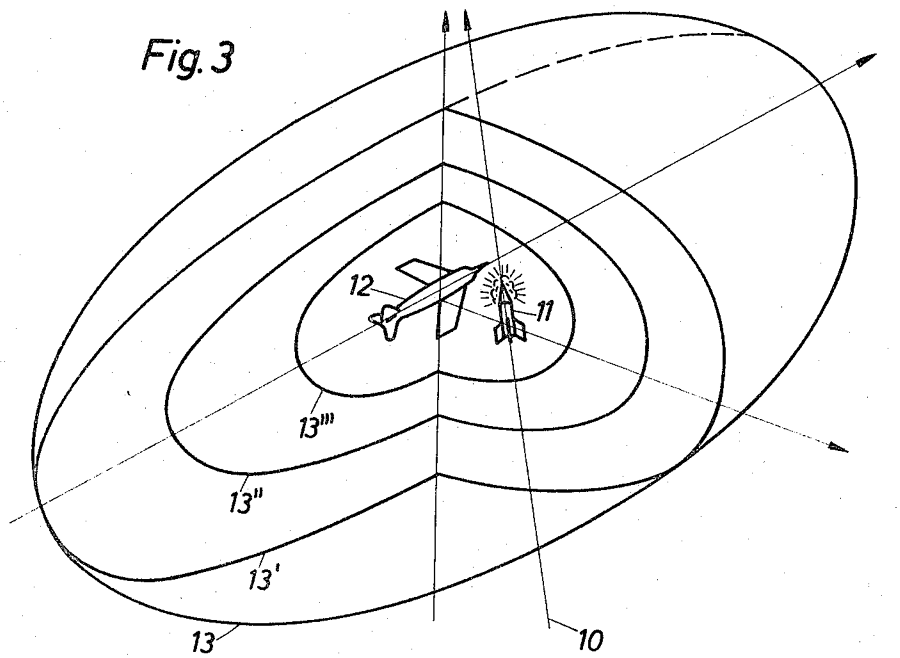
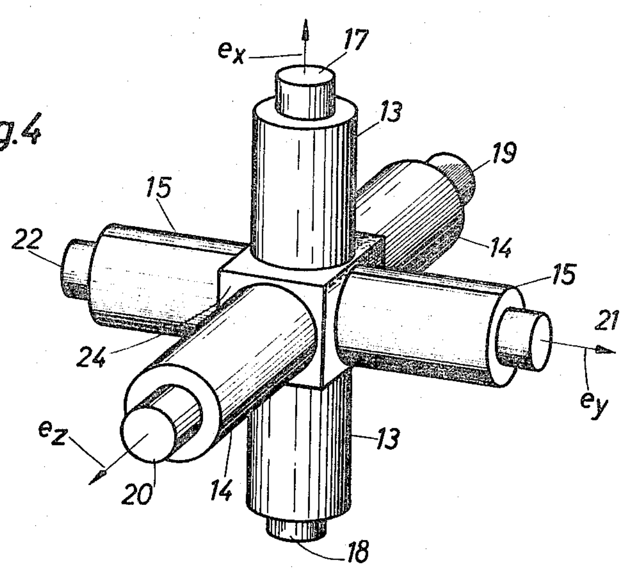


Fig. 4



INVENTOR

Johannes Peters

By McGlew and Toren

ATTORNEY

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PASSIVE MAGNETIC PROXIMITY FUSE

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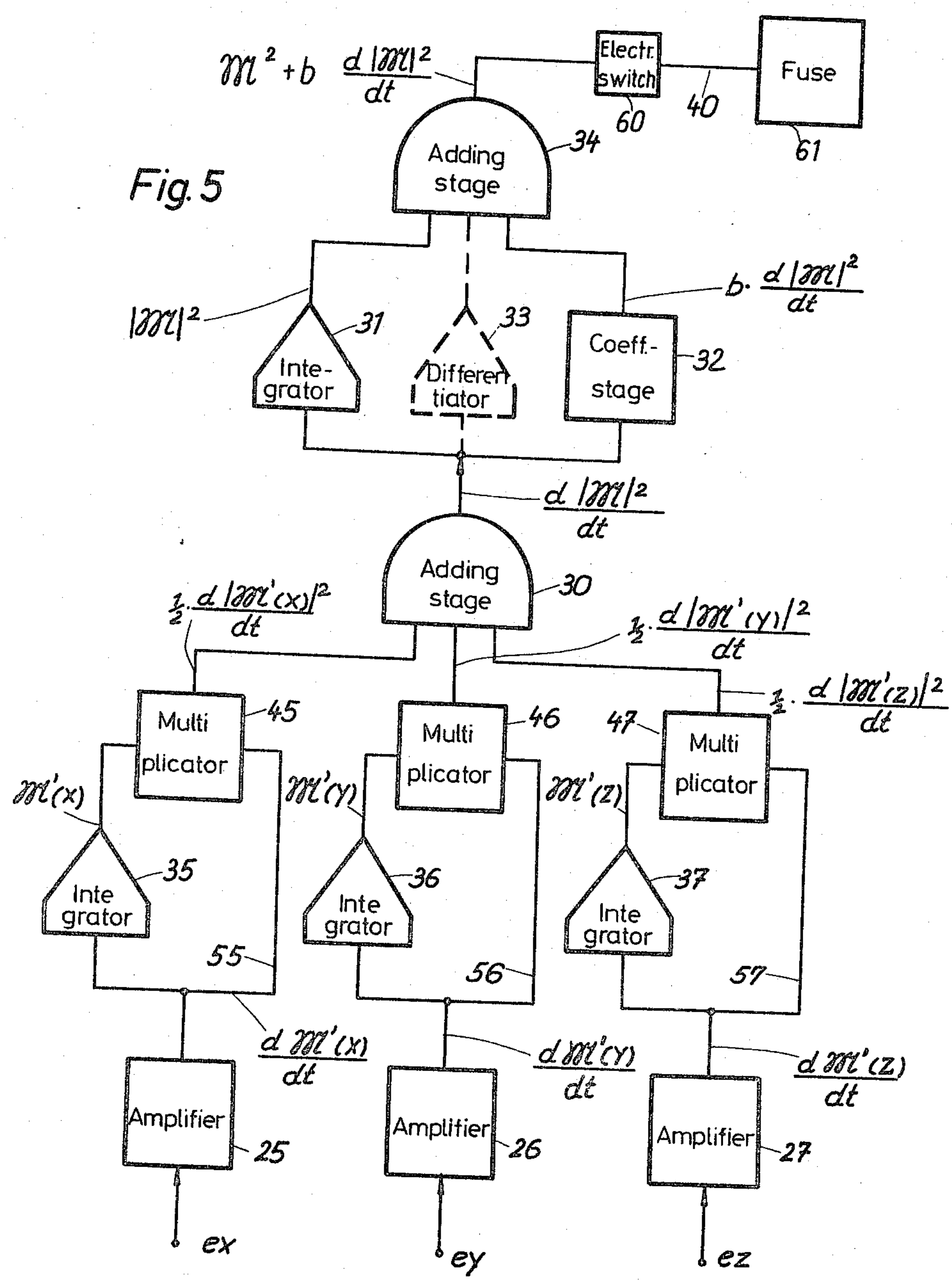

Fig. 5

INVENTOR

Johannes Peters

By McGlew and Toren

ATTORNEYS

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PASSIVE MAGNETIC PROXIMITY FUSE

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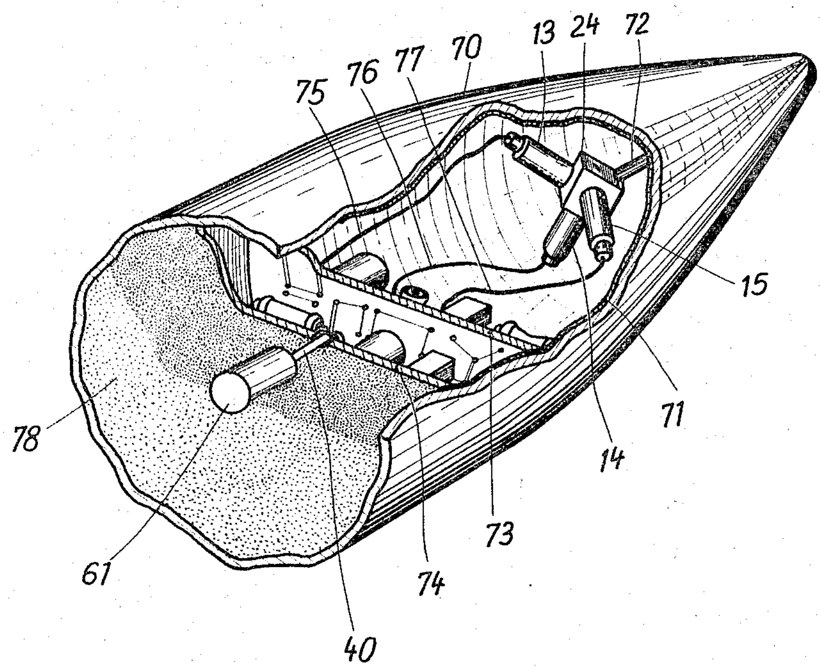
Fig. 7



INVENTOR

Johannes Peters

By McGlew and Toren

ATTORNEYS

United States Patent Office

3,308,760
Patented Mar. 14, 1967

3,308,760

PASSIVE MAGNETIC PROXIMITY FUSE

Johannes Peters, Deisenhofen, near Munich, Germany, assignor to Bolkow Gesellschaft mit beschrankter Haftung, Hamburg, Germany

Filed Nov. 29, 1962, Ser. No. 243,177
Claims priority, application Germany, Dec. 23, 1961, B 65,340
7 Claims. (Cl. 102—70.2)

The invention relates to a proximity fuse for the ignition of a moving explosive charge, a magnetic field, superimposed to the earth's magnetic field and caused by ferromagnetic objects, serving as release pulse, e.g. for igniting shells, warheads of missiles, and the like.

Such passive fuses are responsive to changes with respect to time and/or space of the earth's magnetic field which is homogeneous by nature, said changes being caused by bodies which can produce a magnetic field around them, which field superimposes to the earth's magnetic field. This effect can be produced by bodies consisting of ferromagnetic material or having current-carrying, loop-type conductors, for instance land- and seacraft, guns, as well as concentrations of small arms and steel helmets.

Such a passive ignition device for igniting an explosive charge carried by a torpedo has been described in the U.S. Patent No. 2,993,440. For measuring the change of the component of the earth's magnetic field in the longitudinal direction of the torpedo this device has two induction coils connected in opposition. A change of this field component produced by the magnetic field of a hull releases the ignition.

As shown in the U.S. Patent No. 2,431,319 it is moreover known that an explosive charge is ignited by an artificially produced magnetic field being disturbed by such a target.

For igniting torpedo charges this so-called active method is applied in such a way that one current-carrying coil each is fitted in the bow and in the stern of a torpedo, the magnetic fields of said coils being adjusted so that there is a state of balance. When the torpedo approaches its target, the state of balance will be disturbed by the iron masses of the ship. The resulting current flow makes the explosive charge detonate after appropriate amplification.

The above-mentioned fuses cannot be used for charges carried by missiles, because magnetic field meters used there are responsive to one component field only. Hence the magnetic field meter does not indicate the true field intensity M, but $M.\cos\nu$, where ν is the angle formed by the direction of the field to be measured and by the direction of the maximum sensitivity of the measuring instrument. If this angle is changed by the measuring instrument being moved in the field, said instrument will certainly indicate this change. This means that the explosive charge would already be ignited, for instance, by rotations of the missile carrying said charge.

It is another disadvantage that the known magnetic fuses are not protected against enemy countermeasures and can therefore be released, too, by other bodies instead of the target to be attacked.

It is the object of the invention to create a passive magnetic fuse for quickly moving charges, said fuse being insensitive to inherent movements of its sensitive device and igniting the explosive charge, if possible, before reaching that point of the trajectory which is nearest to the object to be attacked, i.e. igniting it independently of the flight or firing direction relative to the direction of the earth's magnetic field.

It is another object of the invention to create a passive magnetic fuse which is insensitive to an erroneous release of the ignition in the case of disturbances by an enemy, of too great a distance from the target and of small or non-existing relative speed at the point of nearest approach between exposive charge and target.

It is still another object of the invention to provide that, in the case of a proximity fuse for igniting an explosive charge having a relative speed with respect to a target which causes a change of the earth's magnetic field, said changes of the earth's magnetic field are measured simultaneously in three coordinates in quadrature to each other in the form of induced voltages, the partial voltages thus determined are amplified individually and multiplied by their own time integral, and the products thus arising are added for producing a summation voltage proportional to the differential quotient of the square of the amount of the field-intensity change, said summation voltage being supplied to the fuse as ignition voltage. At this, provision can be made that the ignition voltage be supplied to the fuse only after said voltage exceeds a predetermined voltage threshold value.

FIG. 1 diagrammatically illustrates the components of a measuring and sensing device, embodying the invention, within the earth's magnetic field, the sensing device having a ball characteristic which is not sensitive to direction;

FIG. 2 diagrammatically illustrates the decrease of the disturbance of the earth's magnetic field as caused by a ferromagnetic body;

FIG. 3 is a diagrammatic perspective illustration of the disturbance of the earth's magnetic field caused by a flying body, indicated as a target, and which is to be attacked by a second flying body carrying a payload;

FIG. 4 is a perspective view of a possible arrangement of the inductive components forming the sensing device;

FIG. 5 is a block diagram of the electronic circuitry incorporated in the invention;

FIG. 6 is a set of curves illustrating the voltage at the output of the circuitry of FIG. 5 as the flying body, carrying the explosive charge, approaches the target as shown in FIG. 3; and

FIG. 7 is a partial perspective view, partly in section and partly broken away, of one embodiment of the magnetic igniting device of the invention.

A fuse working according to the method of the invention has a sensitive device with ball characteristic without directional preference. Apart from the very next environment, the changes experienced by the earth's homogeneous field due to a ferromagnetic body of any form can also be produced by an equivalent ball with the radius R, the material of which has the relative permeability constant μ, the radius R having to be chosen in such a way that the same magnetic moment arises.

If such a ball is brought into the earth's magnetic field, the dipole field

$$M=\frac{\mu-1}{\mu+2}\left(\frac{R}{r}\right)^3\left(-M_0+3\frac{\mathfrak{r}}{r}|M_0|\cos\nu\right) \quad (1)$$

will superimpose to the original homogeneous field with the field vector M_0 being constant with respect to space and time.

In this case

$$\nu=\text{arc}\cos\frac{M_0\cdot\mathfrak{r}}{|M_0|\cdot r} \quad (2)$$

is the angle which is formed by field vector M_0 and by radius vector $\mathfrak{r}$ directed from the measuring point to the ball centre. Moreover, $r=|\mathfrak{r}|$ is the distance between the measuring point and the ball centre.

The proportionality factor

$$\frac{\mu-1}{\mu+2}\left(\frac{R}{r}\right)^3$$

can be suppressed by considering field M' on the surface of a concentric ball with the radius

$$r_o=\sqrt[3]{\frac{\mu-1}{\mu+2}}\cdot R \quad \sim R \text{ (if } \mu\gg 1) \qquad (3)$$

said radius coinciding with R with sufficient accuracy in all practical cases.

With the same angle ν the field on all the other concentric balls with the radius $r>R$ is

$$M=\left(\frac{r}{r_0}\right)^3\cdot M' \qquad (4)$$

Hence, the disturbance vector of the field does not change its direction by proceeding on a ray from the ball centre. Its modulus, however, decreases with the third power of the distance. For completely describing field M_0 it will therefore be sufficient to know field M' according to Eq. 4. For reasons of symmetry it is even sufficient to know M' on a great circle of the ball with the radius r_0 the area of which lies on a plane in the direction of the original magnetic field of the earth M_0.

If in this plane, cf. FIG. 1, the component in the direction of M_0 is denoted by x, the component lying in the normal direction thereto in the plane is denoted by y, and the component vertical to the plane is denoted by z, we obtain the components of M' to be:

$$M'_x=|M_0|(-1+3\cos\nu.\cos\nu) \qquad (5a)$$
$$M'_y=|M_0|.3\cos\nu.\sin\nu \qquad (5b)$$
$$M'_z=0 \qquad 5c)$$

The modulus of M' is

$$|M'|=(M'^2_x+M'^2_y)^{1/2} = |M_0|(1+3\cos^2\nu)^{1/2} \qquad 6)$$

Hence, there are zero directions for the components of M' in which said components disappear, while the modulus of |M'| according to Eq. 6 has the advantage not to have any zero directions. Depending on the angle ν, |M'| therefore changes only in the ratio 1:2 between minimum and maximum value. It follows moreover that the modulus of the disturbance being produced in the earth's magnetic field by introducing a ferromagnetic body does not disappear completely at any measuring point with the finite distance r from the ball centre. Distance r then depends on the order of magnitude of the target to be attacked.

Therefore, a family of concentric curves

$$r_n(\nu)=n^{1/3}(1+3\cos^2\nu)^{-1/6} \quad \text{for } n=1, 2, 3\ldots \qquad (7)$$

being arranged symmetrically with respect to rotation around the axis $\nu=0$ (cf. FIG. 2), forms shell-shaped envelopes each of which representing loci for certain measuring values. The trajectory **10** of a flying body **11** (FIG. 3) passing within a close distance of target **12** therefore crosses the individual envelopes **13**, **13'**, **13''**, **13'''** etc. of different field intensities as shown in FIG. 3. At this occasion the missile passes through a sequence of measuring values which, in function, of time, form a steady function reaching its maximum value very near the point at which the distance of the flying body from the target is smallest.

In order to guarantee ignition release before reaching the target, the voltages induced by the earth's magnetic field and corresponding to the three coordinates in quadrature to each other are, according to the development of the invention, amplified individually, multiplied by their own time integral, and the sum is formed of these voltages to which sum is/are superimposed its time integral and/or its differential quotient with respect to time.

The ignition point is preferentially fixed near the inflection point of the curve of measured values, i.e. the ignition is released in function of the differential quotient with respect to time.

To eliminate changes of the earth's magnetic field occurring over larger distances or during longer intervals, particularly for geophysical reasons, the intervals to be integrated are considered the less important the more time has elapsed since then, which consideration is according to the invention. Said intervals are preferably such which elapsed about one hundredth second ago.

A fuse working according to the method described above has three pairs of coils **13**, **14**, **15** serving as sensitive devices, cf. FIG. 4, said coils being mounted to freely ending cores **17**, **18**, **19**, **20**, **21**, **22** of highly permeable material. The cores are fixed to the surfaces of a cube. For the voltages induced by the earth's magnetic field in the above-mentioned coils there holds

$$e_x=\frac{dM'x}{dt};e_y=\frac{dM'y}{dt};e_z=\frac{dM'z}{dt} \qquad (8)$$

Hence, the undisturbed field M_0 cancels out automatically. Inversely, there is of course:

$$M'x=\int_{t_0}^{t}e_x dt;M'_y=\int_{t_0}^{t}e_y dt;M'_z=\int_{t_0}^{t}e_z dt \qquad (8)$$

The lower limit of the integration is the time t_0. This point of time is the moment shortly after launching the missile, when the electronic equipment of the fuse is switched in. The equation shows that the earth's magnetic field M_0 existing at this moment automatically cancels out which was already shown above.

The voltages induced in the coil pairs and being denoted by e_x, e_y, and e_z in FIG. 4 are supplied to one amplifier each being denoted by **25**, **26**, and **27** in FIG. 5. The output of the amplifiers have one integrator each denoted by **35**, **36**, and **37**, said integrators being connected to one multiplicator each denoted by **45**, **46**, and **47**.

Finally amplifier **25** is directly connected to multiplicator **45** through line **55**, amplifier **26** is directly connected to multiplicator **46** through line **56**, and amplifier **27** is directly connected to multiplicator **47** through line **57**.

The outputs of the multiplicators are connected to integrator **30**. The summation voltage obtained is supplied to integrator **31**, and it is supplied to an adding stage **34** through stage **32**, in which the coefficient is inserted, and possibly through differentiator **33** represented by dashed lines.

At output **40** of the wiring diagram according to FIG. 5 there arises a voltage proportional to the modulus of

$$|M'|^2+b\cdot\frac{d|M'|^2}{dt} \qquad (10)$$

if, as a measure for the change of the field, the differential quotient of its square

$$\frac{d|M'|^2}{dt}=\frac{d(M'x)^2}{dt}+\frac{d(M'y)^2}{dt}+\frac{d(M'z)^2}{dt} \qquad (11)$$

is calculated, the differential quotient being

$$\frac{d(M'x)^2}{dt}=2e_x\int_{t_0}^{t}e_x dt \qquad (12)$$

Coefficient b is to be chosen as a function of the desired lead of the ignition. Line **40** leads to an electronic switch **60** in which a desired threshold value for the ignition voltage can be adjusted. This stage which is not absolutely necessary is followed by the actual fuse **61**.

In order to eliminate all changes of the field extending over longer periods, each integrator **35**, **36**, **37** is equipped with the so-called "bad memory," which was already mentioned. If a strict integration supplies

$$G(t)=\int_{t_0}^{t}F(t)dt \qquad (13)$$

there shall now be

$$G(t)\epsilon^{-\alpha t}\int_{t_0}^{t}F(t)dt \qquad (14)$$

where $1/\alpha$ is the time constant of the memory. Such an arrangement considers only those changes which take place within a period of the order of magnitude of the time constant of the integrator.

The effect of the above described fuse is independent of autorotations of its sensitive device. If we assume that this device rotates around the z-axis at the angular speed ωt, cf. FIG. 1, there results:

$$\frac{dM'x}{dt}=\frac{d(|M|\cdot\cos(\nu+\omega t))}{dt}$$

$$=\frac{d|M|}{dt}.\cos(\nu+\omega t)-|M|.\omega.\sin(\omega t+\nu) \quad (15)$$

and

$$\frac{dM'y}{dt}=\frac{d(|M|.\sin(\nu+\omega t))}{dt}$$

$$=\frac{d|M|}{at}.\sin(\nu+\omega t)+|M|.\omega.\cos(\omega t+\nu) \quad (16)$$

$$M'_x.\frac{dM'-x}{dt}+M'_y.\frac{dM'y}{dt}=|M'|.\frac{d|M'|}{dt} \quad (17)$$

Hence, the result is independent of ω. The same result also arises, when the sensitive device rotates around any axis.

The voltage at output **40** of the wiring diagram according to FIG. 5 essentially follows curve **3** of FIG. 6, which progress of the curve is independent of the orientation of the firing direction with respect to the earth's magnetic field. It is the sum of curve **1**, which gives the square of the modulus of the interference field, and of its differential quotient (12). By choosing coefficient b and release threshold **4** (cf. FIG. 6) the release pulse which causes the ignition of the explosive charge can be advanced to time t_1 so that the actual ignition will occur only at time t_2 due to the ignition delay t_2-t_1, while the nearest approach to the target is reached at about time t_3 where curve **1** has its maximum.

The impulse induced in the solenoids **15**, **16**, **17** by the dipole field fills a spectrum having its maximum near

$$f\,\text{max.}=\frac{v}{2a} \quad (18)$$

where v is the modulus of the velocity of the missile relative to the target, while (a) is the distance from the target at which the ignition shall occur. Hence, neither the frequencies considerably below the maximum nor the frequencies considerably above the maximum must be allowed to pass. The safety against disturbances of the fuse according to the invention is thus increased. Therefore amplifiers **25**, **26**, and **27** have been designed so that they have a certain dependency on frequency, preferentially of band-pass character. By suitable choosing the pass frequency the proximity fuse can moreover be designed so that it responds to certain targets. It is an advantage that the amplifying characteristic has been designed for adjustment.

For the above-mentioned reason it is moreover possible statically to screen the whole equipment including the coil pairs by a copper or aluminum jacket. Though such a jacket lets alternating magnetic fields of low frequency pass, fields of higher frequency are screened completely.

From the above description there results that a fuse working according to the invention is a component part which in its design needs few spaces only, which is shown by FIG. 7.

This figure shows a sectional view of head **70** of missile **11** (cf. FIG. 3), the internal jacket surface of which being formed by a copper covering **71** serving for screening. Cube **24** carrying the sensitive devices **13**, **14**, and **15**, the latter having but one coil each, is fixed to bolt **72** anchored in the cone of the missile so that the cube's main diagonal coincides with the longitudinal axis of the missile.

The electronic parts of the ignition device shown in FIG. 5 as a block diagram are arranged on two plates **73** and **74** of conventional design and are connected to the sensitive devices through lines **75**, **76**, and **77**. Line **40** leads from plate **74** to fuse **61** shown schematically only, said fuse **61** projecting into the explosive charge **78** of the missile. Another arrangement of the structural elements of the ignition device is certainly possible, too.

Owing to its screening jacket such a fuse can hardly be released by a jamming station, because an alternating magnetic field of low frequency has to be produced for which do not exist any aerials of an efficiency worth mentioning. Hence, either the dimensions of such an electromagnetic dipole should be very considerable or a correspondingly high energy has to applied in order to reach a high magnetic moment, which energy has moreover to increase with the third power of the required range.

What I claim is:

1. In a method for igniting an explosive charge having a relative speed with respect to a target, which target causes a change of the earth's magnetic field, which change induces voltages in an ignition device and which voltages are added to produce an ignition voltage: the improvement comprising simultaneously deriving, in a manner known per se, the induced voltages corresponding to such changes in the earth's magnetic field in three coordinates in quadrature with each other, individually amplifying each induced voltage, multiplying each amplified induced voltage by its own respective time integral, adding the thus obtained products of amplified voltages to derive a summation voltage proportional to the differential quotient of the square of the modulus of the change of the intensity of the earth's magnetic field, and applying said summation voltage to a fuse as an ignition voltage.

2. In a proximity fuse responding to changes of the earth's magnetic field as produced by ferromagnetic bodies, the improvement comprising three coils arranged in quadrature with each other, three amplifiers each connected to a respective coil, three multiplication stages each connected directly to a respective amplifier, three integration stages each connecting a respective mutilplication stage to its respective amplifier, a summation stage connected in parallel to all of the multiplication stages, an output stage, a further integration stage and a damping element connecting said output stage to the output of said summation stage, and a fuse connected to the output of said output stage.

3. In a proximity fuse responding to changes in the earth's magnetic field such as produced by ferromagnetic bodies, the improvement comprising three coils arranged in quadrature with each other, three amplifiers each connected to a respective coil, three multiplication stages each directly connected to a respective amplifier, three integration stages, each connected between a respective multiplication stage and its associated respective amplifier, a summation stage commonly connected to all of said multiplication stages, an output stage, a further integration stage, a damping element and a differentation element connected in parallel with each other between the output of said summation stage and said output stage, and a fuse connected to the output of said output stage.

4. In a proximity fuse responding to change of the earth's magnetic field such as produced by a ferromagnetic body, the improvement comprising three coils arranged in quadrature with each other, three amplifiers each connected to a respective coil, three multiplication stages each directly connected to a respective amplifier, three integration stages each connected between a respective multiplication stage and the associated respective amplifier stage, a summation stage connected in common to all of said multiplication stages, an output stage, an integration stage and a damping element connected, in parallel with each other, between said output stage and the output of said summation stage, means for deriving a threshhold voltage value, means for comparing said

threshhold voltage value with the output of said output stage, a fuse connected to the output of said output stage to said fuse when said output voltage exceeds said threshhold value.

5. In a proximity fuse responsive to changes of the earth's magnetic field such as produced by ferromagnetic bodies, three coils arranged in quadrature with each other, three amplifiers, each being connected to a respective coil, each of said amplifiers constituting a band pass amplifier having an amplification characteristic adjustable in accordance with the size of the target or the velocity of the fuse, three multiplication stages each directly connected to a respective amplifier, three integration stages each connected between a respective multiplication stage and the associated respective amplifier, a summation stage commonly connected to all of said multiplication stages, an output stage, a further integration stage and a damping element connected in parallel with each other between said output stage and the output of said summation stage, and a fuse connected to the output of said output stage.

6. The improvement in a method of igniting an explosive charge, as claimed in claim **1**, including the step of superimposing, upon said summation voltage, its own

respective time integral in a manner such that ignition is effected in the proximity of the point of maximum value of the curve of measured values resulting when the charge to be ignited is moved.

7. The improvement in a method of igniting an explosive charge, as claimed in claim **1**, comprising the step of superimposing, upon said summation voltage, its own respective differential quotient with respect to time in such a manner that the ignition is effected in the proximity of the point of maximum value of the curve of measured values resulting when the charge to be ignited is moved.

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SAMUEL FEINBERG, *Primary Examiner.*

BENJAMIN A. BORCHELT, *Examiner.*

L. L. HALLACHER, W. C. ROCH, *Assistant Examiners.*