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FUZE DEVELOPMENT FOR HOLLOW CHARGE BOMBS
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TECHNICAL REPORT NO. 269-45

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FUZE DEVELOPMENT FOR HOLLOW CHARGE BOMBS

SUMMARY

This report concerns the development by the Germans of a "discriminating" type fuze for use in Hollow-Charge bombs which would bring about detonation at the proper instant depending upon relative expenditures of initial velocity due to the nature of the target. Herein also described, are various modifications in the construction of the bomb body designed to obtain maximum effectiveness.

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TABLE OF CONTENTS

	<u>Page</u>
1. Introduction.	3-10
2. Requirements of a fuze for hollow-charge bombs.	10-14
3. Velocity sensitive fuzes.	14-26
a. Spring and oil damped fuzes.	14-17
b. Eddy current damped fuzes.	17-22
c. Further possibilities for a lead ^{lead} -dependent fuze.	22-26
1. Use of soft lead or other plastic material as a damping medium.	22, 25
2. Use of Mercury capillary damping.	25
3. Vibration of a Tuning Fork.	25
4. Velocity-sensitive contacts.	25, 26
4. Controlled deformation of the Bomb Nose.	26-30
5. Conclusion.	30, 31
6. Appendix.	32, 33

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FUZE DEVELOPMENT FOR HOLLOW-CHARGE BOMBS

1. Introduction.

The primary consideration in the development of a fuzing system for the Hollow-Charge Bomb was to produce a "discriminating" type of device which could "classify" its target upon impact and fire accordingly. To be effective it is necessary that the bomb be allowed to penetrate the thin plating of a ship's hull without firing before reaching the actual layer of armor plate, at which time however, because of its comparatively light construction, the fuze must fire instantly in order to prevent deflagration of the bomb. On the other hand, should the bomb strike an exceptionally resistant target, such as a turret, it must detonate without delay, at once. Fuzes are herein described which bring about this detonation when the initial velocity of the bomb is expended to the proper degree.

As an example of the construction of a Hollow-Charge Bomb, Figure 1 shows a cross-section of the 50 kg experimental model.

The hollow (shaped charge) space is made hemispherical on the basis of investigations which indicate this form to produce the most favorable Monroe effect when detonated at slight angles to the target. Next to the surface of the hollow space lies a layer of explosive about 15% of the diameter of the hemisphere in thickness. The front opening is covered with a rounded shell of thin steel sheeting, into which is screwed a vertical suspension lug. This lug, as will be described, later, considerably decreases the effectiveness of the bomb.

A hollow charge must be detonated centrally and as far as possible from the surface of the hollow space. In order to accomplish this and still enable use of the conventional fuze charging plugs, the electric fuze must be located athwart the bomb body as in standard bombs. The detonating impulse, therefore, is led to the centrally located igniter, through a connecting tube. Only a detonator is connected to the igniter, leaving the space usually occupied by a booster empty. As illustrated in Figure 4, the booster charge, if left in its normal position, would considerably decrease the explosive effect.

The strengthened portion in front of the hollow space (Fig. 1) has the function of providing the spacing between the hollow charge and the target which is necessary for the most favorable explosive effect. This

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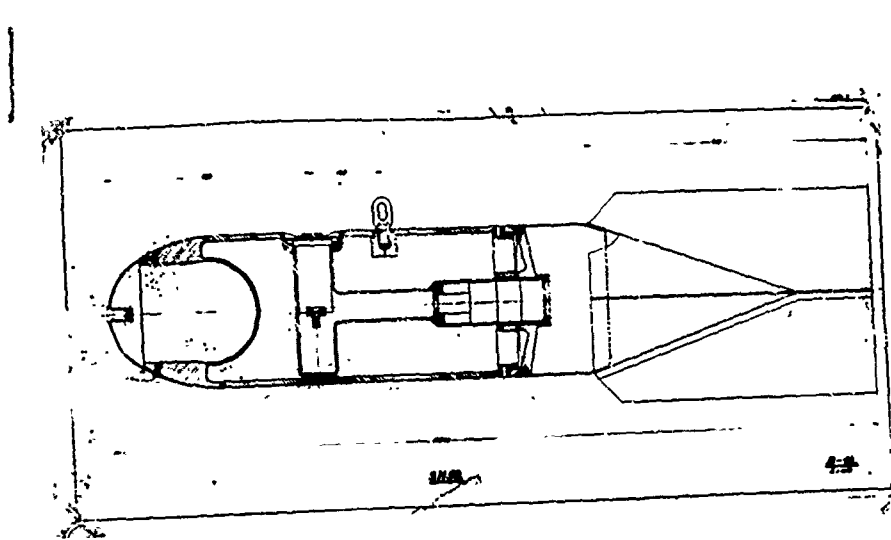


FIGURE 1

50 kg. experimental Hollow-charge bomb.

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FIGURE 2

50 kg. Hollow-charge bomb set for test firing on 15 cm armor plate.

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FIGURE 3

Results of test firing on 15 cm armor plate.

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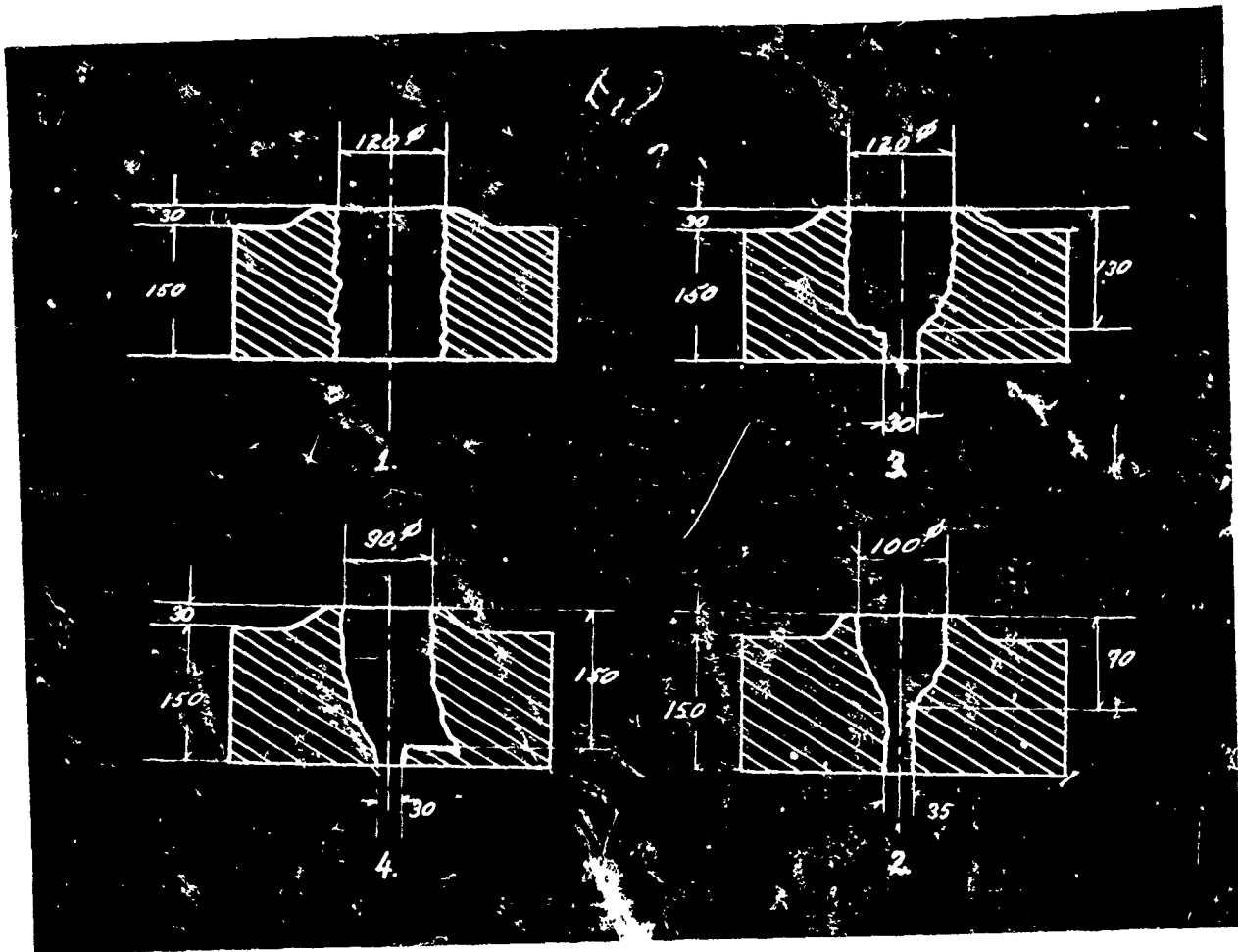


FIGURE 4

Graphic representation of results of varied test shots.

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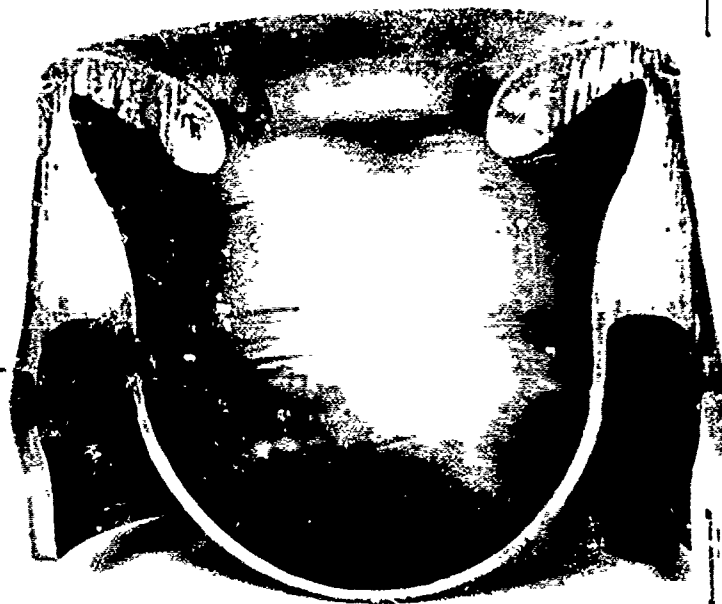


FIGURE 5.

Deformation of bomb noses.

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Introduction (Cont'd.)

must be solid enough to retard the bomb sufficiently upon impact to actuate the fuze at the correct time. Since the dome-shape of the hollow charge has very little resistance against a force acting upon it from the side, a stiffening ring is placed in front of the charge to compensate for these forces which occur whenever, as is most common, the bomb does not strike absolutely vertically. In a more recent method of construction, deformation notches were cut into this ring. The bomb then tends to deform at these notches when subjected to impacts which endanger its construction. In this manner time to detonate the bomb properly is gained.

Figure 2 shows a 50 kg hollow charge bomb in a static test on a 15 cm piece of armor plate. This test was made without using the nose cover plate and without the nose suspension lug.

Figure 3 illustrates the results of the test firing as in Figure 2. The 15 cm armor plate was cleanly perforated. The hole was almost cylindrical, having a diameter of 12 cm, almost as large as the diameter of the hollow charge dome which is 14 cm. Diameter of the bomb itself is 20 cm.

Figure 4 represents graphically the damage inflicted upon 15 cm armor plate by the test firing of 50 kg Hollow-charge bombs under varied conditions.

Drawing #1 illustrates the result of a test shot without the nose cover plate and without the nose suspension lug (As in Fig. 3.). #2 illustrates a shot under the same conditions except that the bomb was offset 2.0 meters from the surface of the armor plate. The same 15 cm plate has been perforated by this bomb from even greater distances than that shown here. Drawing #3 shows the decrease in explosive effect caused by inclusion of the nose cover plate and the suspensinn lug. Although the plate was perforated the lower portion of the hole is considerably smaller. This loss of effect has also been experienced in smaller Hollow-charge bombs which employ a nose fuze in this same position. #4 illustrates the decrease in explosive effect caused by locating the booster charge eccentrically. The booster, in this case, was placed in its usual place directly under the electrical fuze. The explosive force, as can be seen, was deflected off to the side, and the armor plate was perforated only with a small hole.

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Introduction (Cont'd.)

As these examples illustrate, the effective use of hollow charges can be spoiled by rather slight changes in the design and/or method of firing of the charges. The task of the fuze is to ensure that the good results of the static tests can be duplicated in actual operational use of the bomb.

Figure 5 illustrates the result should a bomb of this light construction fail to detonate instantly upon impact with an armored target. In this case the model was filled with tar in lieu of explosive for experimental purposes. It can be seen that both head and hollow space are completely deformed. A favorable explosive effect is therefore not to be expected, and the bomb must be detonated before such deformation can take place.

2. Requirements of a Fuze for Hollow-Charge Bombs.

In service against naval targets for which purpose the Hollow-charge bomb is principally intended, the best results would be obtained if the bomb were to penetrate the light plating covering the armor in a purely mechanical action before detonating. The striking velocities are in general, sufficient for this purpose. When the bomb finally arrives at the armored deck it must be instantly detonated before it can fall apart or be deviated otherwise the effect of the Hollow-charge would be to the side rather than against the armor plate. If the bomb makes a direct hit on an armored turret or some similar target which it cannot penetrate, the charge must detonate instantly without time delay, otherwise the bomb will disintegrate. The fuze of a Hollow-charge bomb, therefore, must operate when the forces caused by the striking of the bomb have been expended. Such a fuze must continually measure the velocity of the bomb as it strikes. The usual methods of measurement, for example, by means of static pressure as used in aircraft, are out of the question here because the bomb in striking or penetrating a ship's deck is not moving through undisturbed air. The velocity measurement must be contained within the body of the bomb-fuze. A device is therefore desired which measures the increments of deceleration as the bomb penetrates individual decks and which integrates this over time, by means of generating impulses.

In Figure 6 the velocities and decelerations of a bomb passing through a ship's deck are plotted graphically. One should note the deceleration peaks which occur each time the bomb penetrates a deck layer. The time integral of such a deceleration is a representation of

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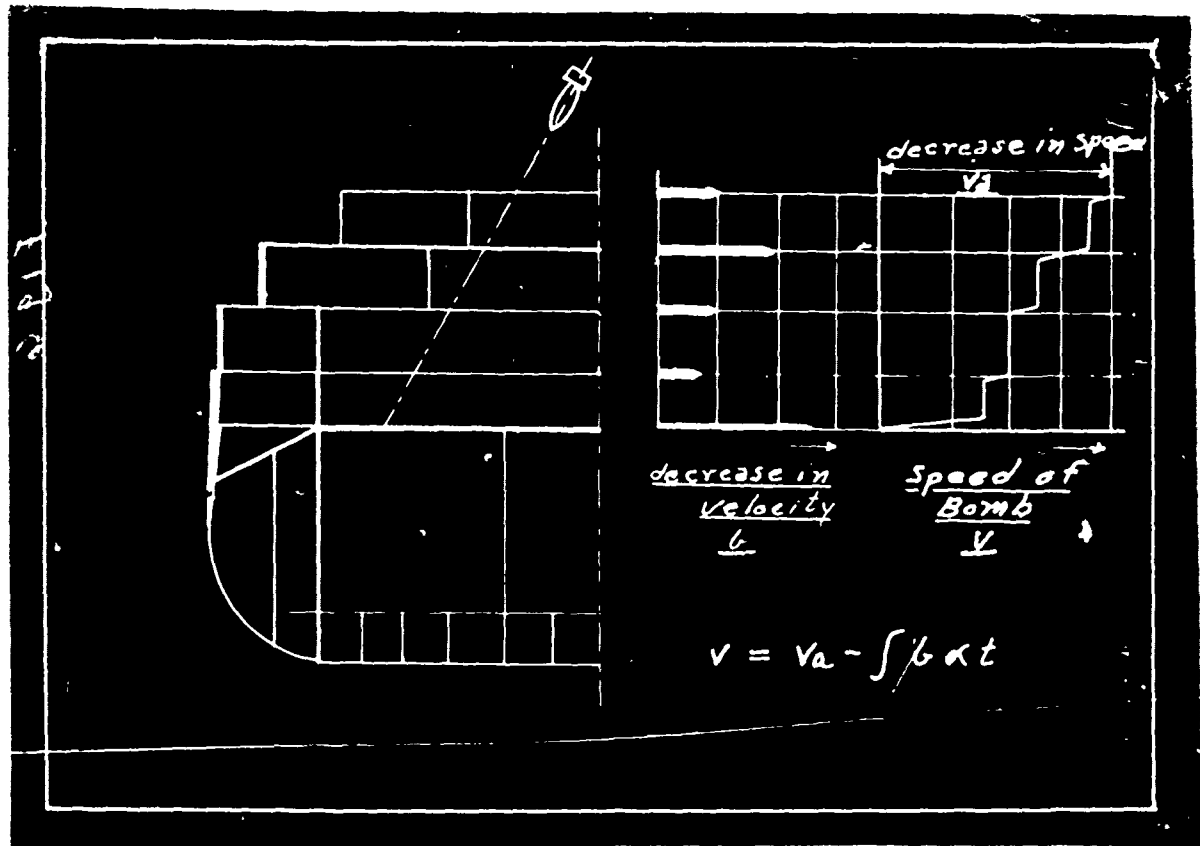


FIGURE 6

Graph of velocities and decelerations of a bomb passing through a ship's deck.

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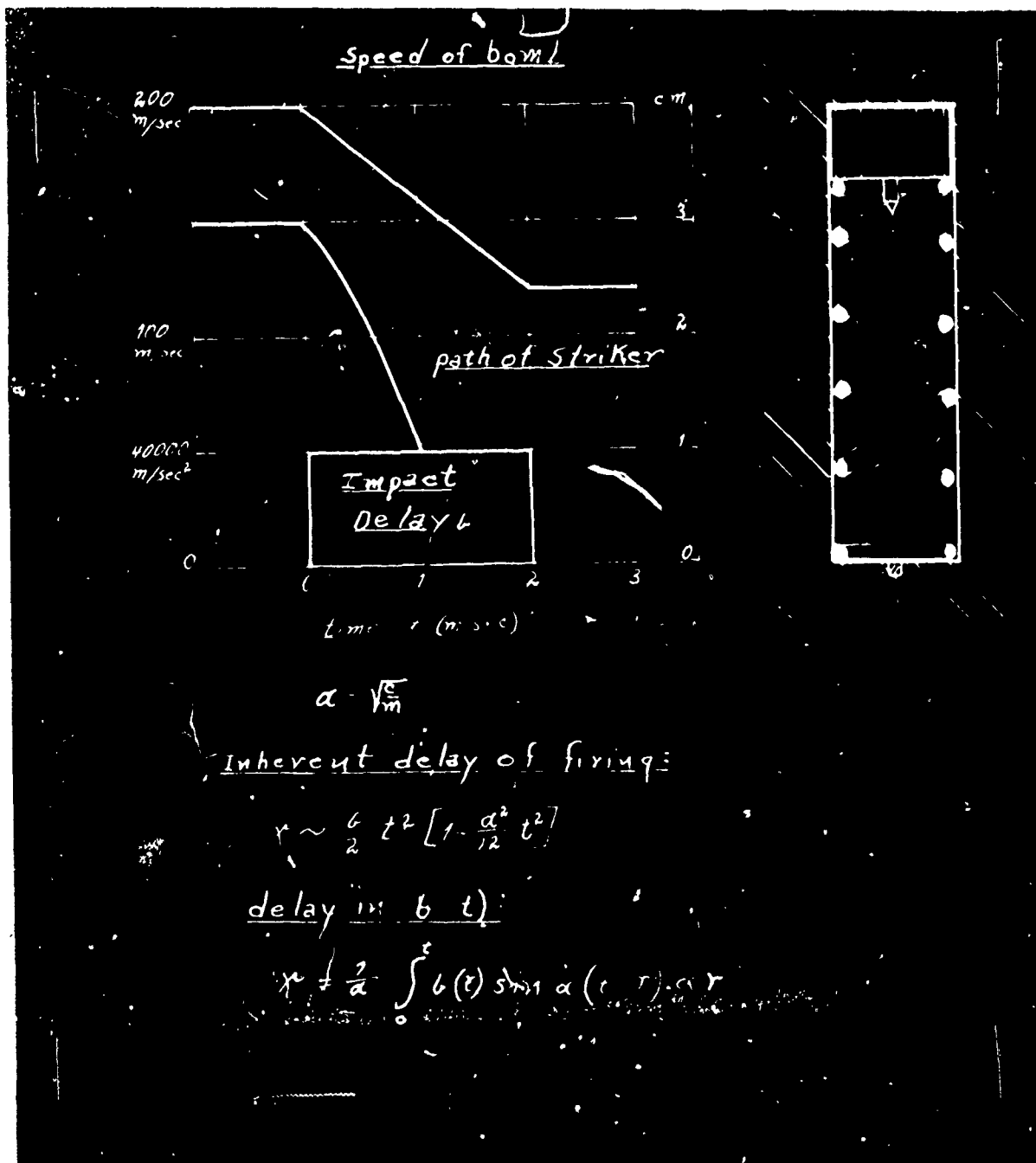


FIGURE 7

Spring restrained striking pin.

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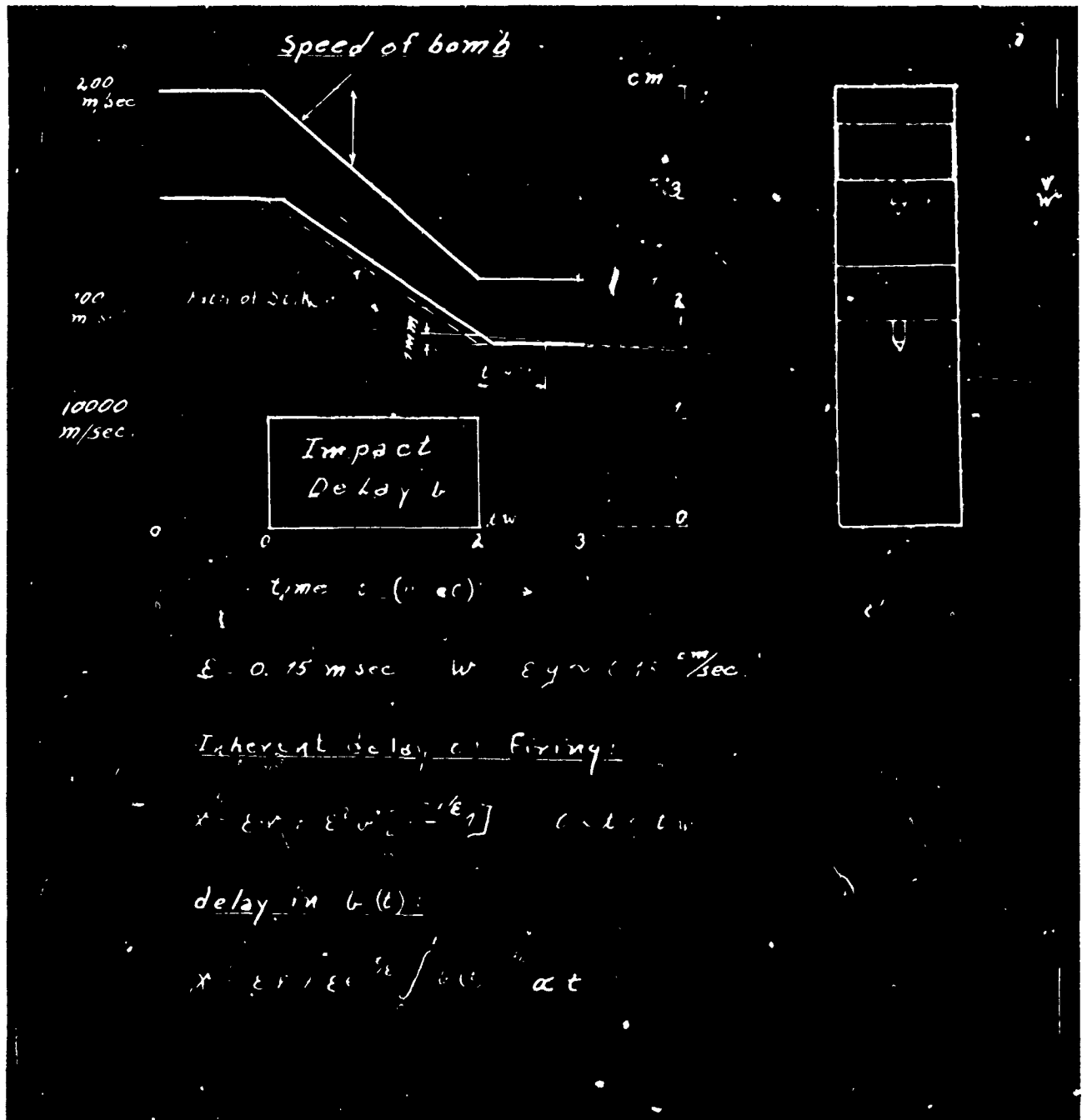


FIGURE 8

Striking pin restrained by "dash-pot" action.

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Requirements of a Fuze for Hollow-Charge Bombs (Cont'd.)

the loss of velocity sustained by the bomb as it passes through the decks. After passing through one deck the bomb continues to the next with almost unvarying velocity:

It is not absolutely necessary that the bomb be detonated when the velocity has become precisely zero. The energy is a function of the square of the velocity. If the bomb still possesses 20% of its striking velocity, the striking force is already reduced to 4% of the original. A device may be contained within the fuze which is capable of measuring time and deceleration and can measure by intergration the loss of velocity upon striking. It cannot, however, measure the absolute velocity (v) of the bomb, and therefore, also not the absolute value of the loss of energy $\frac{m}{2} (v_1^2 - v_2^2)$ because the magnitude of the

absolute velocity must be known in order to determine the energy. In any case, since the fuzes for hollow-charge bombs must fire on energy loss, the fuze must be made to measure "impulse loss".

3. Velocity Sensitive Fuzes.

a. Spring and oil damped fuzes.

Figures 7 and 8 show schematically two possibilities for the construction of this type fuze. Fig. 7 shows the usual type of spring-restrained striking pin; Fig. 8 a striking-pin with oil damping instead of a spring. When the striking-pin moves forward the damping oil must flow through small channels, thus creating a braking force which is proportional to the velocity.

The motion of the striking-pin can be calculated if the curve of deceleration versus time is known.* The end results are shown in Fig. 8 for a case where deceleration is constant with time. The curves illustrate the drop in velocity, and the path of the striker in the case of a striking deceleration of 4000g in 2 milliseconds.

It can be seen in Fig. 8 that the oil-damped striking-pin should fulfill the requirements quite satisfactorily. Because of laminar friction in the little passages of the striking pin there results a braking force which is proportional to the relative velocity of the pin. This

* See Appendix for derivation of formulas.

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Velocity Sensitive Fuzes (a)(Cont'd.)

braking force, after the initial starting transients are damped out, remains in balance with the forces of acceleration. This means that the striking pin moves with a constant velocity relative to the fuze housing; the effect of a constant deceleration. This relative velocity of the striking-pin (W) is therefore, if one neglects the starting transient phenomena, proportional to the deceleration (b):

$$W = \epsilon \cdot b$$

The proportionality factor (ϵ) has the dimensions of time. The following is therefore true of the path of the striking-pin in the fuze housing:

$$X = \int W dt = \int \epsilon \cdot b dt$$

and because (ϵ) has a constant magnitude the following holds true:

$$X = \epsilon \int b dt$$

The movement of the striking-pin is therefore proportional to the acceleration time integral and also proportional to the loss of velocity on striking (V). In this calculation the starting transients have been neglected. In Fig. 8 these have, however, been considered and the curves and formulas stated in thereon are more accurate. The second consideration of solving for (X) is a source of error due to the starting phenomena. It is proportional to ϵ^2 (in the accompanying formulas must come before the integral sign when integrating).

The magnitude of the quantity (ϵ) must be very small since the striking velocity of bombs lie in the order of 200 m/sec., generally somewhat higher. The path travelled by the striking pin must remain short. In the previously given example it was assumed to be 3 cm. For this value (ϵ) must be equal to 0.15 milliseconds. It is obvious from this that the errors introduced by starting transient phenomena, which are proportional to (ϵ^2) are not capable of exerting any great influence.

The path of the striking-pin, as Fig. 8 shows, is approximately proportional to the loss of velocity. The pin does not reach full velocity at once, but lags somewhat. Moreover, when the retardation ceases it does not lose its velocity at once. Its velocity returns asymptotically to the value it had at the cessation of the starting-transient phenomena. Practically speaking, this value is reached after a relatively

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Velocity Sensitive Fuzes (a)(Cont'd.)

short time. At the time of the following deceleration, the integration in time of the striking deceleration is therefore started from the proper point.

It is evident, then, that fuzes with oil-damped travel in lieu of spring restraint fulfill the requirements of a velocity-sensitive fuze. It is important however, that the value (ϵ) be kept small, since then only can the errors in the fuze and mistakes due to the starting-transient phenomena be small.

Figures 7 and 8 show only schematic designs of the fuzes. The actual fuzes are much more complicated.*

Most German bomb fuzes are electrical fuzes. When the bomb is released a reservoir condenser is charged. During the dropping time a second condenser called the firing condenser, is charged through a resistor, so that the fuze is armed only after a certain interval following release. The impact of the bomb closes a contact which discharges the condenser through the detonator, exploding the bomb. This contact is normally accomplished by a very weak spring. In place of this system the velocity dependent fuze considered here employs an oil dash-pot in lieu of the spring system in order to obtain an impulse measuring element. This oil cylinder has the task of closing the necessary contact at the proper instant.

The construction of this type fuze would be a very simple matter if the viscosity of all known damping fluids were not so dependent upon temperature. A temperature range from $+20^{\circ}\text{C}$ to -40°C must be taken into consideration with any munitions intended for dropping from aircraft. There is no oil known which maintains the slightest degree of constancy of viscosity within these temperature limits. The synthetic damping oil developed by I.G. Farben (type V 120) which has the best temperature characteristics, changes its viscosity by a factor of 1:30 in this range and is therefore quite unsuitable. A small temperature change of 10°C will produce an error of 40 milliseconds in the measurement of the velocity at an impact velocity of 200m/sec. Oil damping, therefore, seems to be out of the question unless a thermostatic control could be included in the fuze.

* Even the use of a dashpot is to be regarded only as schematically represented. Any type of damping which is proportional to velocity may be used.

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Velocity Sensitive Fuzes (a)(Cont'd.)

The only liquid which remains relatively unchanged in viscosity within this temperature range is mercury. This metal, although considered as a possibility, was found to have characteristics prohibiting its use.

It appears, therefore, that a suitable damping liquid is still to be found for a fuze of this type. An eddy-current braking effect, however, as described in the following pages, seems to fulfill the requirements much more satisfactorily.

b. Eddy current damping.

Eddy current damping is already in common use in electrical measuring instruments. As is shown in the upper left hand corner of Fig. 9, a magnet will slow down a rotating aluminum disc which is brought into its field. Between the pole pieces of a magnet a piece of aluminum or copper sheeting is moved. A force is set up which is contrary to the direction of motion, and this force is proportional to the velocity at not-too-high velocities. This is explained by the fact that currents are set up by induction in the moving conductor and these currents are in a direction towards the viewer if the motion of the piece of metal is in the opposite direction. These currents are schematically represented in Fig. 9. Circular current paths are formed, with the current returning outside of the field of the pole-pieces. From this a force results only in the part of the path lying within the magnetic field. The induced currents in the moving part possess a magnetic field of their own which tends to weaken the original magnetic field. For this reason the moving part is not braked proportionally to the velocity at high velocities, but somewhat less.

The damping effect can be improved if several magnets are so arranged that currents are induced in the return path as well as the original magnetic field. With an arrangement as illustrated at the right in Fig. 9 a noticeable damping force is obtained even from a free fall in the earth's gravitational field, of an order of 1 or 2 cm/sec. To gain optimum operation of this effect it is necessary that the strips of metal project somewhat outside the magnetic field in order to provide return paths for the induced currents. The portion of material not in the field however, is in excess since no braking force results from this part.

This excess material can be done away with by using a rotationally

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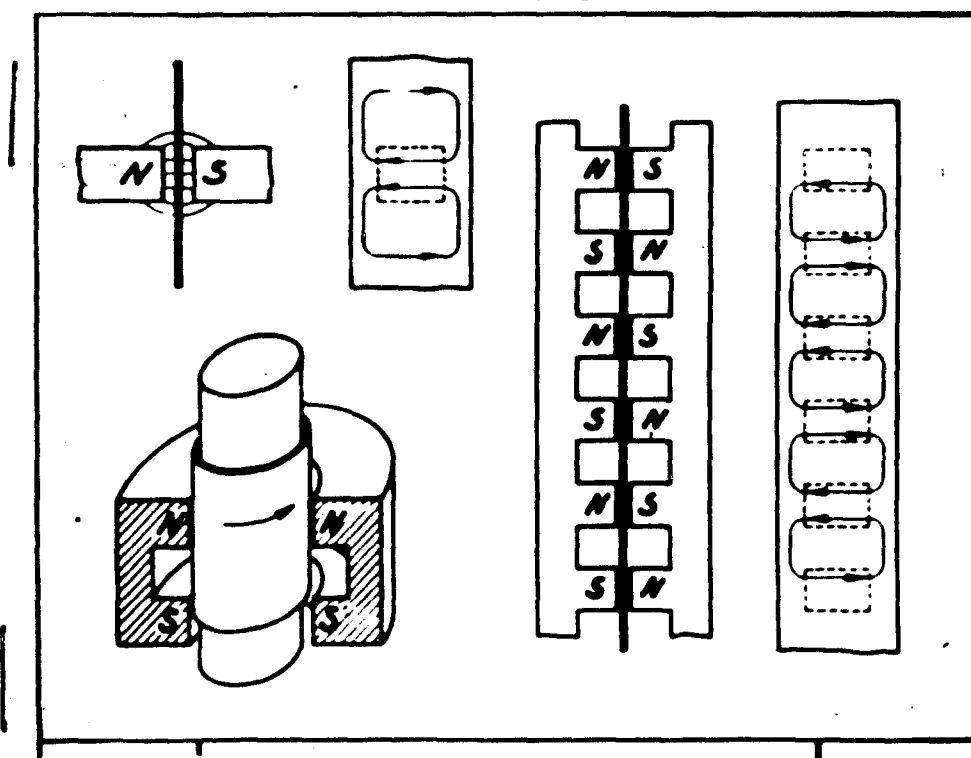


FIGURE 9

Eddy-current damping principle.

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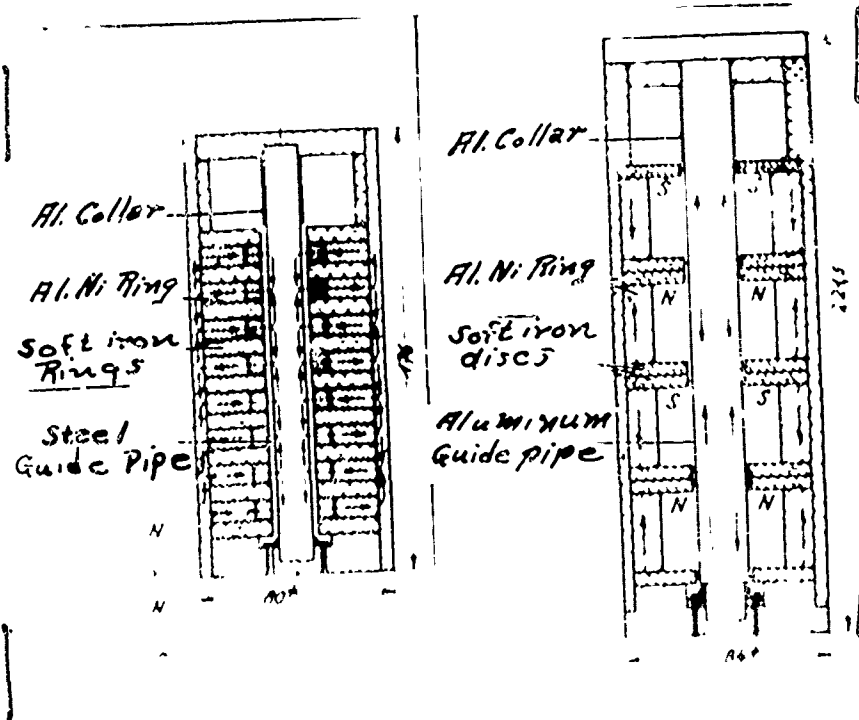


FIGURE 10

Practical form of eddy-current fuzes.

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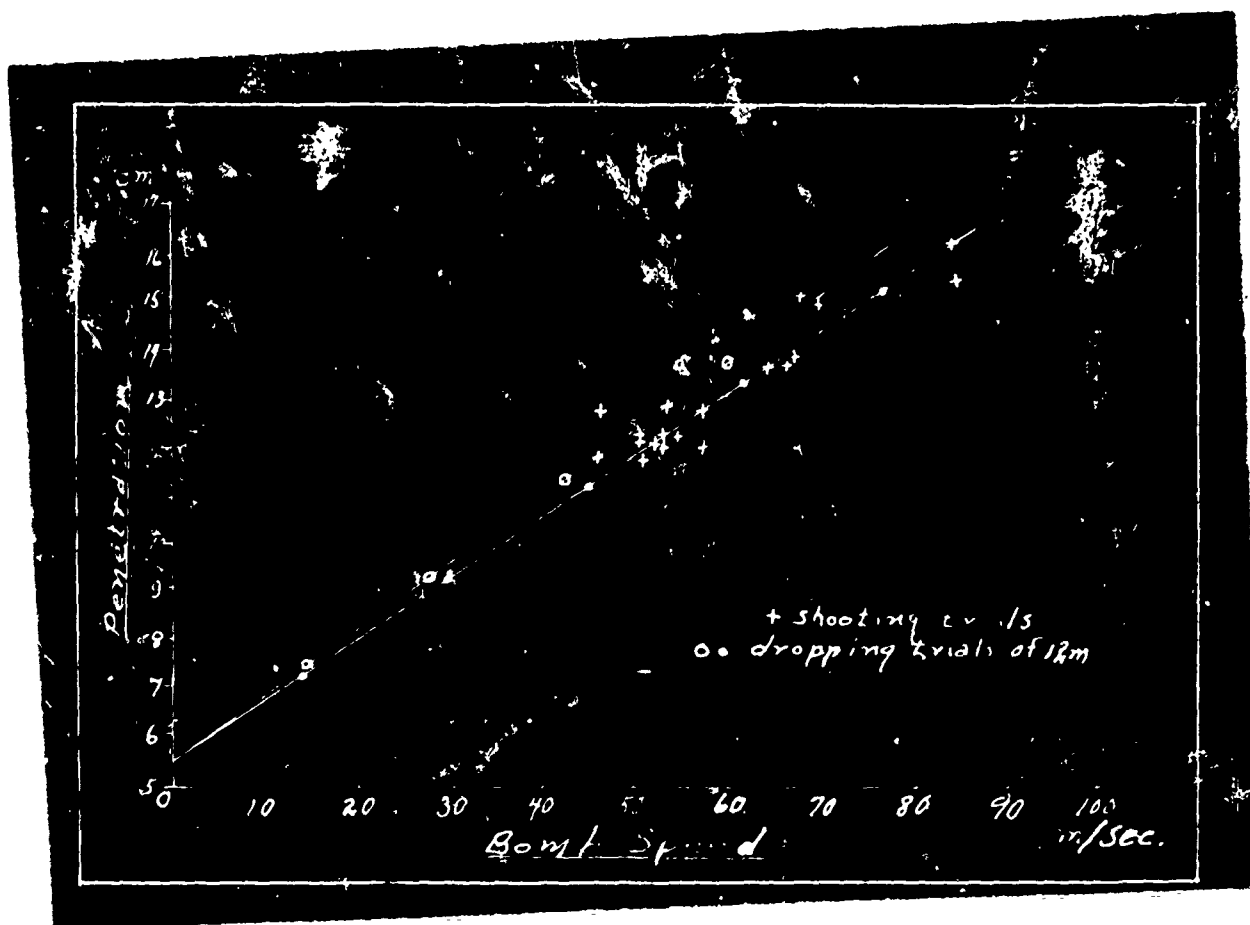


FIGURE 11

Results of shooting and dropping trials of eddy-current damped fuzes.

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Velocity Sensitive Fuzes (b)(Cont'd.)

symmetrical system such as is illustrated by the drawing in the lower left corner of Fig. 9. The part which it is desired to brake is a small aluminum collar which slides on a piece of steel tubing and which passes through changing magnetic fields as it moves. The eddy-currents follow the direction of the arrow in the collar. There are no additional parts required in the system, as the return currents pass through the parts outside the pole-pieces.

With such a system it is possible to achieve a stationary rate of sinking in the earth's gravitational field of less than 1 cm/sec. This value is large compared to that attainable with the oil-damped cylinder. The fuze, therefore, becomes relatively large. Moreover, the errors due to starting transient phenomena are also comparatively large, but calculations and experiments show that they are within the tolerable limits.

Figure 10 shows a possible solution of the practical form of such an eddy-current fuze. Only the impulse measuring portion is represented. The task of such a device is to close a contact at the proper instant.

The drawing on the right in Fig. 10 shows a design which puts to use permanent-magnet rings much the same as those used in loudspeaker construction. These rings are axially magnetized. The magnetic flux is led via soft iron rings to the core, upon which a thin aluminum collar slides. The collar must be held in the upper position by a device not shown in the drawing which releases the collar after the bomb is in free-fall. Since the bomb falls practically without deceleration, the collar remains in its upper position. Upon impact the collar slides down and is braked by the eddy-currents. When it has travelled its whole path, the bomb velocity having been reduced to a fixed fraction of its striking velocity, it closes a contact which detonates the bomb.

Fig. 10, at the left, shows a method of construction using radially magnetized rings. By this method the fuze can be built much smaller. The mode of construction shown on the right is used for striking velocities of 100 m/sec., and that on the left is used for striking velocities of 200 m/sec.

Figure 11 shows the test results obtained with the fuze shown at the right in Figure 10. These experiments were carried out in such a manner that the aluminum collar moved with friction against the core and could only be displaced by heavy impacts. It was thus possible to

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Velocity Sensitive Fuzes (b)(Cont'd.)

measure the displacement of the collar before and after the firing trials. In order to carry out many tests with the same equipment, the tests were conducted at relatively low velocities. In Figure 11, the impact velocity is represented as a function of the displacement of the aluminum collar. The crosses show the results of the firing tests. As can be seen, the relation between impact velocity and displacement of the collar is satisfactorily proportional, and the scattering is fairly small.

The figures in Figure 11 represent a check by dropping tests from a low height. The results of such tests indicate very little scattering.

With the aid of such dropping tests it was possible to determine how much the magnetism was reduced by the shock of impact. The lower curve shows dropping tests from low heights before the firing tests, and the upper curve the results after approximately thirty firing tests. It may be seen that the magnetism is not appreciably reduced by impact shock.

The Eddy-Current fuze, therefore, satisfies, insofar as may be determined from these trials, the requirements for a bomb fuze dependent on velocity. Tests at higher velocities, however, have yet to be carried out. Further development should show whether or not the disadvantages of this fuze in regard to its weight and size may be reduced.

c. Further possibilities for a speed dependent fuze.

1. Use of soft lead or other plastic material as a damping medium:

Figure 12 shows further possibilities of speed-dependent fuzes. They concern proposals made by Prof. Erwin Madelung, Frankfurt-am-Main.

The drawing at the upper left of Figure 12 shows a device which uses soft lead or other plastic material as a substitute for the highly temperature-sensitive oil in the oil cylinder, and is characterized by small dimensions and simple construction. Trials have shown that this apparatus does not measure the speed loss, but the square of the speed loss. Such a device measures

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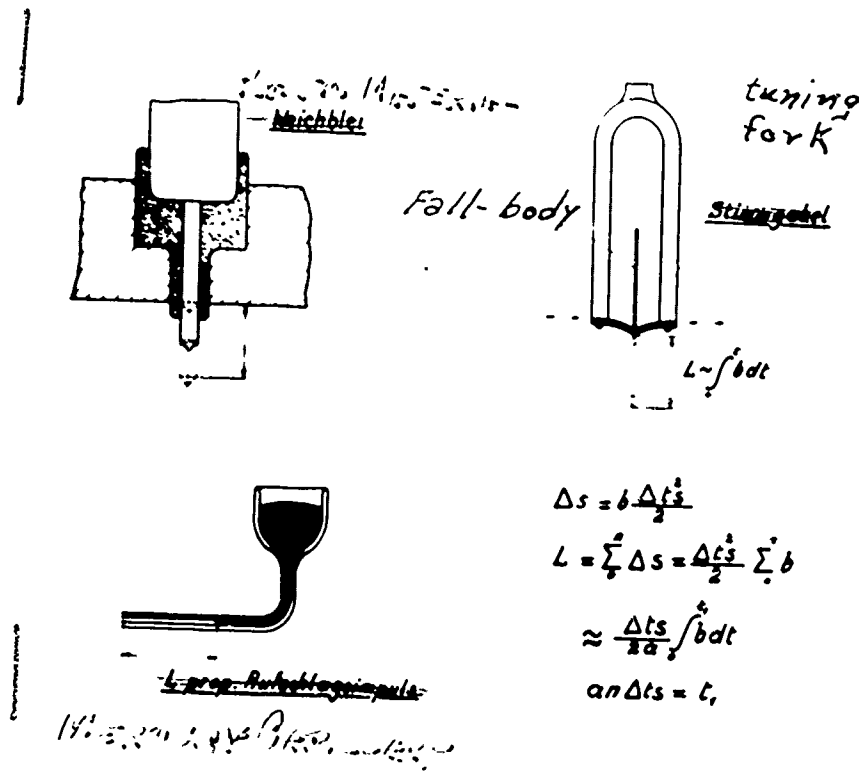


FIGURE 12

Various further possibilities for a speed-dependent fuze.

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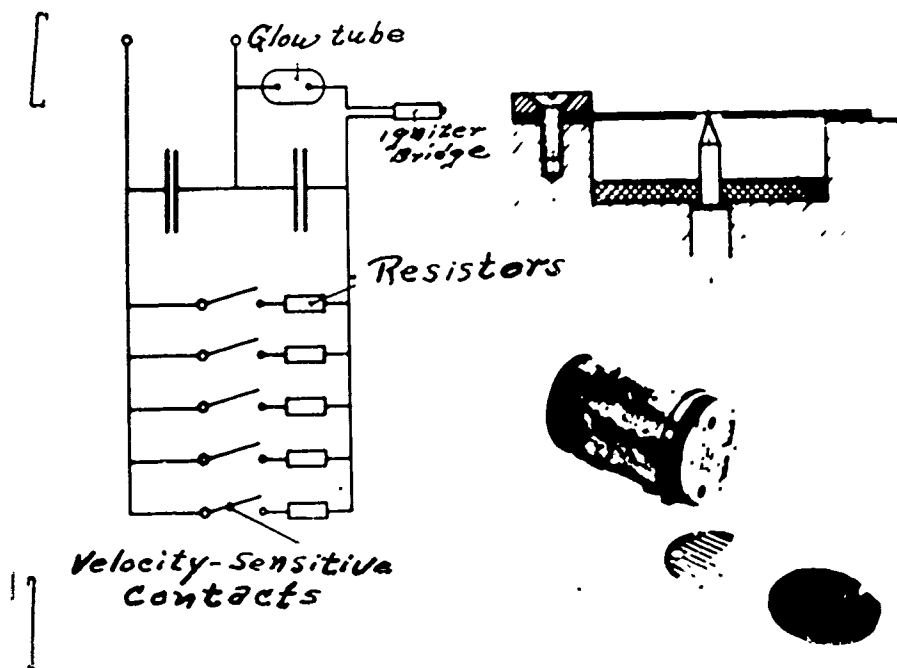


FIGURE 13

Electric fuze employing velocity-sensitive contacts.

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Velocity Sensitive Fuzes (c)(Cont'd.)

widely different magnitudes; whether the speed loss happens all at once as with impact of a thick deck, or one after the other in several increments as with penetration of several thin decks. The device is therefore not suitable for the desired purpose.

2. Use of mercury capillary damping:

According to calculations of Prof. Madelung, the penetration of mercury into a constricted capillary is proportional to the time integral over the delay (Fig. 12, lower left). This fact can be utilized in a "mercury fuze" whereby the mercury thread is of a corresponding length to that of the impulse change of the bomb. Detonation is brought about by the thread of mercury making contact with a lead in the capillary. This fuze can also be held to very small dimensions. The use of mercury, however, is not convenient, and the housing would be extremely complicated.

3. Vibration of a Tuning Fork:

The third proposal of Prof. Madelung employs a tuning fork, which is put in vibration shortly before impact of the bomb. This fork holds, by means of clamps, (Fig. 12, upper right) a thin steel wire (fall body), which is fixed beforehand and gives the fork its frequency "n", corresponding to "n" times during a small unit of time Δt_s . During this process the deceleration of the bomb causes a relative movement Δ_s of the wire with respect to the fork. As the formulas in Fig. 12 show, the sum of these movements Δ_s is approximately equal in relation to the time integral of the impact retardation. This relation becomes more accurate as the frequency of the tuning is increased.

Figure 13 shows an electrical solution to the problem of measuring time impulse changes. As with the normal electric fuze systems, one condenser is given an electric charge which, through a resistor charges a second condenser while the bomb is falling. As soon as the second condenser or "firing condenser" reaches a definite potential the fuze is armed. With this proposed speed-dependent fuze the unloading between the two condensers is not accomplished fast but rather employs a row of resistances that are switched in by acceleration-sensitive contacts. The greater the deceleration, the more contacts close, the smaller is the resist-

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Velocity Sensitive Fuzes (c)(Cont'd.)

ance between the two condensers, and the quicker the firing condenser is charged. When deceleration ceases, the contacts must at once re-open. With smooth working of these acceleration-sensitive contacts, the potential in the firing condenser climbs corresponding to the speed reduction of the bomb on impact. If the bomb has lost almost all of its speed, the potential of the firing condenser has reached the value at which a tube passes current through an ignition squib and detonates the bomb. The construction of the acceleration-sensitive contacts for this fuze caused many difficulties. It is already known from torque-acceleration measuring devices that it is difficult to achieve springs calibrated to accelerations such as these. A further difficulty arose in that the springs broke upon contact. In order to avoid this, the following execution was proposed. The actual measuring spring which is calibrated to a certain deceleration is provided with a hole at the contact place. A very thin spring lies on top of the measuring spring. This thin spring has no stiffness, and therefore follows the movements of the measuring spring. The measuring spring can swing by the contact freely while the thin contact spring lies on the contact tip and closes the circuit. When the spring jumps back, the contact spring follows.

The diagram at right in Figure 13 shows the execution of such a fuze: The condenser tubes and resistors are housed in the casing. The contact terminals are visible in the side of the casing. Contact springs are all consecutively stamped from one piece. The spring seat, in the diagram, lies in front.

The results of experiments with the devices shown in Figures 12 and 13 were not, at this stage of the development, entirely satisfactory.

4. Controlled Deformation of the Bomb Nose.

Should a hollow charge bomb strike an extremely resistant target such as a gun turret, it must detonate instantly before it is broken up by the force of impact. The available time for firing is extremely short, and a fuze dependent on speed cannot fulfill this function. The bomb nose may be completely crushed while the after part continues on through the plate with practically uninterrupted speed. When the fuze dependent on the speed is housed, as it probably is in most cases, in the after part of the bomb, it is affected by the loss of impact energy

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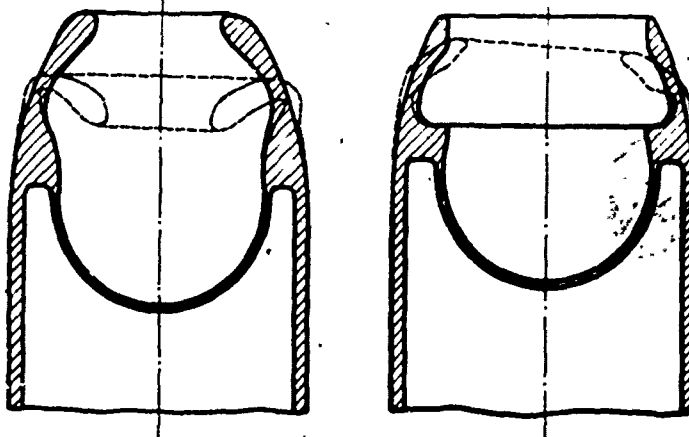


FIGURE 14

Hollow-charge bomb heads with deformation indentations.

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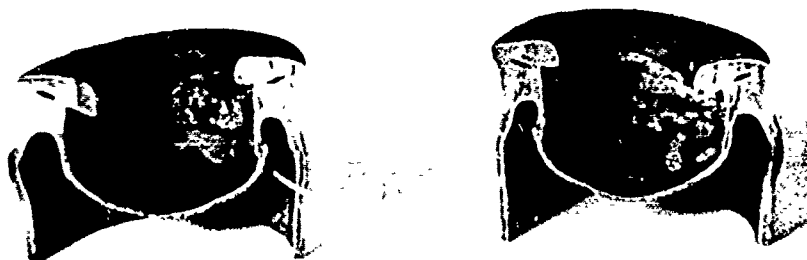


FIGURE 15

Effect of impact on deformation indentations.

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FIGURE 16

Effect of impact on deformation indentations.

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Controlled Deformation of the Bomb Nose (Cont'd.)

too late.

A "fracture" fuze has the job of determining when the physical security of the bomb construction is endangered. The impact deceleration alone can not be set as a standard. The bomb can survive high, but short, percussions without danger. Longer lasting decelerations of less magnitude, however, may lead to breaking up of the bomb. The fracture fuzes presently employed by the Luftwaffe are not activated by the magnitude of the deceleration alone, but also take account of the duration of the retardation. If a fracture fuze is given too great a margin of safety it may happen that the bomb detonates too early, or detonates when it is not necessary. If the safety margin is too narrow, the danger arises that the bomb is deformed to a degree that the detonation, if it does finally occur, will be of little or no consequence. This is to be especially feared in hollow-charge whose open nose is not equal in strength to that of the normal bomb. Experiments have proven, however, that hollow-charge heads are ordinarily able to penetrate thin steel plates without being excessively deformed. The object that a hollow-charge bomb should penetrate mechanically the thin plates over the armor does not fail because of the strength of the bomb body.

Figure 14 shows hollow charge bomb heads with deformation indentations at the weakest points in the nose stand-off piece. As illustrated in the following figures, 15 and 16, these indentations can withstand considerable shock. Only when the tip has folded over completely, as in Figure 16, does the bomb body itself begin to deform. The time consumed by this deformation is relatively long compared with the inherent fuze delay, and thus makes possible proper detonation of the bomb. A further possibility is to actuate the "fracture" fuze by percussion rods extending back from the indentations. The bomb is then detonated when the indentations have been almost completely collapsed. Experiments have proven these methods quite satisfactory.

5. Conclusions.

The ignition of a hollow-charge bomb must follow:

1. When the initial velocity of the bomb has been expended to the proper degree. The necessary speed-dependent fuze has been described extensively.

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Conclusions. (Cont'd.)

2. When the structure of the bomb itself is threatened. The "fracture" fuzes now in use are quite suitable. The operation of this type fuze may be facilitated by the above described constructional measures.
3. after the termination of a certain delay period. This may be accomplished by known time delay fuzes.

NOTE: No further information on the development of this type bomb, or on the proposed fuzing system to be employed in it has been discovered by this mission. The Hollow-Charge Bomb was never used operationally.

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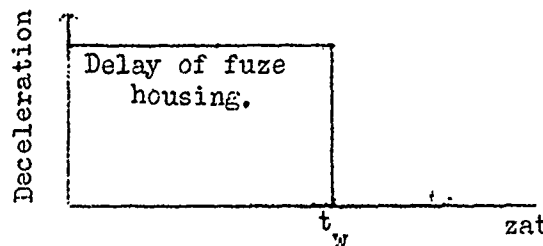
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6. Appendix.

Derivation of the formulas in Figures 7 and 8 for the fuzes checked by springs and those checked by damping systems:

a) The Spring Fuze.

If the spring resistance value c works on the spring fuze of the body m , which at the beginning of the bomb delay finds itself relative to a bomb at rest ($X_0 = X'_0 = 0$), in the sense that the inherent time constant of the fuze's small time interval $0 \leq t \leq t_w$, the constant deceleration b , then it can be said that the following formula is applicable to the movement of the firing pin relative to the bomb:



1.

$$X = \begin{cases} \frac{2b}{\alpha^2} \sin^2 \frac{\alpha}{2} t & \text{for } 0 \leq t \leq t_w; \sqrt{\frac{c}{m}} \\ \frac{2b}{\alpha^2} \sin \frac{\alpha}{2} t_w \cdot \sin \frac{\alpha}{2} (t - t_w) & \text{for } t \geq t_w; \end{cases}$$

which results in a simple integration of the movement equation.

2. $m\ddot{X} + cX = mb$

as is known, the general integral in the prescribed standards is:

3. $X = \frac{1}{\alpha} \int_0^t b(t) \sin \alpha(t-t) dt.$

with smaller values of αt ($\leq \alpha t_w$) the results of (1.) give the development of the approach formula:

4. $X \approx \frac{b}{2} t^2 (1 - \frac{\alpha^2}{12} t^2).$

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Appendix (Cont'd.)

b) The Fuze Checked by Oil Damping.

Since the damping of the speed is proportional, we have as movement equation:

$$5. \quad \ddot{X} + \frac{\dot{X}}{\xi} = b^*$$

The first integral is

$$6. \quad \dot{X} + \frac{X}{\xi} = \int_0^t b dt = V$$

When we show the V time interval (QT) resulting from the loss of speed of the bomb, Integrally in general it follows that:

$$7. \quad X = \xi V(t) - \xi e^{-\frac{t}{\xi}} \int_0^t \frac{t}{\xi} b(t) dt,$$

Therefore for b = constant.

$$8. \quad X = \xi V - \xi^2 b(1 - e^{-\frac{t}{\xi}}), \quad (0 \leq t \leq t_w).$$

* The equation is, of course, only good when the lazy mass of the oil as opposed to the lazy mass of the piston may be reduced, and when the compressibility of the oil as well as its temperature variations has no great influence on the process.

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