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TECHNICAL REPORT No. [redacted]

GERMAN ELECTRICAL TIME AND IMPACT FUZES AND COMPONENTS

September 1945

[redacted]

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U. S. NAVAL TECHNICAL MISSION IN EUROPE
c/o Fleet Post Office
New York, N.Y.

File: A9-16(3)(40/Hn)

Serial: 01141

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24 September 1945.

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TECHNICAL REPORT No. 400-45

GERMAN ELECTRICAL TIME AND IMPACT FUZES AND COMPONENTS

SUMMARY

The development of electrical time and impact fuzes was carried on by the Rheinmetall-Borsig organization of H. Rhulemann. A large number of documents concerning electrical fuze development have been obtained from Rhulemann's laboratory and shipped to the Explosives Investigation Laboratory, Indian Head, Md. The present report contains information obtained in interrogations of Rhulemann and in visits to factories where electrical fuze components were made. It is written to supplement the documents, and is intended to cover only the following subjects, with some introductory matter:

(1) The volume of production of the more important German electrical fuzes.

(2) Performance of electrical time and impact fuzes; difficulties encountered in service.

(3) Details of manufacture of fuzes and components.

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2. Operation of Electrical Impact and Time Fuzes.

(a) Impact Fuzes.

Electrical impact fuzes contain the following basic parts: (See figures 1 and 2.)

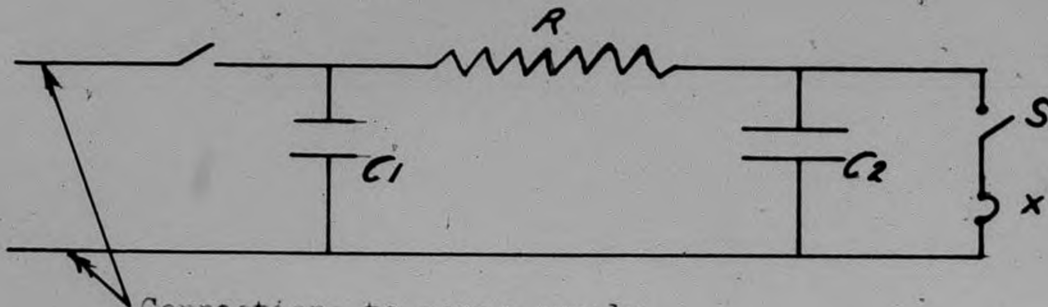
Storage condenser	C_1
Resistor	R
Firing Condenser	C_2
Switch	S
Igniter	X

At the instant the round is started on its trajectory, an electric charge is placed on the storage condenser. During flight, part of this charge leaks through the resistor to the firing condenser. When the charge on the firing condenser is sufficient to fire the igniter, the fuze is armed. Firing takes place when the switch closes upon impact, allowing the firing condenser to discharge through the igniter.

Two or more circuits of the type shown in Figure 1 are usually incorporated in the same fuze. In one of these the igniter fires directly into the gaine; the igniters in the other circuits fire into pyrotechnic delays. The choice of instantaneous or delay action can be made by connecting the proper circuit immediately before releasing the bomb.

(b) Time Fuzes.

Time fuzes contain essentially the same basic parts as impact fuzes except that the switch is replaced by a vacuum tube which becomes conducting at a critical, known voltage. (See figures 3 and 4.) At the instant the round is started on its trajectory, an electric charge is placed on the storage condenser, and another, smaller charge is placed on the firing condenser. The time setting of the fuze is adjusted by varying the amount of charge placed on the firing condenser. During flight, part of the charge on the storage condenser leaks through the resistor to the firing condenser. As the charge on the firing condenser increases, the voltage across the tube increases. When the firing voltage of the tube is reached, the firing condenser discharges through the tube and igniter, firing the fuze.



Connections to power supply
(The upper connection is made
through a charging pin. The
lower connection is made
through the fuze case.)

Figure 1

Circuit of German Electrical Impact Fuze

(Only the basic parts of one circuit are shown. Two or more circuits are usually incorporated in each fuze. A switch in the aircraft enables selection of the circuit to be charged.)

Basic Parts:

C_1	Storage condenser
R	Resistor
C_2	Firing condenser
S	Trembler switch
X	Igniter

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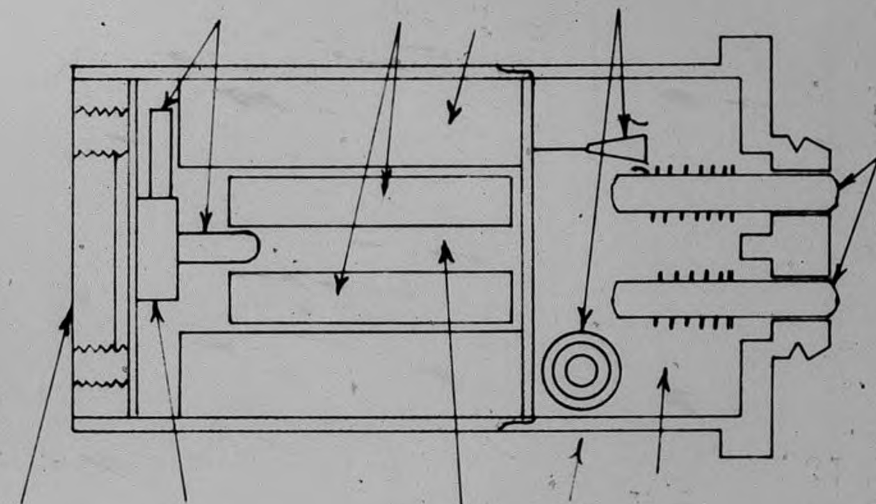

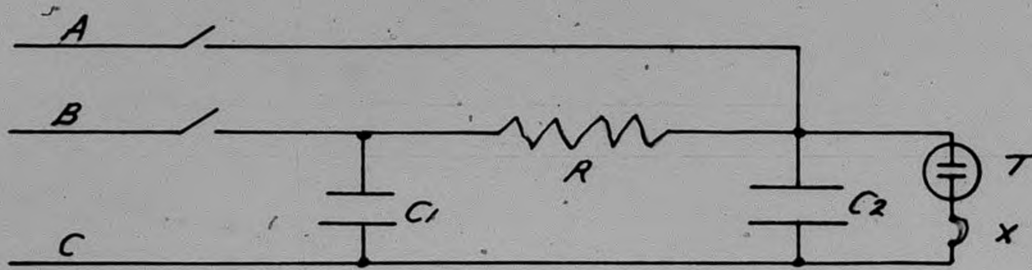

Figure 3

Circuit of [illegible] Electrical Impact Fuze

Only the [illegible] part [illegible].

Connections A and B are made through charging pins, connection C is made through the fuze case. A fixed voltage is [illegible] between B and C. A variable voltage is [illegible] between A and C; the value of this voltage determines the time setting.

Basic Parts:

C_1 Storage c[illegible]

R Resistor

C_2 Fi[illegible]

T Cold [illegible]

X I[illegible]

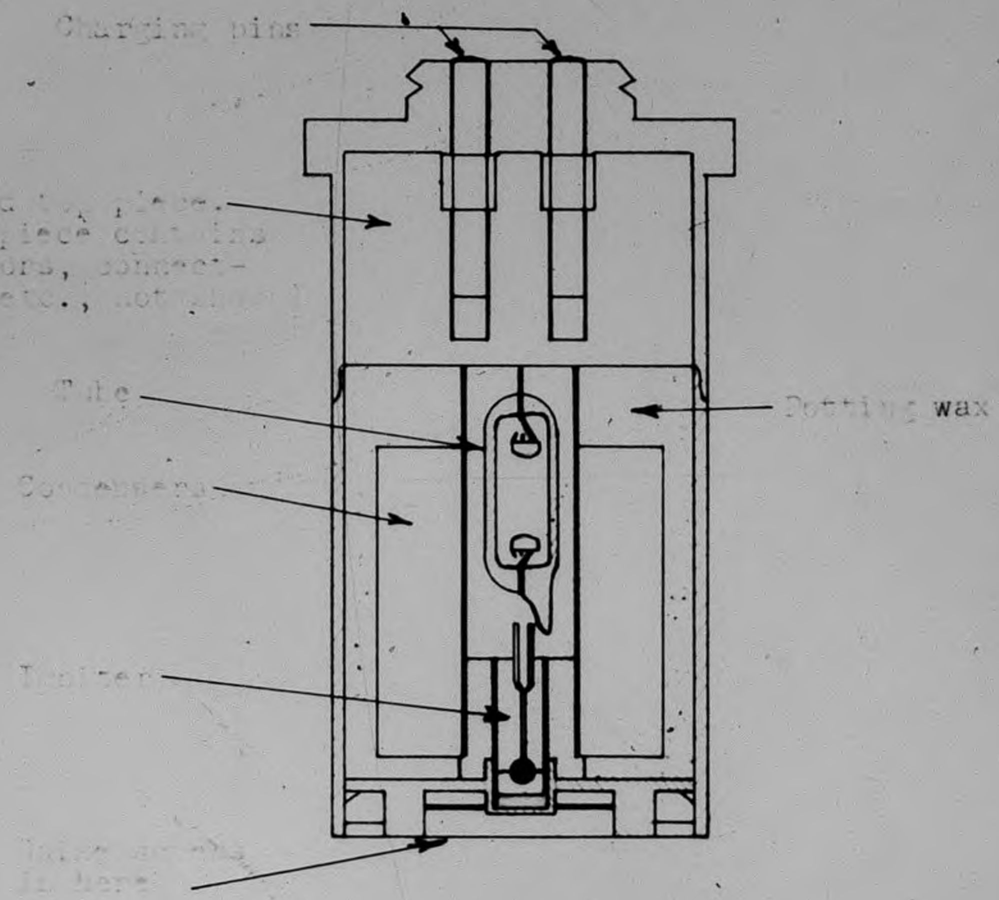

Figure 4

German Electrical Time Fuze [illegible]

(Only the major parts are shown. Connections between parts, and many smaller parts are not shown.)

2. (b) Time Fuzes (Cont'd).

Both the storage and the firing condensers of German time fuzes are charged, in order that the voltages used can be kept reasonably low. An increased time setting requires an increased voltage. If only one condenser of a time fuze were charged, an excessive voltage would be required to obtain a time delay of, say, 30 seconds. (The arming times of impact fuzes are generally 5 seconds or less.)

3. Advantages of Electrical Fuzes.

When Rhulemann was asked what factors influenced the German military authorities to adopt electrical fuzing, he listed the following advantages:

(a) The fuzes can be set by remote control immediately prior to the instant of firing. Dead time is eliminated in time fuzes, and impact fuzes can be set for instantaneous or delayed actions as each round is used.

(b) Electrical impact fuzes are extremely rapid in action because the only mechanical part, the trembler switch has but little inertia and friction. With an "instantaneous" fuze setting, a bomb can be made to explode without deep penetration of the target.

(c) The electrical scheme has great flexibility. The same components were used in a variety of time and impact fuzes having nearly identical appearance but a wide range of characteristics.

(d) The fuzes are safe to handle, ship and store. Whereas in most mechanical fuzes the source of energy to ignite is always present (as a stressed spring, for instance), energy is not introduced into the electrical fuze until the moment of use. Extensive trials were made with voltages as high as two million volts, which showed that properly designed electrical fuzes are not affected by atmospheric electricity.

3. Advantages of Electrical Fuzes.(Cont'd).

(e) The Germans found the electrical fuzes less expensive to manufacture than mechanical fuzes having the same characteristics, when made in comparable quantities. (Rhulemann stated that the cost ratio was about two to three, and added that parts out of tolerance for time fuzes could be used in impact fuzes, so that the total manufacture had small shrinkage loss.)

4. Volume of Production of Principal Fuzes.

Rhulemann said that the more common German electrical impact and time fuzes were produced in the quantities listed below:

Fuze Number	Type of Fuze	Quantity Produced
9	Time fuze, range 2 to 25 seconds.	Production was limited by the output of cold-cathode tubes. Peak production was 40,000 per month; this fell to 25,000 per month after the Siemens works was bombed.
25D	Rhulemann stated that this was an impact fuze having instantaneous and 3 delay actions.	Maximum 400,000 per month.
38A	An impact fuze having instantaneous and 2 delay actions.	Production was small.
45A	An impact fuze, developed early in the war.	Maximum 30,000 per month.

4. Volume of Production of Principal Fuzes.(Cont'd).

Fuze Number	Type of Fuze	Quantity Produced
55	An impact fuze having instantaneous and one delay action.	This fuze replaced many other impact fuzes. It was produced by several factories; the total number produced was estimated to be 15 or 20 million.

5. Performance; Difficulties Encountered in Service.

No definite figure of merit indicating the performance of electric fuzes used in combat was obtained from Rhulemann, but he implied that the overall performance was better than 90%.

When trouble was encountered in service, it was generally due either to (1) use of substitute materials, (2) presence of too many electrical connections in the space available, or (3) first encounters with extremes of temperature or humidity, before special materials were developed. All of these difficulties can be avoided by proper design.

Specific difficulties described by Rhulemann were:

(a) Attempts to use substitute impregnation material in condensers caused duds.

(b) The wax packing in the igniters was replaced by sulphur at one time, causing the rejection of several hundred thousand fuzes.

(c) Difficulties were encountered with the insulation of fuze 25D, which had four circuits, and this fuze was replaced by fuze 55, which had two circuits.

5. Performance; Difficulties Encountered in Service.(Cont'd).

(d) The storage life of the No. 9 time fuze was said to be about 2 years, while the storage life of the much simpler No. 55 impact fuze was said to be about 5 years, when components were made of materials of similar quality.

(e) It was found necessary to replace the normal Trolitul No. 3 used for the central insulating core and top insulator, by a special compound, Trolitul EF, for use in hot, damp climates.

(f) Certain condenser impregnation compounds which were very satisfactory at normal temperatures, failed to give up all their energy when used at very low temperatures (about -60° C).

6. Description of Manufacture of An Electrical Impact Fuze.

(a) The resistors were placed in the central insulated core.

(b) The igniters were placed in the central insulated core.

(c) A plastic protecting ring was slipped over the central core.

(d) The condenser annulus was assembled over the protecting ring.

(e) The leads from the resistors and igniters were at this point projecting through appropriately placed holes in the top of the central insulated core. These leads, together with the condenser leads were twisted together to form the necessary connections, and cut to length. This was done with a hand tool operated by a flexible shaft.

6. Description of Manufacture of an Electrical Impact Fuze (Cont'd).

(f) The twisted leads were melted together. A special electric welding tool held in the operator's hand was used.

(g) The moulded top piece was placed over the condenser and central insulated core. This top piece contained the impact switches, and holes for the necessary leads and connections, and holes for charging pins.

(h) Electrical tests were made. The igniters were tested for continuity; the storage condenser was charged and the voltage measured on the firing condenser at the end of an accurately timed interval. (All trembler switches were held open during this test.)

(i) The fuze was put in its metal case.

(j) The case was crimped or notched near the base and in some models at the top also, to hold the assembly in position.

(k) The assembly was potted in a bituminous composition.

(l) The tests of operation no. (h) were repeated.

(m) A rubber sealing ring was placed around the top of the case.

(n) The charging pins and their springs were inserted.

(o) The metal top was placed over the case and crimped on; 5 tons force was used.

(p) The pyrotechnic delay element was placed in the bottom of the fuze.

(q) The waterproofing was tested with ½ atmosphere air pressure.

6. Description of Manufacture of an Electrical Impact Fuze (Cont'd).

(r) Electrical tests were again made.

(s) The protecting cap was put over the charging pins.

(t) The completed fuze was painted.

7. Description of Manufacture of an Electrical Time Fuze.

The manufacture of time fuzes for bombs followed the same general pattern as the manufacture of impact fuzes. The values of the components of the time fuze, however, were more critical than those of the impact fuze, and the following steps were included in the manufacture:

(a) After the tube, condenser, and all but one of the resistors had been assembled, the firing voltage of the tube was measured.

(b) A standard resistor was inserted in place of the missing resistor, and a standard voltage applied to the fuze. The time of firing of the tube was measured, and the first adjustment of the circuit elements was made by selecting the proper "trimmer" condenser (from among 3 or 4 assembled in the condenser annulus). This "trimmer" condenser was added to the firing condenser in order to bring the firing time of the tube closer to the correct firing time expected for the standard value of voltage applied.

(c) The timing test of the fuze was repeated, and the final adjustment of the circuit elements was made by selecting a resistance value and inserting this resistor into the fuze in place of the standard value used previously. (The resistance consisted of three units of about 15 megohms each; one of these could be removed and replaced at any time up to the final closing of the fuze.)

8. Resistors Used in Electrical Fuzes.

(a) The resistances of high ohmic value used in German electrical fuzes were of three types:

(1) Wire wound resistors of moderately high value were made, using the same type of wire used in Sx5 and Sx6 igniters.

(2) Resistors of the highest values necessary were made by spraying amorphous carbon onto a ceramic core. These were produced by the Rosenthal Company, and were said to have good temperature characteristics, but were not so uniform nor so stable as those made by Siemens (see (3) below).

(3) The Siemens Company produced uniform, stable resistors of very high ohmic values by cracking heptane and depositing a thin film of crystalline carbon on a heated ceramic rod. Rhulemann believed that the crystalline carbon was a most important factor in obtaining stable characteristics.

(b) The Siemens manufacturing process involved the following steps:

(1) A ceramic rod of proper size was obtained. The resistors were about 3 or 4 mm in diameter and 20 to 25 mm long. Any good ceramic, preferrbly fine grained, was satisfactory.

(2). The rod was cleaned by sand blast and washed in distilled water.

(3) The rod was heated to 800 or 900 C in a vacuum of 0.01 mm of mercury.

(4) After 4 to 16 hours of pumping (the time depended upon the number of resistors being produced simultaneously) heptane was introduced into the chamber and cracked, leaving a thin film of crystalline carbon on the heated rod. The thickness of the film was of the order of 10 molecules to 0.001 mm, and depended on the amount of heptane used.

8. Resistors Used in Electrical Fuzes (b) (Cont'd).

(5) After cooling, the ends of the resistor were covered with carbon suspended in water.

(6) The resistor was dried immediately in warm air.

(7) The resistor was measured and placed in a group according to the resistance between its ends, which was now of the order of 20,000 ohms.

(8) A helix was ground into the surface of the resistor, using a carborundum wheel. The width of the carbon helix which was left on the rod was determined by the initial value of the resistance between the ends, and by the desired final resistance value. In a typical resistor, the groove cut out might be 0.2 mm to 0.3 mm wide, and 0.3 mm deep, and the pitch of the helix might be 0.6 mm.

(9) End connections were made.

(10) Duco red lacquer was applied and the resistor was dried and put in storage for two to four weeks.

(11) After storage the resistor was measured and labelled.

9. Condensers Used in Electrical Fuzes.

Some of the condensers used in Rheinmetall fuzes were made by Siemans, some by A.E.G., and some by Rheinmetall-Borsig. The manufacturing process was similar in all three plants, and involved the following steps:

(1) Two thickness of paper were wound between layers of aluminum foil. The paper was 0.008 to 0.009 mm thick, and the foil 0.005 to 0.006 mm thick. Winding was generally done in a controlled atmosphere at 18-24 C, and 50-60% relative humidity.

(2) All condensers for a fuze were wound into a

9. Condensers Used in Electrical Fuzes (Cont'd).

single integrated annulus. Connections were made by strips inserted into the winding at the proper points.

(3) Following winding, the condensers were dried for 8 hours at 110 C.

(4) The condensers were vacuum-impregnated for 8 hours. The impregnating compound (Synthetic chlorinated napthalene, with a dielectric constant about 5) was made by I. G. Farben at Leverkusen, and was known as D 88.

(5) After impregnation and cooling, the condensers were dipped in D 88, then enclosed in a metal container and the top sealed with pitch.

(6) After sealing, each condenser was tested for breakdown. 500 volts were applied across the terminals, and 1500 volts were applied between the electrodes and the case.

The Germans believed that although tinfoil was not available for electrodes, aluminum foil was fully as good.

The placing of leads in condensers was considered extremely important. (See figure 5.) The leads from the two electrodes of a condenser must be brought out opposite each other (within 1 cm. or so). This was necessary to eliminate inductance, by which the firing condenser might acquire a charge from the charging of the reservoir condenser. If several condensers have an electrode in common, a lead must be brought out of the common electrode opposite each lead brought out of the separate electrodes.

In certain models made by A. E.G., in which several condensers were wound in the same annulus, a short-circuited turn was wound between the condensers to provide magnetic shielding. This was not necessary in the condensers built by Siemans.

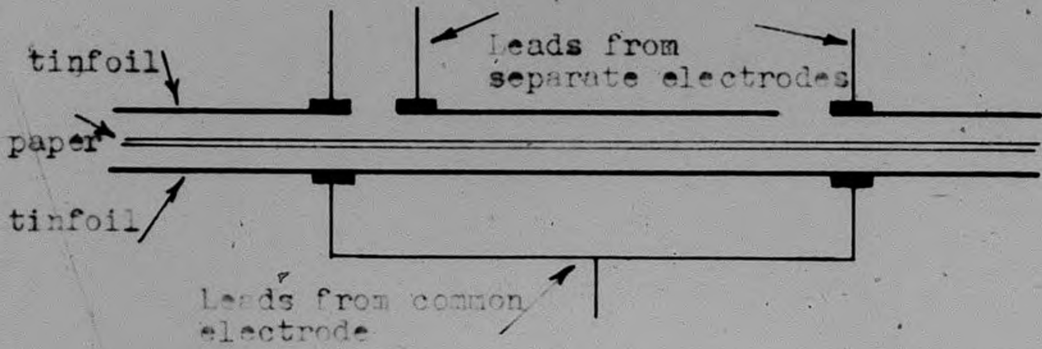

Figure 5

Schematic Diagram of Condenser Winding

The winding illustrated consists of three condensers having a common electrode. A separate lead must be brought out of the common electrode opposite each lead (or pair of adjacent leads) from separate electrodes.

10. Igniters, Type Sx5 and Sx6, Used in Rheinmetall Fuzes.

Electrical igniters of the low-voltage wire bridge, or "match head" type were made at the Dynamit A. G., in Troisdorf.

The following manufacturing process was used:

(1) Tinfoil sheets were pasted to both sides of a piece of cardboard slightly thicker than a book match.

(2) The cardboard was cut to the shape shown in Figure 6 (a). A sheet of cardboard carried about 25 projections, each of which would become the central core of an igniter.

(3) Sheets were stacked in piles of 12, overlapping, and the wire which would become the igniter bridge was laid over each row of 12 projections (See figure 6 (b)). The wire was soft-soldered to each projection.

(4) The sheets were turned over and the wire soft-soldered to the other side of each projection, forming the igniter bridge. A small loop of wire was left, as shown in figure 6 (c).

(5) The 12 sheets were separated, and each sheet was inspected, using a magnifying glass. Defective igniters were cut out; 20 to 23 good igniters generally remained on a sheet.

(6) The sheets were dipped in the explosive mixture. There were two dips, first in azotetrazol lead, then in lead trinitroresorcinate. The explosive was rather viscous and clung to the wire loops, forming the "match heads". Drying by warm air followed each dipping.

(7) The igniters were dipped twice in lacquer, then dried.

(8) Leads were soldered to the igniters.

(9) The igniters were now cut away from the parent sheets.

10. Igniters, Type Sx5 and Sx6, Used in Rheinmetall Fuzes (Cont'd).

(10) The igniters were inspected, and sorted for size by shaking them through a slot of progressively increasing width (a taper gauge) into sorting bins.

(11) The igniters were tested for resistance and continuity.

(12) A covering tybe of plastic "Trolite #3" or "Mipolam" (polyvinol chloride) was slipped over each igniter.

(13) The remaining space in the plastic tube was filled with chlorinated napthalene wax of a good quality. The completed igniter is illustrated in figure 6 (d).

The success of these igniters depended upon the extremely fine wire used for the bridge. This wire was cold-drawn, 80% nickel, 20% chrome, and was produced by the Rheinish Fine Wire Co. of Bargis Neustadt. The wire was about 0.008 mm in diameter; however it was not specified by its diameter, but by its resistance. That used in the Sx5 igniter was 8000 ohms per meter, and that used in the Sx6 igniter was 12,000 ohms per meter.

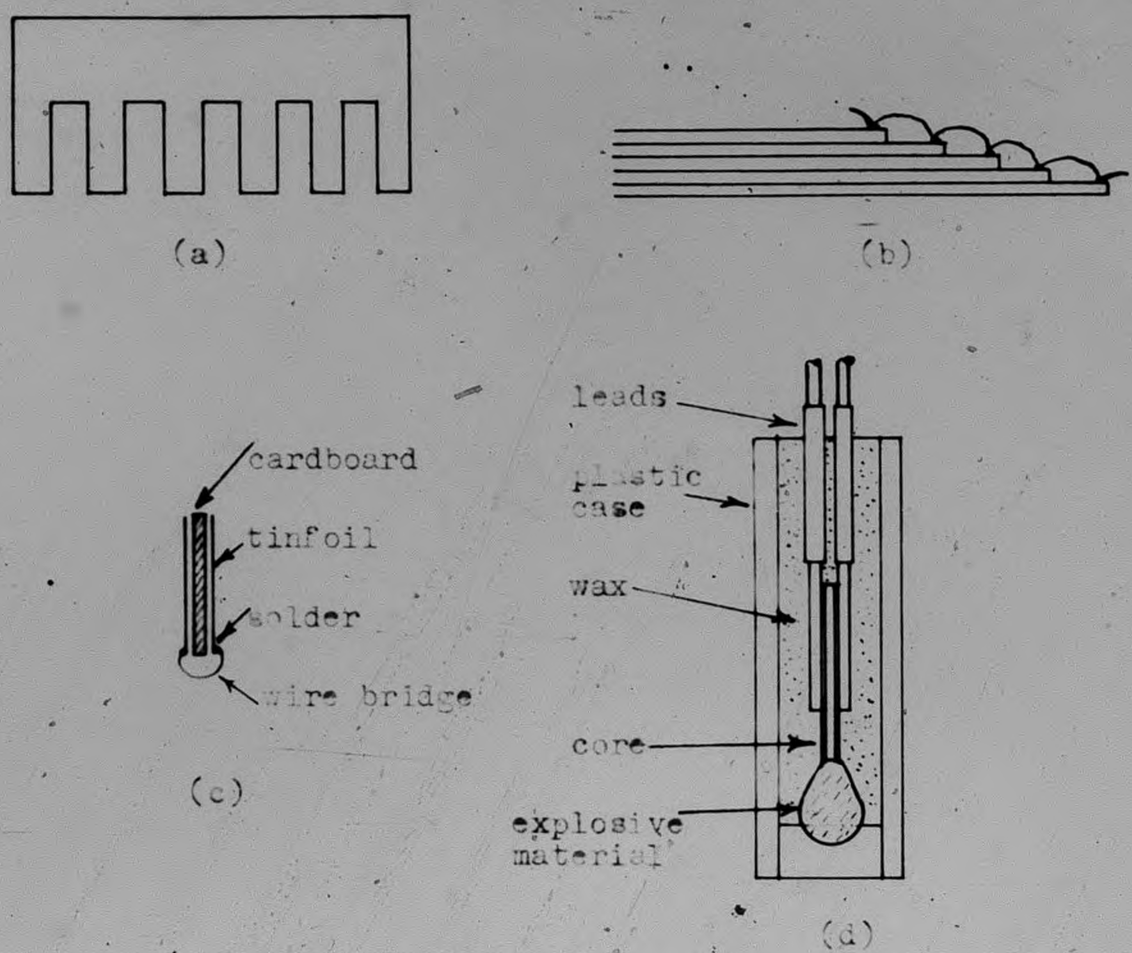

Figure 6

Steps in the Manufacture of Igniters
(Type Sx5, or Sx6)

Fig. 6(a) Portion of a cardboard strip from which igniter cores are made. The cardboard is covered with tinfoil on both sides. The complete sheet contains 25 projections, each of which will become the core of an igniter

Fig. 6(b) Side view of a stack of sheets of igniter cores. About a dozen sheets are stacked in this way, and a wire is soldered to the corresponding projection on each sheet.

Fig. 6(c) Side view of the core of an igniter, after the wire has been soldered to both sides, forming the bridge. This core has not yet been dipped in the explosive material.

Fig. 6(d) Cross section of a completed igniter. The core of Fig. 6(c) has been dipped in explosive, leads have been attached, and the assembly has been put in a plastic case and packed with wax.

10. Igniters, Type Sx5 and Sx6, Used in Rheinmetall Fuzes (Cont'd).

The lacquer in which the igniters were dipped (step 7) was a 15% solution of collodion in amyl acetate. Two hundred grams of aluminum powder were added to each liter of solution. When the lacquer dried, the aluminum formed a high-resistance shield which covered the match head; this added to the safety of the igniter without impairing its effectiveness.

11. Tubes Used in Electrical Time Fuzes.

The tubes used in Rheinmetall electrical time fuzes were cold-cathode, argon-filled diodes (see figure 7). They were produced by Siemans, in Berlin, and were said to cost about 4.9 Reichmarks. The manufacturing process is described below; when 80% of the tubes manufactured were acceptable, performance was considered "very good". The firing voltage of the tubes considered below was 160 volts. In service, the tubes fired with an arc (not a glow) discharge.

(1) The electrodes were fabricated to the proper hemispherical shape, of oxygen-free iron, nickel plated.

(2) Three copper covered steel wires were welded to each electrode.

(3) A bead of lead glass was formed around the three wires supporting the electrode; one of these wires became the lead in.

(4) A tube of lead glass was slipped over the electrodes to form the envelope. The envelope was 11 or 12 mm in diameter, and about 20 mm long, with walls about 1 mm thick.

(5) The anode was heated and a capsule of potassium was evaporated into the tube. Nearly all of this condensed on the cathode to form the electron-emitting surface.

(6) The tube was evacuated to 10^{-6} mm of mercury.

[redacted]

11. Tubes Used in Electrical Time Fuzes (Cont'd).

(7) The leads were connected to a 160 volt source which was capable of supplying only enough current for a glow discharge. Argon was introduced into the tube until a glow discharge took place; the tube was then sealed off. The pressure was usually 10 to 15 mm of mercury.

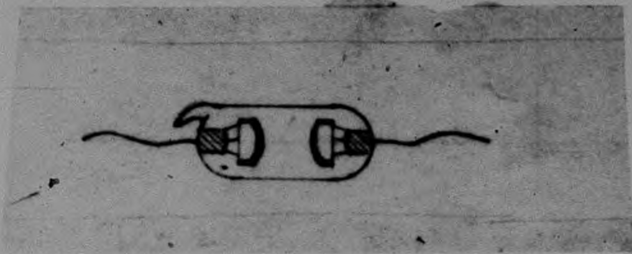

FIGURE 7
COLD-CATHODE DIODE USED
IN ELECTRICAL TIME FUZES

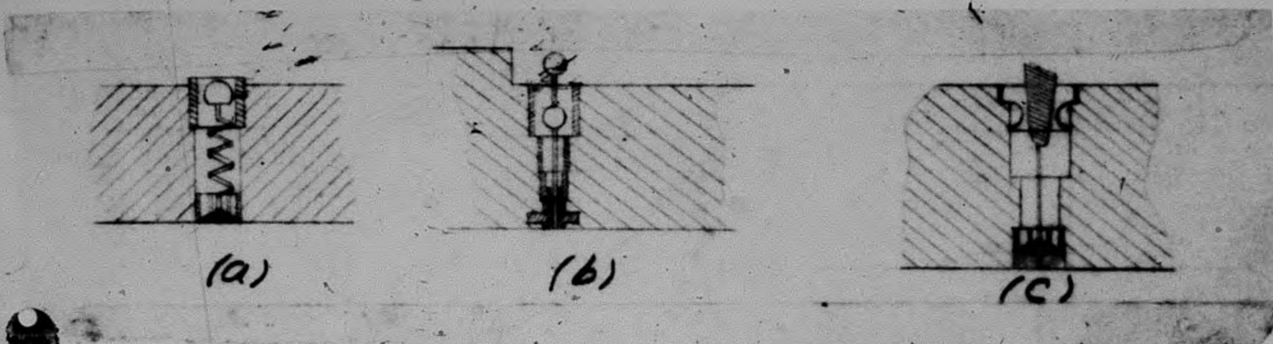

FIGURE 8
TREMBLER SWITCHES USED IN
IMPACT FUZES

FIG. 8(a) EARLIEST MODEL
FIG. 8(b) LATER MODEL
FIG. 8(c) FINAL MODEL

[redacted]

11. Tubes Used in Electrical Time Fuzes (Cont'd)

(8) A pencil-mark of radioactive material (zinc sulphide) about 10 mm long and 1 mm wide was made on the outside of the tube.

(9) The tube was dipped in a graphite suspension; this outside covering was connected to the cathode but not to the anode.

(10) The firing voltage (for an arc discharge) was checked, and each tube was numbered. Firing voltage limits were 156.5 to 164.5.

(11) The tubes were placed in racks and aged for a period of four to six weeks. The racks were so arranged that the firing voltage of each tube could be checked automatically from time to time. The arcing voltage of each tube had to remain stable within $\pm$ 0.3 volts, or the tube was rejected.

12. Trembler Switches Used in Impact Fuzes.

The trembler switches used to fire impact fuzes originally consisted of a small steel ball, about 3 mm in diameter, supported on a bronze wire inside a metal tube about 5 mm in diameter (figure 8(a)). All parts of the switch were chrome plated.

The contact time of the original switches was too short; a second ball was therefore added (figure 8 (b)). Only the lower ball made contact. The function of the upper ball was to hold the lower ball against the wall of the tube during a "swing". This type switch was abandoned because of the difficulty of drilling small steel balls.

The final type of switch employed a spiral of chrome plated bronze wire as the moving contact (figure 8 (c)). The spiral extended beyond the fixed contacts, in order to obtain the effect of the upper steel ball of the previous design. The fixed contact was a chrome plated ring; this ring and the base of the moving contact were fixed in the plastic moulded top piece of the fuze by a spot-heating process.

[redacted]

13. Power Supplies for Electrical Bomb Fuzes.

Dry batteries were originally used to supply power for bomb fuzes. Batteries were not satisfactory at high temperatures, and had an average life of only 3 to 5 months in the African campaign.

Batteries were replaced by a motor-generator and stabilized power supply unit. The motor took power from the airplane's 24 volt system, and the generator delivered 500 volts. The stabilizer was said to hold the output voltage constant with ± 1.5%. The various voltages used in charging time and impact fuzes were obtained from taps on a resistor connected across the output of the stabilizer.

The chief disadvantage of the motor-generator and stabilizer unit was that the voltage-dividing resistor became overheated if several bombs were dropped in rapid succession.

At the end of the war, a new motor-generator had been developed for charging impact fuzes but had not been used in combat. The machine had 3 commutators (24 volt input, 150 and 240 volt output).

14. Improvements Considered by the Germans to be Necessary.

When asked what improvements were contemplated in electrical time and impact fuzes, Rhulemann said that the following were considered important:

(1) The condensers were to be put in hermetically sealed cans. Lead wires would be brought out through glass seals.

(2) The charging plungers would be replaced by contacts mounted on a diaphragm, the periphery of which would be sealed to the moulded insulating top piece of the fuze assembly.

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14. Improvements Considered by the Germans to be Necessary (Cont'd).

(3) A condenser having a rolled plastic dielectric, such as styroflex, would be very desirable. This would improve the storage life and reduce the size of condensers. However, it had not so far been found possible to make sufficiently thin sheets of plastic having no flaws or bubbles.

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