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TECHNICAL MEMORANDUM

Subject: Leuchtfisch - An Optical Torpedo Exploder

Introduction. Leuchtfisch was the German code name for a torpedo with an optically actuated exploder. This optical method was conceived and developed by Dr. Ing. Frank Früngel of Hamburg-Rissen, Germany, during the period of 1943-45. This device never came into production, although some twenty experimental models were built. Experimental trials to the extent of about 2,000 firings were carried out both in the Baltic Sea and in the Mediterranean. According to Dr. Früngel these trials were thoroughly successful, and the German Government had decided to start production of these exploders, but the end of the war interfered with the plans.

The optical exploder consists of a high intensity light source pulsed at 20 times per second and filtered so that only the ultra violet and the near violet are allowed to escape into the water. The light source is mounted on the most forward end of the cylindrical section of the torpedo. A reflector system beams the light slightly forward and at an angle of about 60° with respect to the long axis of the torpedo, i.e., the light goes out almost at right angles but inclined slightly forward of a line to the track of the torpedo. The receiver part of the system is a vacuum photocell mounted in a mirror about 3 ft. aft of the light source. The mirror of the receiver is so directed forward that its optical axis intercepts the axis of the light source at about 20 ft. above the torpedo. It is to be understood that both the light transmitted and the light received are not strictly confined to the optical axes but that there will be a volume of intersection.

When a pulse of light is sent out there will be illumination scatter and reflection from suspended material in the water. The amount of light then returned to the receiver will be very small and will represent something of the

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order of one part in 10^8 of the transmitted light. However, the light source is so intense and the photocell and amplifier sensitivities are sufficiently great so that the system is capable of operating under conditions where even less light is returned to the photocell.

The sequence of operations of this device when in use is as follows: the torpedo is fired and the electronic circuits are simultaneously turned on. After about 7 seconds the circuits begin functioning and light flashes are emitted. These light flashes are picked up by the photocell and amplified. The amplified pulses operate a relay system which in turn delivers a voltage back into the amplifier which reduces the gain of the amplifier. This operation continues for a number of seconds until the gain of the amplifier is so far reduced that under the particular conditions of depth, water cloudiness, light intensity, etc., the amplified intensity of the received pulses becomes small enough so that the relay is no longer actuated and the amplifier maintains itself just on the edge of operation. The voltage controlling the gain of the amplifier is allowed to leak off slowly through a resistor-capacitor system so that the gain of the amplifier slowly increases, and under these stable conditions an occasional pulse comes through the amplifier to maintain the amplifier in its stable state. Once the amplifier is in this stable state other circuitry comes into action to arm the exploder mechanism. The circuitry attached to the exploder mechanism is not responsive to single pulses which come through to maintain the amplifier on the edge of operation but is responsive if approximately 10 or more successive pulses come through with no interuption between them. Such a succession of pulses can be caused if the torpedo comes close to the keel of a ship.

As was explained, the normal stable system of the amplifier is maintained by the light scattered back from the water itself and the amount of this light is normally very small. In water such as Baltic Sea water, the attenuation has been found to be about a factor of 10 for each 3 ft. of double path, i.e., 3 ft. out from the transmitter and 3 ft. back to the receiver, a total of 6 ft. of water path. If, now, some object is intercepted by this light beam within the range of approximately 18 inches to 25 ft. there will be a sudden increase in the light received by the photocell. The coefficient of reflection of the intercepting object will always be in practical cases above 10%, and under these new conditions, the distance from the light source to the effective reflecting point and back to the receiver is reduced. Even though the coefficient reflection may be small, the shortening of the light path through the water is even more important for increasing the amount of light returned to the photocell. Consequently, within the range of operation, in this case as much as 25 ft. below the keel, there will be an increase of returned light which will be able to operate the amplifier for a short interval before the amplifier gain is reduced. At this time, however, before any appreciable effect is exerted upon the amplifier, the series of pulses have operated to actuate the exploder mechanism and fire the torpedo.

Technical Details. The circuitry and operational features will be considered in some detail under the following headings:

a. Light source
b. Photocell
c. Amplifier
d. Output circuit
e. Arming and exploder circuit
f. Power supply
g. Character of water

a. Light Source

The light source is an unconventional gas discharge tube. For the present circuit it consists of a spherical glass bulb approximately one inch in diameter, provided with two cylindrical glass projections along one axis of the bulb. Tungsten wires are sealed into the cylindrical projections, and the terminal ends of the wires project into the center of the bulb with a spacing of a few millimeters separating them. This spacing depends upon the voltage used to actuate the light source, usually 6 Kv or 12 Kv. The gas filling is approximately at atmospheric pressure and may be either Argon or Xenon. The discharge capacitor in this circuit is 0.005 - 0.01 microfarads and the whole circuit including the capacitor is built to have an extremely low inductance. A figure of 0.03 microhenries was quoted. An appropriate resistor connects this circuit to the power supply and the light source will flash at regular intervals whenever a voltage of about 6 Kv is reached. In this case the resistor is so adjusted that the flash rate is about 20 cps. According to Dr. Früngel, the peak electrical power of this light source is of the order of 1 megawatt, the effective blackbody temperature of the order of 50,000°K, and the light conversion efficiency is 5%. The light output is supposed to reach its peak within 0.1 microsecond and to tail off to a negligible value within 1 microsecond. Special glass is used throughout the optical system so that the cut-off at the ultra violet end is about 0.25 microns and a filter is used in the near ultra violet so that no radiation is transmitted beyond about 0.4 microns.

The light source is positioned in a reflector system such that the axis of the reflector system is upward and tilted slightly forward to an angle of about 30° from the normal of the torpedo track. The beam is somewhat divergent to an extent of about 15° along the track of the torpedo and about 45° normal to the track of the torpedo. This latter feature is incorporated so that if the torpedo experiences any appreciable amount of roll, or passes near one end of the target, there will still be some illumination to operate the exploder.

b. Photocell

The photocell is of the vacuum type with a caesium-antimony cathode mounted in a glass envelope suitable for the ultra violet range. The reflector system is very similar to that used for the light source, and the divergent angles are much the same. The optical axis of the reflector is pointed forward and upward so that it intercepts the optical axis of the light source at about 20 ft. above the torpedo. The intersection of the optical paths from the light source to the photocell are, of course, not only on the optical axis but are on points throughout the whole of the intersecting volumes of the divergent beams of the two reflectors. This volume extends from a few feet above the torpedo up to perhaps 50 or more feet. The useful part of the range is, however, from about 25 ft. to 18 inches. This vertical range is obtained by spacing the light source and the receiver a proper amount, in this case approximately 3 ft. If the water is very clear it is possible to extend the vertical range, and this has been done by placing the photocell approximately 4 - 5 ft. behind. The effective vertical range may now be extended up to the order of 150 ft. (This is not a very useful modification, however, as it is understood that the most effective distance for the explosion to take place is of the order of 10 - 15 ft. below the hull.)

c. Amplifier

The amplifier is a high gain three-stage system with a bandwidth suitable to pass the pulses from the light source. The first tube is adapted for variable gain by the adjustment of its negative grid bias voltage. In the beginning condition the amplifier is set for maximum gain, and it is only under operation that the negative bias feature comes into action.

d. Output Circuit

The amplified pulses from the photocell are fed into a conventional flip-flop circuit. Each operation of this flip-flop circuit in turn actuates a mechanical relay. The relay then feeds a negative bias to the amplifier, the arming circuit and the exploder circuit. The pulses from the relay are at first blocked from the exploder circuit by the arming relay, but are fed through a resistance-capacitor network of an appropriate time constant back to the amplifier input tube to provide a steady negative bias voltage for alteration of the amplifier gain. A leak circuit is provided so that when the relay is not feeding pulses the bias voltage slowly leaks towards zero and the amplifier gain slowly increases. These time constants are so adjusted that under steady state water conditions only an occasional pulse is large enough to operate the flip-flop circuit and bring the bias voltage of the amplifier back to the point where the amplifier is just on the edge of operation.

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e. Arming and Exploder Circuit

The relay operated by the flip-flop circuit also feeds pulses to the arming and exploder circuits. The exploder circuitry is blocked by the arming circuit until the amplifier reaches its steady state of bias where only occasional pulses are passed. When this state is reached the arming circuit relay is no longer activated by pulses. The arming circuit relay then operates and the pulses from the flip-flop relay are fed into the exploder circuit relay. This latter relay is, however, guarded from operation by casual impulses by a resistor-capacitor network of an appropriate time constant. The settings are ordinarily made so that if 10 successive pulses enter the time constant network then the voltage across the exploder relay will rise to a value sufficient to close the relay. If, however, there is an interruption of pulses during the interval of 10, the time constant network will discharge sufficiently so that the series will have to continue uninterrupted for another period before the exploder relay will close.

f. Power Supply

The power supply is derived from the main batteries in the torpedo. These are tapped off at the 24 volt point. The total circuit demand is just under 200 watts and a voltage variation from 20 - 30 volts can be tolerated.

The 24 volt supply is fed to a converter to produce alternating current for the operation of the individual power supplies for the light source and the receiver. The two power supply units may be mounted in the torpedo wherever desired, but the light source and the receiver unit must of course be mounted under windows at appropriate places in the top surface of the torpedo. The size of each of the four units is approximately 8 x 12 x 12 inches.

g. Character of Water

Some 2,000 trials have been made with this optical system in both the Baltic Sea and in the Mediterranean. These trials were carried out with a recording oscillograph in the torpedo so that the operating results could be recorded. Unfortunately, no records are available. According to Dr. Früngel, the operation of the circuit was very reliable as indicated by the records, and the general features outlined above were completely verified. For the Baltic waters reliable operation was between the ranges already quoted, namely, 18 inches - 25 ft. The range in the Mediterranean was somewhat greater.

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This useful operating range was related to a visual test and the correlation was very good. The visual test consisted of lowering a disc about 18 inches in diameter into the water. This disc was painted half red and half white, in two sectors. Under ordinary conditions of daylight the depths to which the disc could be seen with the eye were very close to the limiting range of operation of the optical exploder mechanism.

Comment. Trials are, of course, necessary to properly evaluate the technical usefulness of this development. In its present simplest form described here there are some objections which may be foreseen.

No provision is made for sudden depth changes or breaching of the torpedo after the arming circuit has come into action. The arming circuit could, of course, be linked with the depth control gear so that the system would become disarmed if the torpedo came closer to the surface than some predetermined value. This might not, however, be quite good enough because if the torpedo rose towards the surface too rapidly but still at the depths where it was armed, the change of illumination might be fast enough so that the amplifier would continue to operate for the 10 pulses (half a second) required to fire the torpedo.

Because of the nature of this circuitry, it is responsive to any increase of reflectivity in the water, and it is very likely that the torpedo would be exploded by ship wakes just as easily as by ships. Some minor and inconclusive experiments were made by the Germans on this point.

Optical countermeasures for this torpedo would be extremely difficult for several reasons. The radiation from the torpedo is not visible to the eye or at least would not be appreciable until one was very close to the torpedo. Even if the torpedo was known to be present, countermeasures would be very difficult optically because of the filters used in the system to limit the wavelength of illumination. Also, the light source would have to be pulsed in order to make the amplifier operate. In addition, the high attenuation of water would make it unlikely that sufficient pulsed light intensity could be produced at the running depths of the torpedo.

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