A Fiber Optic Sensor System for HERO Testing Bridge Wire EEDs

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HISTORY

The electric initiation of explosives dates back to 1745 when it was demonstrated before the Royal Society of England that black powder could be exploded with an electric spark. By 1914, when shipboard radio was still in its infancy and radar was nonexistent, electrically initiated naval ordnance was commonplace. From these early days when ships were first electrified, until the present day, the radio frequency (RF) spectrum has been increasingly utilized for communications, navigation, fire control, electronic warfare, and radar.[1]

In the late 1950's, with the proliferation of high-power emitters aboard ships, the Navy became concerned that enough RF energy could be induced into the bridge wire of an electroexplosive device (EED) to cause it to initiate unintentionally. Shipboard tests and laboratory research supported this concern and the Navy's Hazards of Electromagnetic Radiation to Ordnance (HERO) program was born.

BACKGROUND

A major component of the HERO program is certification of ordnance systems destined for fleet use. This certification program is designed to assess the safety and reliability of ordnance when subjected to simulated fleet radiated electromagnetic environments (EMEs). A determination of these parameters is accomplished by measuring the current induced in the bridge wire of the EED and comparing this value to the established Maximum No-Fire Current (MNFC) for the EED of interest. Measured currents greater than 15% and 45% of the MNFC constitute a failure for safety and reliability, respectively.

A fiber optic sensor system is used in HERO testing to assess the safety and reliability of ordnance when subjected to simulated fleet radiated electromagnetic environments (EMEs).

It is well-known that power is absorbed by a resistor, e.g., a bridge wire, through which an electrical current is flowing. The power is dissipated in the form of heat. The theoretical relationship between current and the change in temperature of the bridge wire is well understood.[2] Naturally, then, measured temperature is a logical parameter by which to infer the amount of current induced in the EED. This is the premise of all current measuring schemes utilized in the HERO program.

The most basic form of HERO instrumentation is the placement of a temperature sensitive material in direct contact with the bridge wire of the EED. Materials which have been used previously include papers with specific char temperatures, and waxes with specific melting points. The drawback of this type of instrumentation, however, is that no real time data is gathered. Instead, the instrumented EED must be disassembled and checked visually after each test sequence to determine if the functioning temperature of the material was exceeded.

A more sophisticated method of temperature sensing for HERO evaluations utilizes thin film thermocouples to measure the heat produced by the bridge wire. The voltage output of the thermocouple, which is directly proportional to the change in bridge wire temperature, can then be used to modulate a fiber optic transmitter and the response data transmitted via fiber optic cable to a remote location for real time display. The most notable concern with this instrumentation system is that the thermocouples, and their associated wires and hardware, can perturb the radiated EM field or actually conduct RF energy into the device under test. Present HERO instrumentation, however, corrects this deficiency by employing fiber optic technology to remove the potentially perturbing electrically conductive objects from the system under test.

FIBER OPTIC TEMPERATURE/CURRENT MEASUREMENT

The Navy's fiber optic EMC test

system offers the advantages of real time data output, nonconductive fiber optic sensors, and performance comparable to thin film thermocouples. The system consists of a data processing unit which can monitor four channels of data simultaneously, up to 1 km of fiber optic extension cable per channel, and a sensor assembly, as shown in Figure 1. Light is transmitted from the data processing unit to the temperature sensitive sensor. Heat produced from the current flowing through the EED's bridge wire is transmitted to the sensor. The temperature change modifies the spectral properties of the sensing element, leading to a color shift in the reflected light. The reflected light is returned to the instrument via fiber optic cables, where the amount of spectral shift is determined using ratiometric techniques. There, an electrical signal proportional to the detected temperature is generated.[3]

Using the relationship between temperature rise and current, the induced current may be calculated from this measured temperature.[4] However, because current is calculated using the temperature change of the bridge wire, fluctuations in the ambient, or baseline temperature can cause significant errors in the calculated current. Therefore, the instrument must be zeroed periodically to compensate for the dynamic ambient temperature. In general, however, this is not a problem because of the minimal drift which occurs in the relatively short duration of most test procedures performed in HERO evaluations.

Specific Navy requirements for the HERO test systems' temperature sensors are numerous, but the key considerations are sensitivity and thermal response time.

Sensitivity. Temperature resolution of the Navy system is approximately 0.1°, which in a Mk 1 Squib, a typical electroexplosive device, translates to a minimum detectable current (MDC) of approximately 5 milliamps, or 2.5% of its MNFC. This is well below the threshold needed to determine margins of safety/reliability for a system utilizing the Mk 1. The MDCs of other EEDs will vary due to differences in the current-temperature characteristics of each bridge wire. It is anticipated, however, that, in terms of percentage of the MNFC, comparable MDCs will be attainable for most EEDs. Another factor in determining MDC is the position of the sensor relative to the bridge wire. The optimum position results from direct contact of the sensor with the bridge wire, which insures maximum thermal efficiency. A comparison of sensor positions and corresponding MDCs is shown in Figure 2.

Thermal response. Thermal response of an EED is defined by tau, the thermal time constant, which is the time needed for the bridge wire, with a current step input, to reach 63% of its final temperature. This parameter provides an indication of the EED's response to external stimuli. For most common bridge wire EEDs, tau is on the order of a few milliseconds. The thermal time constant of an inert Mk 1 Squib, for instance, is typically 12 to 17 milliseconds. Ideally, any instrumentation used for HERO evaluations should be able to *track* the changes in bridge wire temperature for rapidly changing stimuli. However, this is not the case for most instrumentation systems. The response time of fiber optic sensors is typically 50 milliseconds, slightly faster than thin film thermocouples, but slower than most EED bridge wires. In addition, contacting the bridge wire to obtain maximum sensitivity may increase the bridge wire's thermal response time. This can have a negative impact on test results because the sensor may not indicate maximum temperature excursions due to the lag between the bridge wire and sensor responses. Though optical sensors presently do not meet absolute response time requirements, they do offer an advantage over traditional instrumentation in this area.

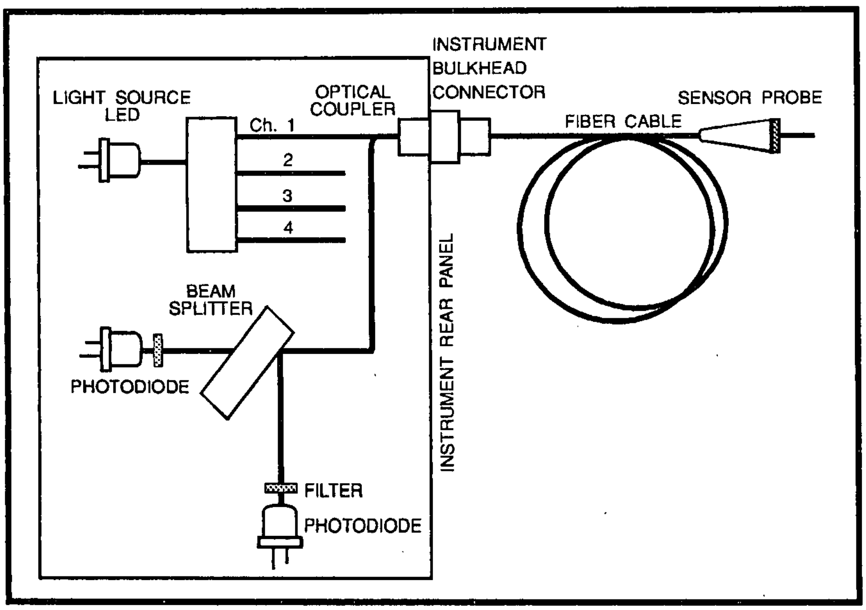

FIGURE 1. *Typical Sensing Channel.*

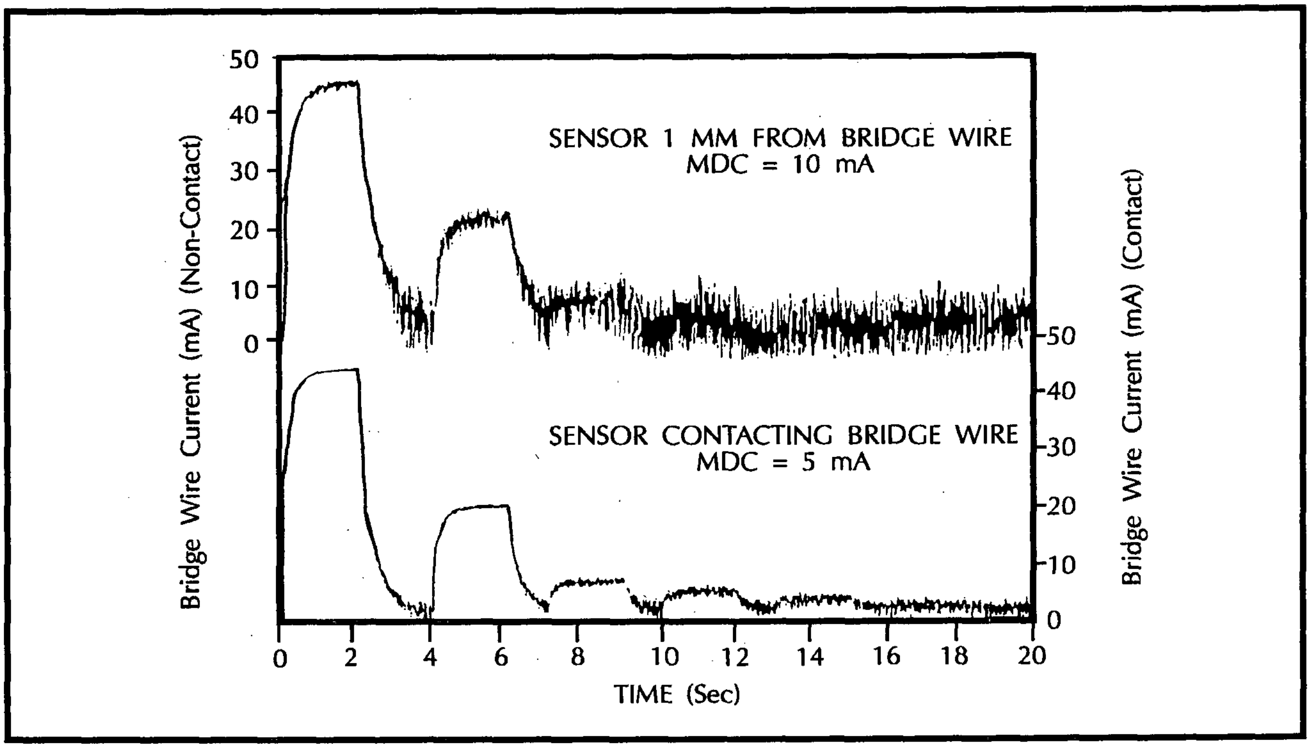

FIGURE 2. *Sensor Responses.*

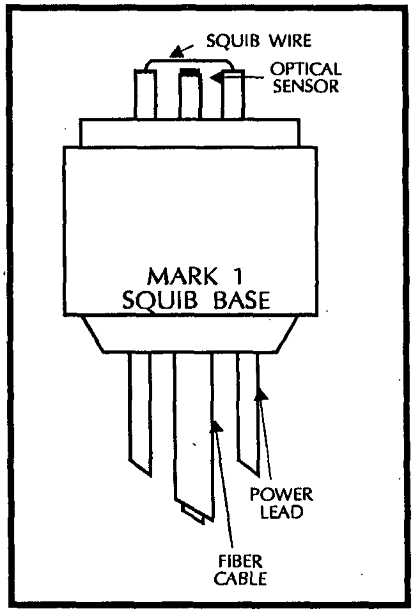

FIGURE 3. *Instrumented Mark 1.*

Instrumenting EEDs is conceptually a simple task. The sensor is inserted into the base plug or any other convenient point of entry of the EED. The sensor is then positioned such that it is in contact with the bridge wire to maximize sensitivity by insuring optimum heat transfer. The assembly is then bonded in place and calibrated. Figure 3 diagrams an instrumented Mk 1 to illustrate the simplicity. Practical problems associated with some EEDs and weapon systems, however, turn this seemingly simple task into a challenge. Frequent problems that arise are fiber optic cable routing problems, difficult EED geometries and EED/weapon system interfaces, and inefficient sensor-to-bridge wire positioning. These challenges, though, exist for most methods of EED instrumention, and are not necessarily unique to optical sensors.

SUMMARY

Temperature sensing is a vital part of the Navy's HERO program. Advances in instrumentation, such as fiber optic sensors, have brought HERO testing into the 1990s. These optical sensors have sensitivity and response time comparable to that of traditional instrumentation, but offer the added benefit of nonperturbation in a radiated EME. Future versions of these sensors, perhaps, will be even more sensitive and faster, to better meet the demands of HERO testing in the years to come.

REFERENCES

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2. Rosenthal, Louis A., "Electro-thermal Equations for Electro-explosive Devices," NAVORD Report 6684, August 15, 1959.
3. Saaski, Elric W., Hartl, James C., and Mitchell, Gordon L., "A Fiber Optic Sensing System Based on Spectral Modulation," Instrument Society of America Proceedings, Advances in Instrumentation, Vol. 41, Part 3, 1986.
4. Idem, Ref. 2.

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