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EXPLODING BRIDGEWIRE DETONATOR CIRCUIT CALCULATIONS

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This memorandum summarizes an extensive report on the results of an exploding bridgewire detonator investigation conducted by Stanford Research Institute for Sandia Corporation. The investigation has yielded a better functional model for an EBW detonator for use in computer simulation of any firing set. When used in an appropriate digital computer program this detonator model will enable the engineer to examine the firing characteristics of any firing set configuration at minimum expense and with fewer experiments than has been possible in the past.

Introduction

Calculations of exploding bridgewire (EBW) detonator firing circuits have been under development since a patent was filed on the EBW detonators nearly a quarter of a century ago. Over the years, Sandia Corporation has played a major role in developing firing circuit calculations to predict threshold initiation and explosive buildup time. However, the ever-increasing sophistication in the design of firing systems demands more precise descriptions of the circuit elements. In particular, to regard the bridgewire resistance as a function of a single variable, deposited energy, is inadequate in the context of a wide variety of possible firing circuits. In early 1967, Sandia Corporation contracted with Stanford Research Institute (SRI) to undertake experimental and theoretical studies of firing systems. The first step in the SRI studies has been to develop an improved mathematical description of the detonator resistivity function for use in digital computer calculations.

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The earliest and simplest calculations considered a firing unit comprised of an ideal capacitor and switch; the unit was discharged through a length of connecting cable (usually assumed to be an inductive element) into a detonator (treated electrically as a resistive element). It was shown that a detonator bridgewire began with a negligible resistance but that later the resistance increased in a self-accelerating manner. A sufficiently large burst of electrical energy was thus deposited in the wire to vaporize it with explosive violence, accounting for the name "exploding bridgewire."

These sketches illustrate the electrical events that take place in an EBW detonator fired with a capacitor unit. Curve (a) represents the first half cycle of current as the capacitor discharges into an inductive and slightly resistive load. The inflection in the rising portion marks the wire explosion. As shown in Curve (b), a pronounced voltage spike occurs when the wire explodes. The instant of maximum voltage is referred to as the burst time of the wire; the prefix "burst" (as, e.g., in "burst current") refers to values determined at this instant of maximum voltage. What happens during the voltage spike is crucial to the initiation of the explosive. Thus, the main tasks in circuit calculations are to make accurate predictions of the time of burst and of the magnitude of quantities such as burst current and burst power.

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Simple but Inadequate Model

A model of the wire explosion was developed some years ago. It assumed that the wire is a resistive element, that essentially no energy is lost to the surroundings during the heating time, and that the electrical energy lost in the resistance simply heats the wire. As the wire is heated, its resistance becomes larger and energy is deposited more rapidly. The process is therefore self-accelerating. In the last stages before burst, sufficient energy is deposited to vaporize the metal and to destroy its conductivity almost completely, but because of the high voltages generated, arcing usually develops in or around the metal vapors and, as shown in the sketch, the voltages thereafter become less.

According to this model, exploding wire resistance is simply a function of deposited electrical energy, as shown in Curve (c). The amounts of energy deposited in the wire in each interval of time are suggested by the dashed lines between Curves (a), (b), and (c). Minor energy deposition in the first large segment of time heats the wire to the melting temperature. The major energy deposition, which causes vaporization of the wire, occurs in a short time period just prior to burst. The gross features of this resistance curve are borne out by experiment and the function has been used extensively in calculations; however, the precise shape of the curve depends on the firing conditions.

The inadequacy of the model can be seen in Curve (d), where three distinct curves corresponding to three firing circuit conditions show the wide variation found in experiment. Obviously, computations based on a single average function (curve) for a wide range of firing circuits would be inaccurate. The main effort at SRI during 1967 has been to overcome this source of computational error by developing a new and more complicated resistance function for use in circuit calculations.

New Resistance Function

The approach has been to use the current as a second variable in a resistance function. Resistance is now expressed as a new function of both energy and current.

In this isometric drawing, the base coordinates are current and energy and the height to the surface is the resistance. Consider the sequence of events as they would occur when a detonator with this resistance function is fired with a capacitor firing unit. At the instant of switch closure, both the current and the energy deposited in the wire start from zero and increase, and the resistance starts from its initial value and increases slowly. On the surface of the isometric figure a

point representing an instant in time moves along a line starting from the heavy dot at the lefthand corner and continuing across the surface to the right. The point moves relatively slowly with the passage of time and mainly in the direction of higher current. As the point begins to ascend the steeper portion of the surface, indicating greater resistance, the rate of energy input increases. The point now moves faster over the surface; the current begins to decrease, the energy increases rapidly, and the resistance continues to increase. As the point crosses the crest of the surface and descends to lower resistance values the voltage spike has been passed through. The maximum voltage across the detonator occurs at or near the crest of the surface; this point is indicated on the sketch by the open circle. We see, therefore, that a particular line over the surface of the isometric figure results from a specific set of firing conditions. The same detonator fired on a different firing circuit would result in a different line. Lines obtained from various firing units could traverse the surface in a number of ways and could cross each other on the surface. Such lines, if projected on the resistance-energy plane, would show a number of intersecting curves of various shapes such as those shown in Curve (d).

Results of This Study

Throughout this discussion we have assumed the existence of a surface. The task performed by SRI has been to collect experimental curves in the resistance-energy-current space and to try to establish if these curves do in fact determine a surface.

Over 100 detonators were fired singly and the electrical records were analyzed in detail. The complete analysis, and reproductions of the oscilloscope records are available in the form of a work manual. The manual contains records on four wire materials and several wire sizes for each material; all combinations were fired in high- and low-inductance capacitor-type firing circuits and under conditions ranging from near threshold initiation to strong firing.

Functions were fitted to the data by a least-squares technique and a FORTRAN computer program was prepared for using the functions on digital computers.

Description of the experiments, the manner of obtaining accurate current and voltage data, the method of data reduction, descriptions of the resistance functions, the fitting technique, and printout of the FORTRAN routines are all discussed in a classified report, "Detonator Circuit Calculations: Resistivity Functions, (U)" prepared by SRI for Sandia Corporation under Contract No. 58-2627, April 1968.

The Next Step

It is already apparent from this work that the new two-dimensional detonator resistance functions are an improvement on one-dimensional functions. Work is continuing to determine how accurately the behavior of a firing circuit can be calculated with such a two-dimensional description and to define circuit conditions beyond which such a surface description is not appropriate. The next step in developing firing circuit calculations will be to improve predictions of threshold initiation and explosive initiation time from burst to the onset of detonation. This work is now in progress under a second contract sponsored by Sandia Corporation.