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DETECTOR SYSTEM

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102

DESIGN OF A PASSIVE CRACK DETECTOR SYSTEM

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ABSTRACT

An inexpensive, passive crack detector system was developed to determine how soon after exposure to radiation a mechanical component would crack. The system was designed so that switches were activated, initially from the radiation and later from the g loading associated with the experiment. This allowed current from cadmium batteries to flow through a conductive element on the surface of the test component. An interruption of the current by the formation of a crack is recorded on a passive current integrating device in series with the conductive element. Upon recovery, the records may be visually inspected to determine when, if any, cracks occurred. The entire package, including spring loaded contacts to the conductive element occupies a few cubic inches of space, and operates reliably in severe thermal, shock, and radiation environments. Detailed calculations, drawings, redundancy, and testing procedures for the system elements are described.

INTRODUCTION

A crack detector system was designed to determine when a crack occurred in a part exposed to radiation. A passive recoverable system was desired because of difficulties in providing lead wires and cables. Only the first 100 msec following the event were of interest, because that is when the part is subjected to large thermal stresses and g loading. A system was designed and tested to meet the following constraints: peak temperatures to 200°F after exposure, take up minimum volume, and survive high g levels for tens of milliseconds.

DESCRIPTION AND OPERATION

A schematic diagram of the system is shown in Fig. 1. Switch B closes in less than 1-msec after exposure to the neutrons. Current from the battery then flows through the taper (E). Approximately 30 msec later a shock wave actuates the inertia switch, causing current to flow through the other taper. If a crack occurs at any time between 0 and 100 msec, the current will cease and the time the crack occurred will be recorded on the taper.

Fig. 1. Schematic diagram of the system.

The two tapers, batteries, and switches provide a means of extending the limited (from 3 to 70 msec) recording time of the taper to 100 msec as well as redundancy in switches and batteries. Note that to minimize interactions between the recording systems, the voltage and polarity are the same in both batteries.

COMPONENT DESIGN

Conductive Strip

The conductive strip and spring-loaded contacts are shown in Fig. 2. For best results, a water suspended ceramic is sprayed to a thickness of 8 to 10 mils and allowed to cure. A silver conductive layer less than 0.001 in.

Fig. 2. Conductive strip and spring loaded contacts.

thick is then painted onto the ceramic surface. After a brief cure period, the element (except the electrical contact area) is again covered with the same ceramic coating and thickness. In actual application it was easier to spray the mating part than to apply a second ceramic spray coat for electrical isolation. It should be noted that on iron surfaces oxidation of the substrate occasionally causes poor adherence.

Cracks 1/2 mil or larger were repeatedly detected after carefully using a fine micrometer to separate two very flat abutting cylinders with the conductive strip on them. When the edges were rejoined continuity was again established, but the resistance was much larger, strongly limiting the current. Typical values were 1 to 2 Ω for an uncracked 6-in. by 1/4-in. conducting strip and about 30 to 40 Ω for a rejoined assembly.

Spring loaded contacts were used to provide positive contact even after shock loading. Bonded contacts were not used because they would make assembly of nested parts virtually impossible. Also, there was some doubt that a bonded assembly could survive the combined g and temperature environments.

Fig. 3. Drawing of the neutron switch.

Various mock assemblies were tested in a high g environment as well as at 500°C . There was no interruption of continuity or conductivity (more than $30\text{ K } \Omega$ resistance) between the conducting paint, contacts, and wires to the substrate.

Neutron Switch

The neutron switch, shown in Fig. 3, is essentially a cantilever beam, with one end soft soldered to a nickel plated Orallooy contact to prevent closure. A large flux of neutrons will cause the temperature of the Orallooy to rise and melt the solder, thus providing a switch closure. The heat transfer time and "swing time" were computed to be less than 1 msec (Appendix A). Tests were performed using the capacitor bank to pulse heat the stainless steel bar used to simulate the Orallooy. The closure was monitored with an oscilloscope to confirm that the total operation was less than 1 msec . Four successful firings were performed without failure.

Inertia or g Switch

The g switch is shown in Fig. 4. When a g level large enough to exceed the spring force is achieved, the cantilever beam is released and provides an electrical closure. Because of similar geometry the calculation for the

Fig. 4. Drawing of the g switch.

neutron switch is valid. This switch also operates in 1 msec, although some contact bounce is encountered for another millisecond. Experimental work indicates thresholds of 200 g or more are required to activate the switch; closing time is about 1 msec. The threshold value may be increased or decreased by turning the spring compression adjusting screw. The switch was activated three successive times without failure.

Batteries

Rechargeable nickel cadmium batteries were used in the experiment although many types were tested in a neutron environment and under a g field. While all batteries survived 10^{15} n/cm² integrated flux from the Super Kukla facility, only the nickel cadmium battery and some of the alkaline batteries performed well at 1200 g. The other batteries lost current or went totally dead and recovered many seconds later after g loading. All of the batteries provide an instant rise in current for a fraction of a second or more. The small wafer-like nickel cadmium batteries are encapsulated in a steel jacket. They can provide 250 to 300 mA for 100 msec. They are typically 1.3 V and have 150 mA hr charge storage.

Current Integrating Device (Tapero)

The current integrating device has been described in detail in Ref. 1. Essentially this device measures the $\int I^2 dt$ through the circuit. However, since the battery provides a constant current we can measure $k \int dt$. A switch

system was designed and built and the battery-taper system was tested using successively longer pulses. No problems were encountered.

Other devices such as "E" cells may be used to measure I_{dt} . However, these devices have severe limitations. Should the cracked component later mesh and provide a conduction path the "E" cell would record this. Since the cell and tapers will have to be recovered to make measurements many weeks later, it is clear that the "E" cell would be saturated, indicating that no crack had occurred.

The tapers were placed in ovens at elevated temperatures for several days to assure survival in the high temperature (200°F) expected in the immediate vicinity of the experiment.

PROOF TESTS

Proof tests of the entire assembly were performed without any failures.

ACKNOWLEDGMENTS

The author wishes to thank J. W. Dini of Sandia Laboratories, Livermore, who nickel plated our Orallloy tabs for the neutron switch, and Bob Coleman for his help and advice in proof testing during the design and assembly of many of the components. Bill Ammerman provided the detailed drawings of our assemblies. Wally West assisted us during the electrical proof testing of our components. Lowell Wendell designed and built the switch system.

APPENDIX
CALCULATIONS

SPRING FORCE

Calculation of the spring force required to maintain contact in a 1,000 g field is given in Table A-1.

Table A-1. Mass of contacts.

Part	Weight (lb)
Plastic plunger	1×10^{-4}
Copper contact	5×10^{-5}
Retainer disk	3×10^{-5}
Total weight	1.8×10^{-4}

The total force = $(1.8) \times 10^{-4} \times 10^3 = 0.18$ lb and the spring force exerted was 0.5 lb, more than enough to maintain continuous contact.

NEUTRON SWITCH

Heat Diffusion

The heat diffusion into the soft solder after an initial neutron pulse is given in Eq. (A1) (see Fig. 5). The thermal properties are as shown below:

Fig. 5. Melting soft solder with a neutron pulse.

$$\kappa = \frac{K}{\rho c} = 0.55 \text{ ft}^2/\text{hr for steel}$$

where

κ = thermal diffusivity, ft^2/hr

K = thermal conductivity, $\text{BTU}/\text{ft}^\circ\text{F hr}$

ρ = density, lb/ft^3

c = specific heat, $\text{BTU}/\text{lb}^\circ\text{F}$.

Using the curves by Carslaw and Jaeger,² and computing the Fourier Modulus for R_2

$$\kappa t/L^2 = 1 \quad (\text{A1})$$

where the solder is assumed to be 0.001-in. thick $t = 1 \times 10^{-3}$ sec.

If the solder thickness were 0.0005 in., the time required to melt it would be $t = 1/4 \times 10^{-3}$ sec. If the Oralloys were hotter than the minimum used for these calculations, the melting time would be less.

Mechanical Movement

The time for the cantilever to travel across the separation is calculated by Eqs. (A2) through (A6) (see Fig. 6).

Fig. 6. Cantilever crossing a separation.

$$\text{Maximum stress} = \frac{3}{2} \frac{Ehf}{L^2} \quad (\text{A2})$$

$$P = \frac{3Ehf}{L^3} \quad (\text{A3})$$

$$P = ma, \quad a = \frac{P}{m} \quad (\text{A4})$$

$$a = \frac{Eh^2 f_g}{2L^4 \rho \text{ sec}^2} \text{ in.} \quad (\text{A5})$$

Since

$$S = \frac{1}{2} at^2, \quad t = \frac{2S}{a} = \frac{4L^4 \rho(S)}{Eh^2 f_g} \quad (\text{A6})$$

where

f = deflection

I = section modulus $\frac{bh^3}{12}$

m = $\rho(b)(L)(h)$

a = acceleration

E = Young's modulus.

For a deflection of 0.020 in., the yield stress of steel is approached [Eq. (A2)].

The time it takes the cantilever to swing across a distance of 0.010 in. is calculated as follows:

Assume one half the weight of the cantilever is at the end and that the end force required to deflect the beam is constant during the motion. The force may be computed from Eq. (A3). Substituting for the force (p), we arrive at Eq. (A5). We have also substituted the dimensions b , L , and h for I and m . Note that b does not enter into the final solution (Fig. 6).

Because of the offset between the ends of the cantilever, the deflection f used to compute the range p is more than S , the distance the end moves to make contact.

Computed time for swinger = 1×10^{-14} sec.

Total swing time is equal to or less than 10^{-3} sec.

OPERATING CURRENT

From Fig. 7, we note threshold action is less than $200 \text{ A}^2 \text{ sec} \times 10^{-6}$ for 163°F coating. For a 300°F coating, as used, the threshold is $400 \text{ A}^2 \text{ sec} \times 10^6$.

Let us compute the current required to exceed the threshold action as shown in Eq. (A7). Also, let us set dt at 5 msec (time required to exceed threshold) in order to find I to exceed the threshold.

$$\int I^2 dt = 400 \times 10^{-6} \quad (\text{A7})$$

$$I = \sqrt{\frac{400 \times 10^{-6}}{5 \times 10^{-3}}} = \sqrt{80.0 \times 10^{-3}} = \sqrt{8} \times 10^{-1} = 280 \text{ mA} \quad (\text{A8})$$

To exceed the threshold for this device, we must have 250 to 300 mA. Maximum recording time (from curves) is $3000 \text{ A}^2 \text{ sec}$.

$$I^2 dt = 3000 \times 10^{-6} \text{ at } (0.280) \text{ mA}$$

$$dt = \frac{(3000) \times 10^{-6}}{8 \times 10^{-3}} \approx 50 \text{ msec.}$$

However, because of some heat transfer for longer times, we can read up to 70 to 80 msec of data.

Fig. 7. Melt line vs action for 1/2 mil stainless steel taper coated with 163°F material.

FOOTNOTES

- * This work was performed under the auspices of the U.S. Atomic Energy Commission.
1. R. Parker, A Passive Technique for Measuring High Transient Currents, presented at the Oct. 26-29, 1970, A.S.I. Meeting, Philadelphia, Penn.
 2. H. S. Carslaw and J. C. Jaeger, Conduction of Heat in Solids (Oxford University Clarendon Press, London, 1959), 2nd ed., p. 101.