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TECHNICAL REPORT ARLCD-TR-83040

**SIMPLIFIED THERMAL TRANSIENT TEST FOR
ELECTRO EXPLOSIVE DEVICES**

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WALLACE E. VORECK**

SEPTEMBER 1983

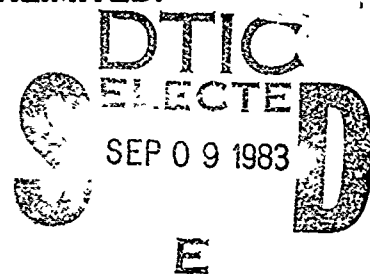


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INTRODUCTION

The Rosenthal thermal transient test for bridgewire-type electro explosive devices (EED) is used for nondestructive testing of the interface between the wire and the explosive (ref 1).

The thermal transient test is based on the application of a current to heat the bridgewire, and then monitoring the change in resistance of the wire as it heats to determine its temperature response. For this reason, only bridgewires with a measurable thermal coefficient of resistance can be tested. This work describes a simplified testing system and an improved method of data analysis.

THEORETICAL BACKGROUND

According to Rosenthal's differential equation for bridgewire temperature rise as a lumped thermal system (ref 1), bridgewire heat balance is:

$$C_p \frac{d\phi}{dt} + \gamma\phi = p(t) = I^2 R_o (1 + \alpha\phi) \quad (1)$$

where

- C_p = heat capacity, watt-second/degree
- ϕ = temperature increase, °C
- t = time, second
- γ = heat loss factor (linear thermal conductance term), watt/degree
- p = power input, watts
- I = excitation current, amps
- R_o = initial resistance, ohms
- α = temperature coefficient of resistivity of bridgewire

The solution for equation 1 is:

$$\phi(t) = \frac{I^2 R_o [1 - \exp(-\frac{\gamma' t}{C})]}{\gamma'} \quad (2)$$

where $\gamma' = \gamma - I^2 R_o \alpha$

The voltage drop $v(t)$ across the bridgewire is:

$$v(t) = IR(t) \quad (3)$$

where $R(t) = R_o [1 + \alpha\phi(t)]$.

By combining equations 2 and 3, the result is:

$$v(t) = IR_o \left\{ 1 + \frac{\alpha I^2 R_o}{\gamma'} [1 - \exp(-\frac{\gamma' t}{C_p})] \right\}. \quad (4)$$

The bridgewire thermal response from equation 4 is represented in figure 1.

The apparent time constant is defined as

$$\tau' = \frac{C_p}{\gamma'}. \quad (5)$$

This time constant is derived from the current wave form, which is intrinsic to an exponential rise in the bridgewire thermal response. From the above equations and figure 1, useful thermal parameters, which can define thermal behavior of the bridgewire-explosive interface, are derived as follows (refs 2 through 9).

Temperature rise (ϕ) is computed from

$$\phi = \frac{\Delta V}{IR_o \alpha}. \quad (6)$$

Thermal conductance (γ'), modified heat loss factor due to feedback, from

$$\gamma' = \frac{\alpha I^3 R_o^2}{\Delta V}, \text{ watts/ohm change}. \quad (7)$$

Heat capacity of the system (C_p) is

$$C_p = \frac{\alpha I^3 R_o^2}{S}, \text{ where } S = \frac{dV}{dt}. \quad (8)$$

Thermal time constant, (τ') from

$$\tau' = \frac{t'}{0.69} = \frac{C_p}{\gamma'} = \text{time to } 0.63 (V_{\max}), \text{ seconds} \quad (9)$$

where t' = time to half voltage, second.

SIMPLIFIED TEST SYSTEM

A simplified thermal transient tester was developed which can be used to control initial current and null out initial resistance of EED. Additional instrumentation included a square wave generator, a digital voltmeter, and two oscilloscopes. One was used to monitor the wave form and the other for recording a digitized wave form. A HP85 desktop computer was used to calculate results from the digital recording and plot data output. The system block diagram is shown in figure 2.

The thermal transient test circuit, which is the heart of the test system, can be easily and economically made, as compared to commercial instrumentation (for example, the Model 605B thermal transient test set, made by Pasadena Scientific Industries). On the other hand, the simplified circuit is slower and requires a skilled operator. Results obtained are the same as those for the more complicated automatic system. Either system is helpful in understanding thermal behavior of bridgewire-explosive interfaces.

The simplified circuit diagram (fig. 3) is basically the same as the standard circuit shown in figure 4. Resistance (R_2) and capacitance (C_2) are eliminated and a separate square wave generator is used. By changing the grounding location, use of a differential amplifier was avoided.

Because it does not have R_2 and C_2 in figure 4, the simplified circuit produces the various types of floating exponential thermal wave forms shown in figure 5. The operator must adjust zero axis and exponential wave forms to set R_1 properly. The exponential wave form can be dropped below the zero axis [fig. 5 (B)] by increasing R_1 and above the zero axis by decreasing R_1 , [fig. 5 (A)]. When the values of R_1 and R_0 (EED net resistance) are equal, the exponential wave form starts from zero axis [fig. 5 (C)]. The net positive exponential wave form is proportional to the value of $\Delta R/R_0$ for the electro explosive device and represents the increasing bridgewire temperature. The peak value can be easily found by adjusting the wave form to that shown in figure 5 (D). The following operational steps are used:

1. The electro explosive device is mounted in a shielded test chamber and electronically connected to the shorted test leads.
2. The square wave generator is turned on and set at 10 cps.
3. The test current is adjusted by using the by-pass button and current control knob. It should be noted that 200 mA for high sensitivity EED cannot be used.
4. The exponential wave form is displayed on both oscilloscope screens. Again, it should be noted that the amplitude of the Nicolet digital oscilloscope is 50 times that of the Tektronix 7904 oscilloscope, since its input is taken from the output of the 7A13 amplifier in the Tektronix 7904.

5. Read hot resistance, equal to (R_1) when the wave form corresponds to figure 5 (D).

6. Reset both oscilloscopes wave forms back to that shown in figure 5 (C).

7. Read offset, zero time, and volts needed to enter data into computer

8. Read the voltage and time when the cursor on the oscilloscope is placed on C_1 of the wave-form (fig. 6) to calculate V_{max} and stop time, and enter data into computer.

9. Steps 7 and 8 are used for thermal time constant, Δv calculations, and for plotting wave forms. A typical data output is shown in appendix A.

The original wave form was recorded on a Nicolet Explorer III oscilloscope and stored on mini floppy disc. Calculations were made on a HP35 calculator. All calculated data were plotted by a HP 7215A plotter.

DATA ANALYSIS

The data analysis is programmed in BASIC. This program provides calculations of equations 6 through 9, plotting of a smoothed thermal exponential wave form, calculation of τ , and print out by paper or plotter. Basically, there are seven steps in the program.

Step 1. Read input data, which is needed for calculations using the cursor on the oscilloscope - t_0 , V_0 , I , α , R_1 , R_0 . Instructions are included in the program.

Step 2. Input data for plotter - X_1 , X_2 , X_3 , Y_1 , Y_2 , Y_3 .

Step 3. Input digital data which is recorded on floppy disc as a function of volts and time (V, t), smooth data, and plot at the same time.

Step 4. Calculate shape of the thermal exponential wave form to define S in equation 8 by moving average method.

Step 5. Calculate V_{max} of the thermal exponential wave form to define equations 6 and 7 by mean value determination.

Step 6. Determine thermal time constant by time interpolated for 0.63% of V_{max} to define equation 9.

Step 7. Print out all results. Plot of % V_{max} versus time, V_{max} , I , R_0 , α , τ , slope, ϕ , λ , and C_p .

A listing of the HP85 BASIC program is given in appendix B. Sample results for two MK1 squib headers (table A-1) having a 1 mil nichrome bridgewire, before and after loading with borax at 10,000 psi, are shown in appendix A.

CONCLUSIONS

A simplified thermal transient testing system has been developed and demonstrated for use in measuring the thermal coupling between the bridgewire and the explosive surrounding it in EED. It can be easily used to measure thermal properties and control the quality of loaded EED nondestructively.

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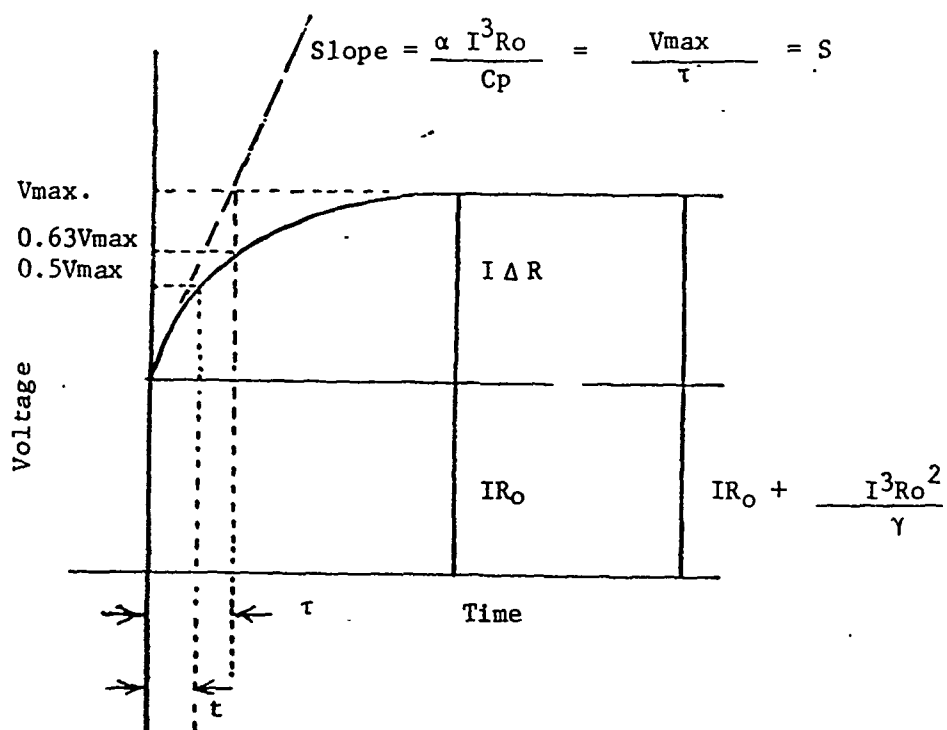


Figure 1. Thermal response curve

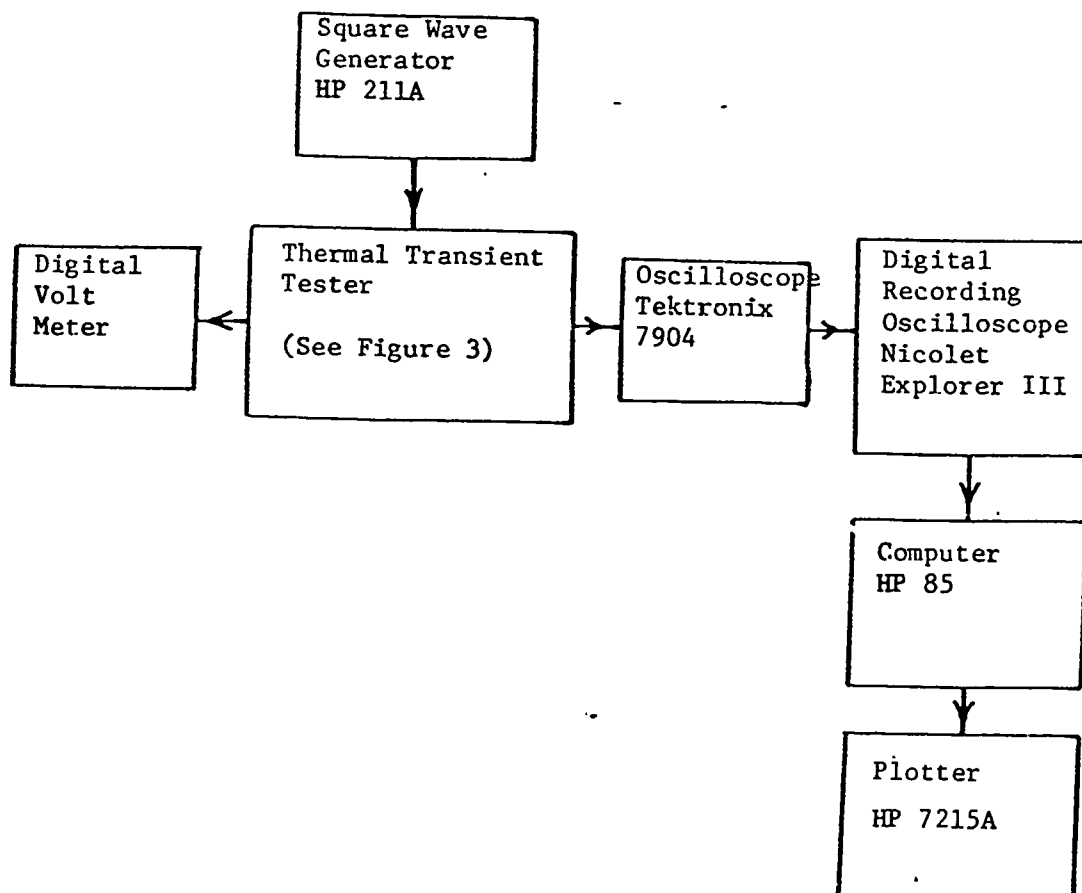


Figure 2. Block diagram of thermal transient test instrumentation

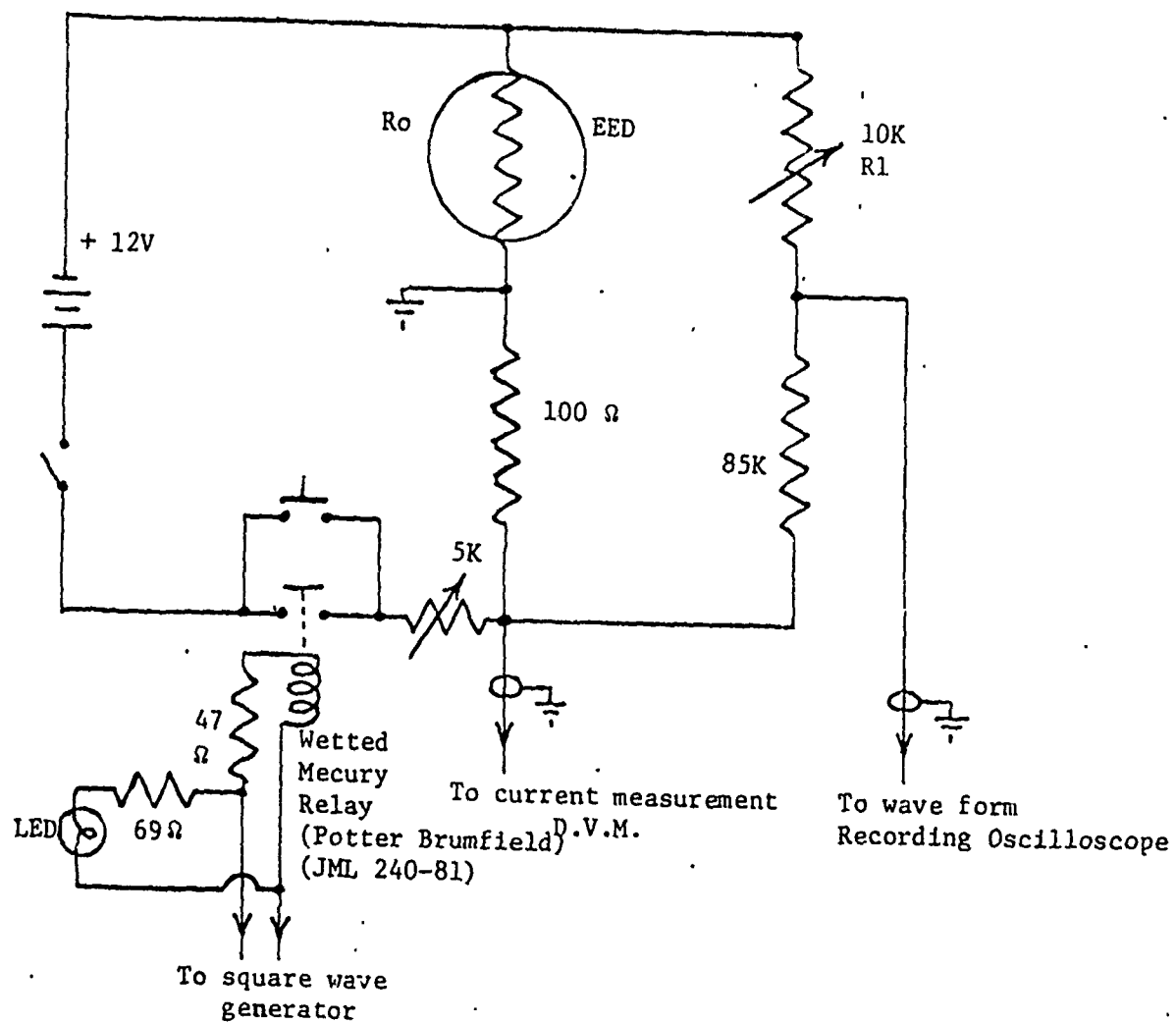


Figure 3. Simplified thermal transient test circuit

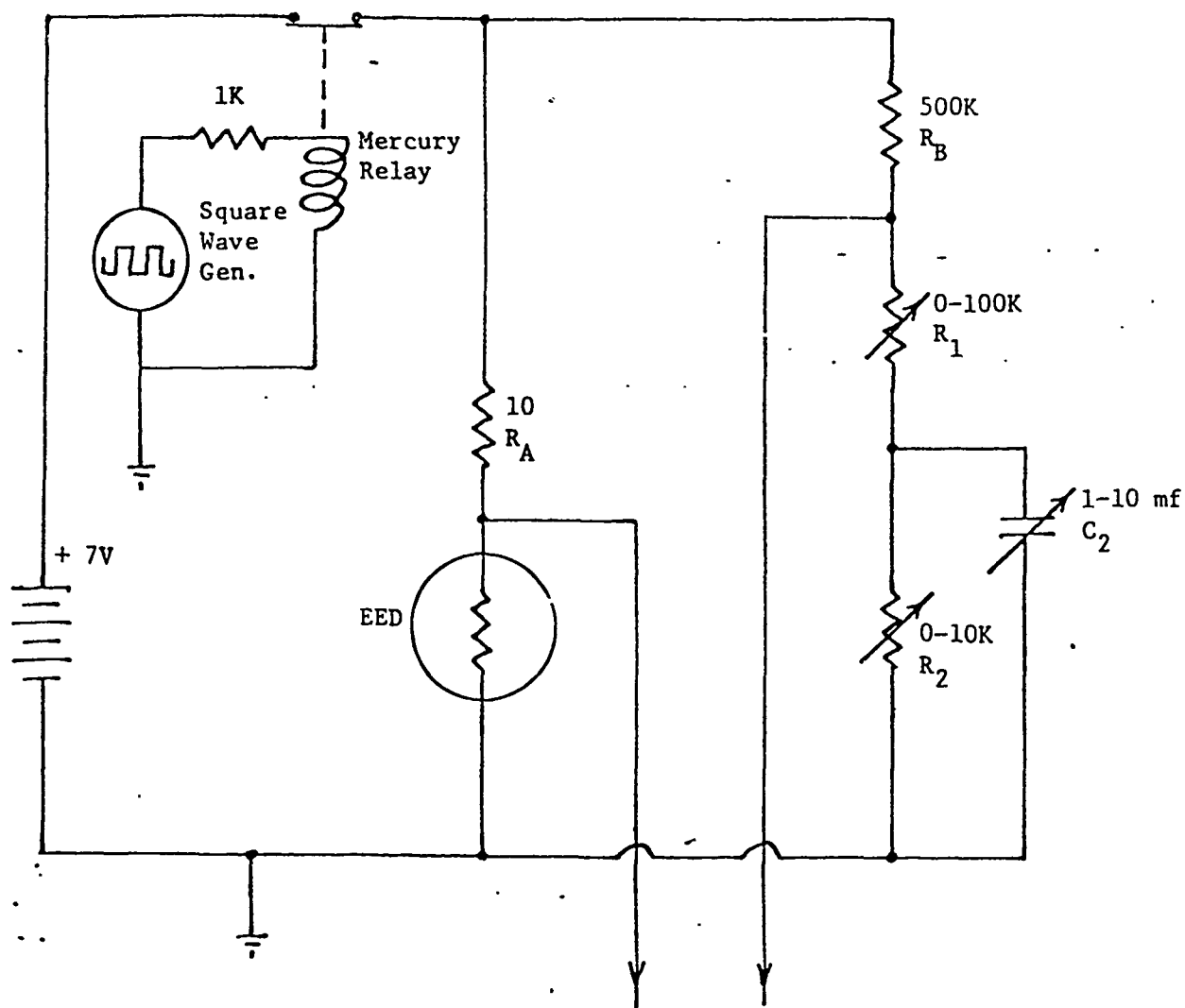


Figure 4. Typical thermal transient test circuit

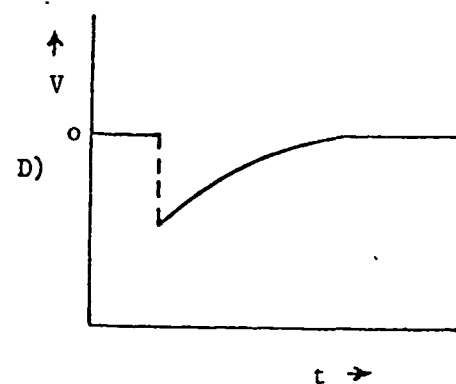
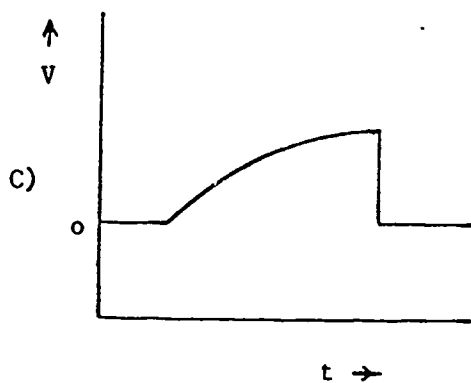
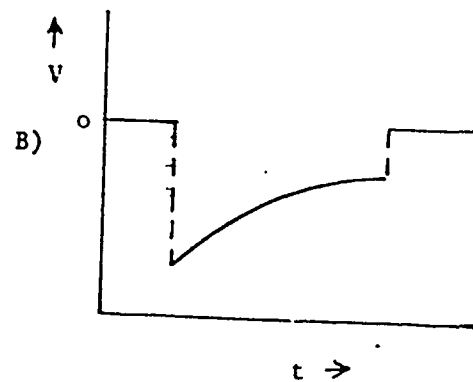
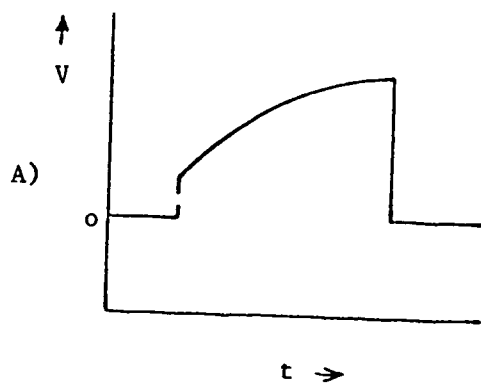


Figure 5. Typical types of wave forms

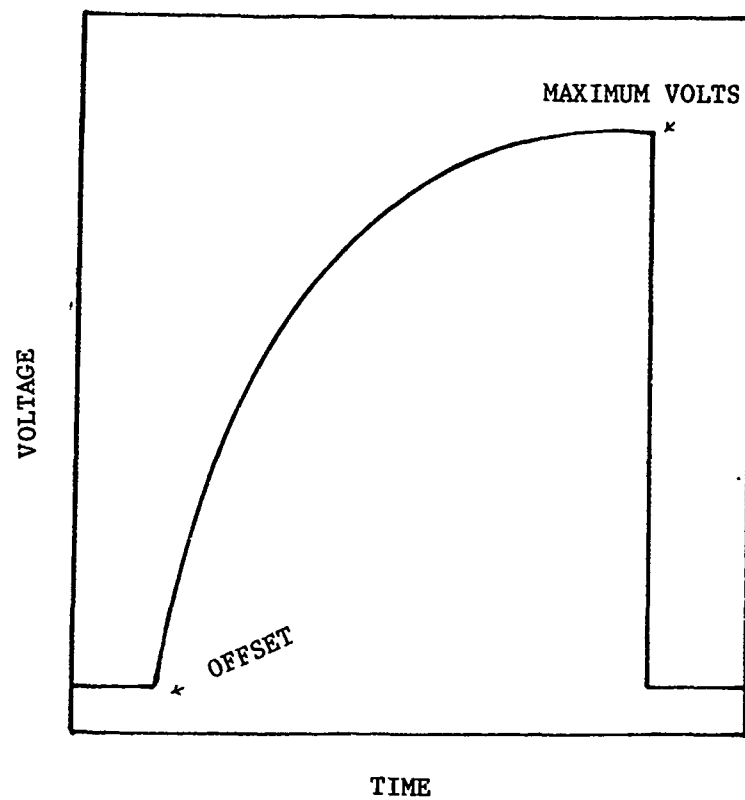


Figure 6. Cursor points on oscilloscope trace to calculate results

APPENDIX A

TYPICAL RESULTS ON MK1 SQUIBS

Table A-1. MK1 squib data summary

Condition	Squib	Initial resistance (ohms) R_0	Test current (amp) I_0	Thermal time constant (millisec) T	Maximum voltage rise (millivolts) V_m	Slope V_m/T	Thermal conductance ^a γ'	Heat capacity ^b C_p	Temp rise (°C) ϕ
Unloaded	1	2.63	0.08	8.216	8.16	0.9932	5.64	4.63	298.0
Loaded ^c	1	2.48	0.08	5.483	4.40	0.8025	9.30	5.11	171.0
Unloaded	2	2.065	0.08	6.517	2.62	0.4020	10.8	7.06	122.0
Loaded ^c	2	2.07	0.08	5.646	1.664	0.2947	17.1	9.69	77.3

Nichrome Properties

Temperature coefficient of resistance = 0.00015 hard, 0.00013 annealed

Melting point = 1400°C

Density = 9.25 g/cm³

Resistivity, ohms/circular mil/ft at 0°C = 630 hard, 675 annealed

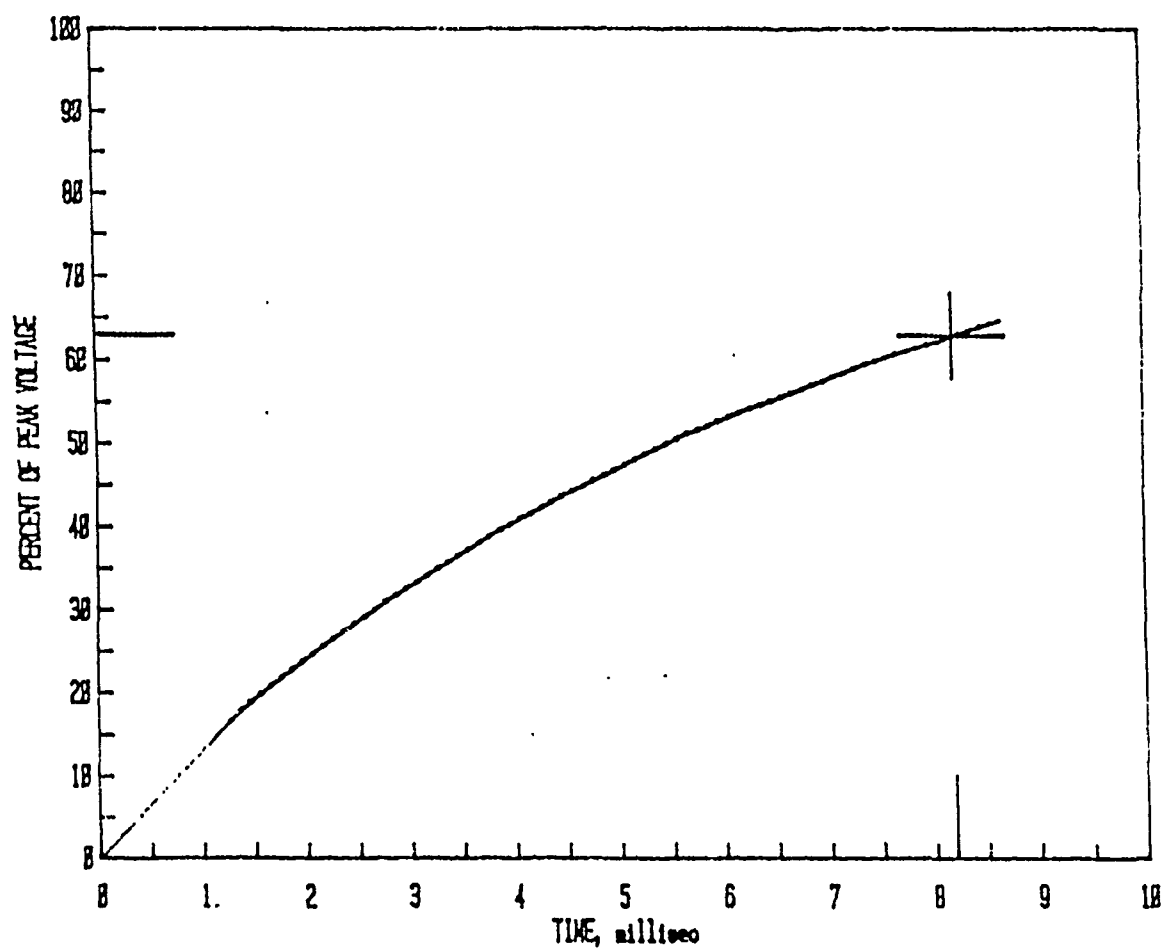
Bridgewire, 0.001 in. diameter, 0.060 in. long

Composition: 61% Ni, 15% Cr, and 24% Fe

^aWatt/°C x 10⁵

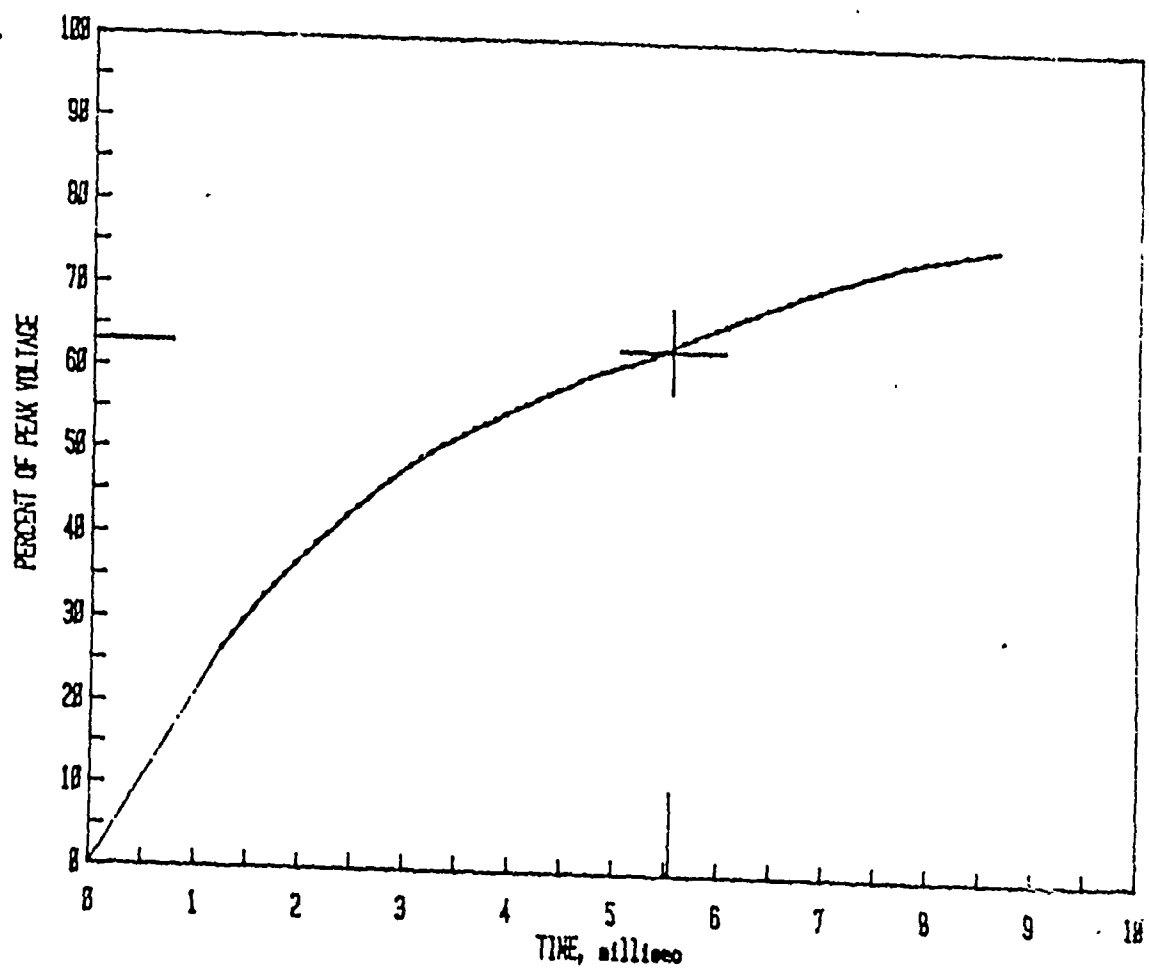
^bWatt-sec/°C x 10⁷

^cLoading was done with borax at 10,000 psi



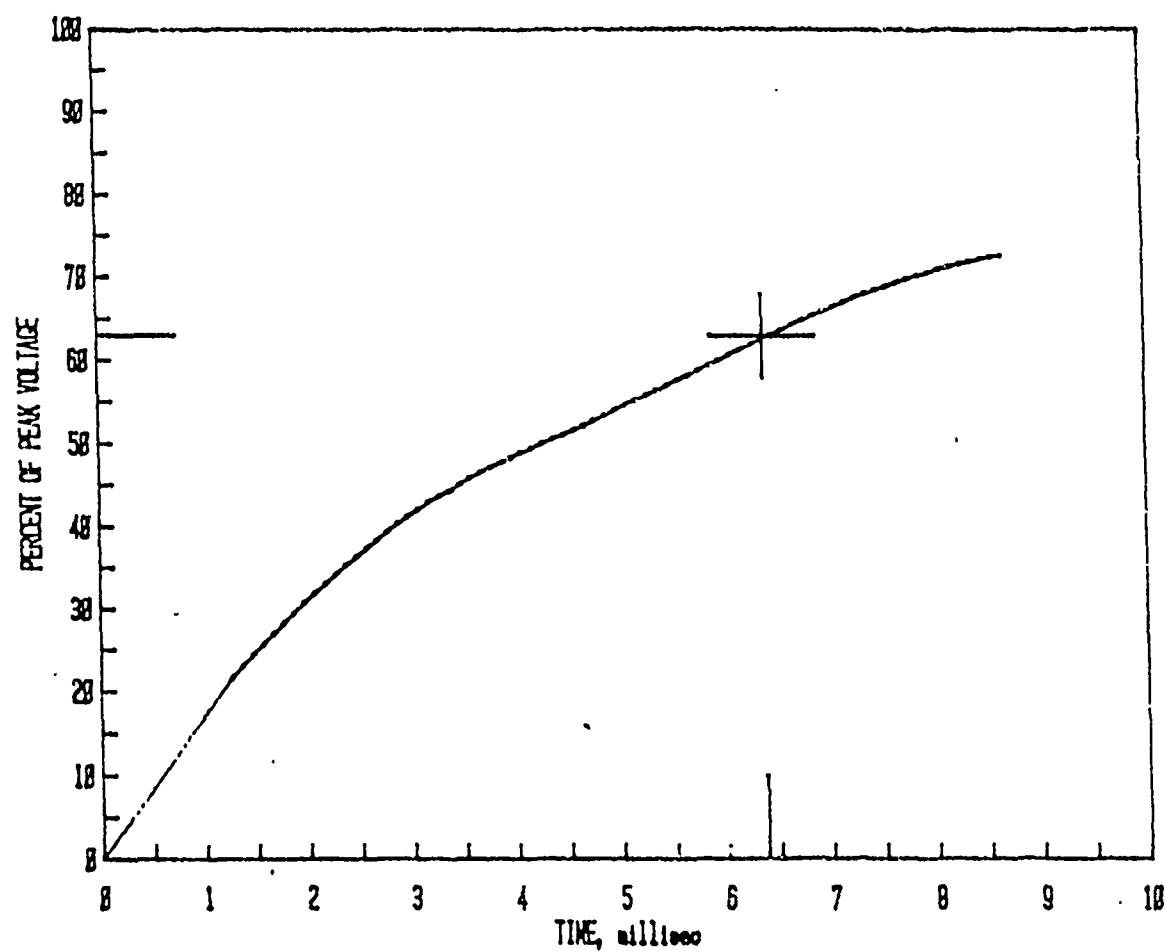
TEST #1, PEAK VOLTAGE = 8.16 millivolts

Figure A-1. Test number 1 on MK1 squibs, unloaded



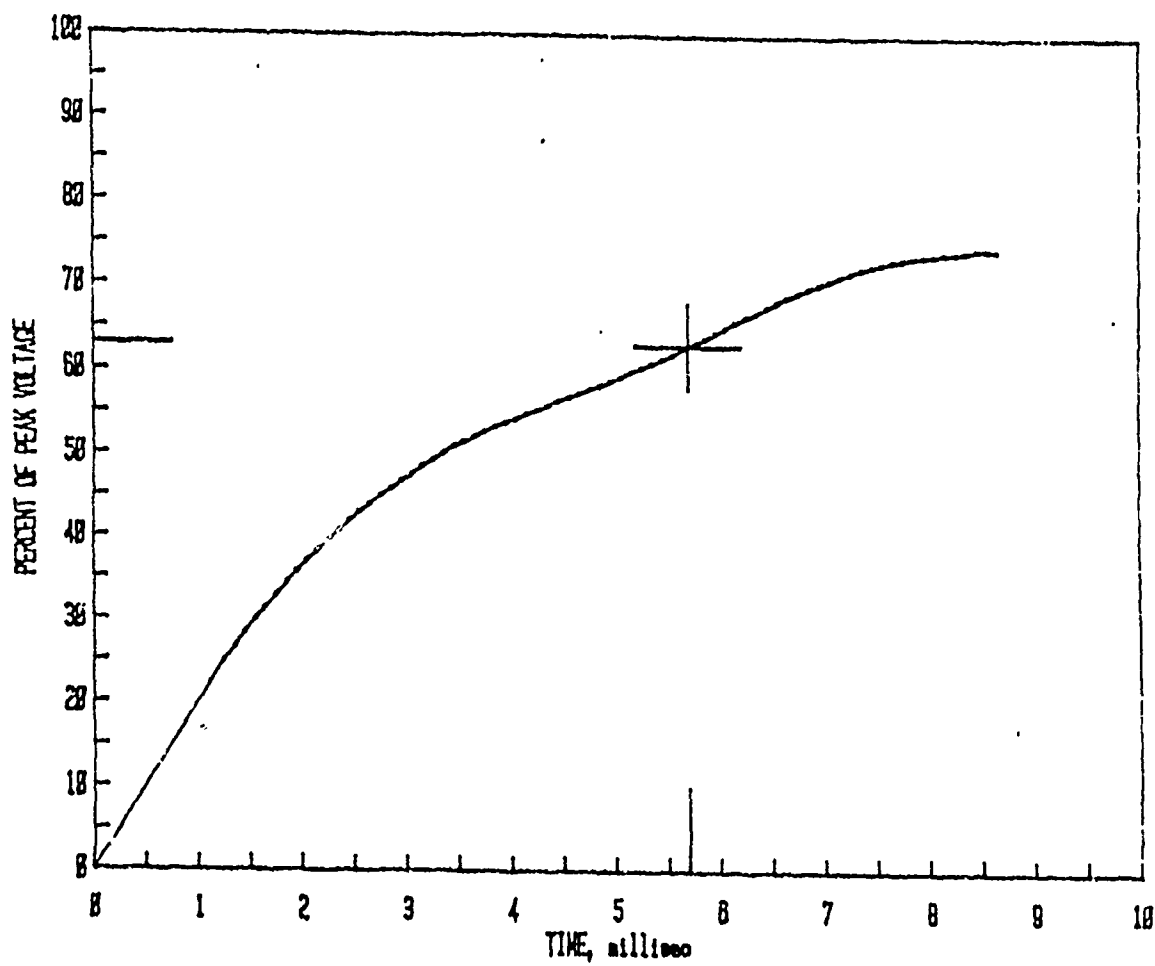
TEST #2, PEAK VOLTAGE = 4.40 millivolts

Figure A-2. Test number 2 on MK1 squibs, loaded with borax



TEST #3, PEAK VOLTAGE = 2.62 millivolts

Figure A-3. Test number 3 on MK1 squibs, unloaded



TEST #4, PEAK VOLTAGE = 1.664 millivolts

Figure A-4. Test number 4 on MK1 squibs, loaded with borax

APPENDIX B

BASIC PROGRAM FOR THERMAL TRANSIENT TEST

```

10 REM CODE "K3WIPE"
20 DISP "ENTER SAMPLE ID"
30 INPUT I$
40 PRINT " "; I$
50 PRINT
60 PLOTTER IS 705
70 LOCATE 30,110,20,80
80 DIM X$[80],Y$[80],T$[80],S$[
180]
90 DISP
100 DISP "ENTER START OF X AXIS"
110 INPUT C1
120 DISP
130 DISP
140 DISP "ENTER END OF X AXIS"
150 INPUT C2
160 DISP
170 DISP
180 DISP "ENTER TIC MARKS FOR X
AXIS"
190 INPUT C3
200 DISP
210 DISP
220 DISP "ENTER START OF Y AXIS"
230 INPUT C4
240 DISP
250 DISP
260 DISP "ENTER END OF Y AXIS"
270 INPUT C5
280 DISP
290 DISP
300 DISP "ENTER TIC MARKS FOR Y
AXIS"
310 INPUT C6
320 X1=C1
330 X2=C2
340 X3=C3
350 Y1=C4
360 Y2=C5
370 Y3=C6
380 SCALE X1,X2,Y1,Y2
390 T$="TEST #3, PEAK VOLTAGE =
2.62 millivolts"
400 S$=""
410 X$="TIME, millisec"
420 Y$="PERCENT OF PEAK VOLTAGE"
430 FRAME
440 FRAME
450 FRAME
460 MOVE X1+(X2-X1)/2,Y2
470 SETGU
480 IPLOT 0,-70,-2
490 SETUU
500 LORG 6
510 CSIZE 4,.5
520 LABEL USING "K" ; T$
530 MOVE X1+(X2-X1)/2,Y2
540 SETGU
550 IPLOT 0,2,-2
560 SETUU

```

```

570 CSIZE 3,.35
580 LABEL USING "K" ; S$
590 AXES X3/2,Y3,X1,Y1
600 CSIZE 3,.35
610 FOR X=X1 TO X2 STEP X3
620 MOVE X,Y1
630 SETGU
640 IPLOT 0,-2,-2
650 SETUU
660 LABEL USING "K" ; X
670 NEXT X
680 MOVE X1+(X2-X1)/2,Y1
690 SETGU
700 IPLOT 0,-6,-2
710 LORG 4
720 LABEL USING "K" ; X$
730 SETUU
740 LORG 8
750 FOR Y=Y1 TO Y2 STEP 2*Y3
760 MOVE X1,Y
770 LABEL USING "K" ; Y;" "
780 NEXT Y
790 MOVE X1,Y1+(Y2-Y1)/2
800 SETGU
810 IPLOT -6,0,-2
820 SETUU
830 DEG
840 LDIR 90
850 LORG 6
860 LABEL USING "K" ; Y$
870 LDIR 0
880 DISP "ENTER OFFSET VOLTAGE (
millivolt)"
890 INPUT G
900 DISP " ZERO TIME OFFSET (mil
lisec)"
910 INPUT 0
920 DISP " ENTER MAX VOLTS IN mi
llivolts"
930 DISP "UNCORRECTED VALUE"
940 INPUT M1
950 DISP "ENTER CURRENT (amperes
)"
960 INPUT I0
970 DISP "ENTER COLD RESISTANCE"
980 INPUT R0
990 DISP " ENTER TEMP. COEFF. OF
RESISTANCE"
1000 INPUT R1
1010 A1=0*40+1
1020 A0=A1
1030 A2=A1+101
1040 A3=1
1050 A5=4
1060 DIM B$[280],A$[8200]
1070 OUTPUT 702 ; "N0"
1080 IOBUFFER B$
1090 TRANSFER 701 TO B$ FHS ; CO
UNT 230
1100 CLEAR 7

```

```

1110 W0=VAL(B$(5,8))
1120 H0=VAL(B$(10,13))
1130 V1=VAL(B$(14,20))
1140 H1=VAL(B$(21,27))
1150 OUTPUT 702 ; "D3D2"
1160 IOBUFFER A$
1170 TRANSFER 701 TO A$ FHS ; CO
    UNT 8192
1180 CLEAR 7
1190 F=0
1200 X5=0
1210 Y5=0
1220 N=0
1230 FOR I=A1 TO A2 STEP 2*A3
1240 P=256*NUM(A$(I)) + NUM(A$(I+1
    )) - 65536*(NUM(A$(I)) >= 128)
1250 J=I/2-.5
1260 V=P*V1
1270 V=V-G/1000
1280 V=V*1000
1290 T=(J-H0)*H1
1300 T=T*1000
1310 T=T-0
1320 X4=T
1330 Y4=V*100/M1
1340 X4=X4+X5
1350 X5=X4
1360 Y4=Y4+Y5
1370 Y5=Y4
1380 N=N+1
1390 NEXT I
1400 PLOT X6,Y6
1410 X6=X4/N
1420 Y6=Y4/N
1430 PLOT X6,Y6
1440 PENUP
1450 Y6=Y6+.005
1460 Y6=INT(Y6*100)/100
1470 DISP Y6,X6
1480 IF F=1 THEN 1500
1490 IF Y6>63 THEN 1710
1500 A1=A1+A5
1510 A2=A2+A5
1520 Y7=Y6
1530 X7=X6
1540 IF A2<A0+40*10 THEN 1200
1550 M1=M1*.02/1000
1560 S=M1/T1
1570 T2=M1/(I0*R0*R1)
1580 C=R1*I0^3*R0^2/S
1590 C1=R1*R0^2*I0^3/M1
1600 PRINT "VOLT (max) =" ; M1
1610 PRINT "CURRENT(amps) =" ; I0
1620 PRINT "R (ohms) =" ; R0
1630 PRINT "COEFF of RES =" ; R1
1640 PRINT
1650 PRINT "TIME CONST =" ; T1
1660 PRINT "SLOPE(Vmax/t) =" ; S
1670 PRINT "TEMP RISE(C) =" ; T2
1680 PRINT "HEAT LOSS =" ; C1

```

```

1690 PRINT "HEAT CAPACITY =" ; C
1700 GOTO 1740
1710 T1=(Y6-63)/(Y6-Y7)*(X6-X7)+
    X7
1720 F=1
1730 GOTO 1200
1740 FOR Z=0 TO .75 STEP .05
1750 L=63
1760 PLOT Z,L
1770 NEXT Z
1780 PENUP
1790 FOR Z=T1-.5 TO T1+.5 STEP .
    05
1800 L=63
1810 PLOT Z,L
1820 NEXT Z
1830 PENUP
1840 FOR L=0 TO 10 STEP .1
1850 Z=T1
1860 PLOT Z,L
1870 NEXT L
1880 PENUP
1890 FOR L=58 TO 68 STEP .1
1900 Z=T1
1910 PLOT Z,L
1920 NEXT L
1930 PENUP
1940 END

```

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