MODEL 605B

THERMAL TRANSIENT TEST SET
INSTALLATION AND OPERATION

Pasadena Scientific Industries
1418 Gunston Road
Bel Air, Maryland 21015

THERMAL TRANSIENT TEST SET - MODEL 605B

SPECIFICATIONS

BRIDGEWIRE RESISTANCE RANGE: 0.50 to 10.50 ohms.

TEST CURRENT: 10 to 2,000 milliamperes (adjustable by 10-turn front panel control).

BRIDGE BALANCE CURRENT: 10 milliamperes.

TEST CURRENT INDICATOR: 3 1/2 digit panel meter (0 to 1999 milliamperes).

BRIDGEWIRE RESISTANCE READOUT: Two 10-turn dials.

CURRENT PULSE MODES: Repetitive or one-shot (selectable by front panel switch).

CURRENT PULSE DURATION: 10 to 70 milliseconds (adjustable by internal control).

CURRENT PULSE REPETITION RATE: 2.5 to 9.0 pulses per second (adjustable by internal control).

BRIDGE BALANCE STATUS INDICATOR: Two (2) light emitting diodes (LED's).

INPUT POWER: 105 - 125V, 50-60Hz, 75 watts (max).

TEMPERATURE: Operating: 0°C to +50°C
Storage : -40°C to +70°C

COOLING: Convection.

DIMENSIONS: 16.88"W x 5.25"H x 12.70"D (bench mount).
19.00"W x 5.25"H x 12.70"D (rack mount).

WEIGHT: 22.5 lbs (approx) net;
26.0 lbs (approx) shipping

ACCESSORIES SUPPLIED: AC power cord; coaxial cable assemblies; References Bridgewire RB101; cabinet tilt stand; Installation and Operating Manuals.

NOTE: The 605B has a single-ended output and is designed for use with a user-supplied oscilloscope with 1mv/cm vertical deflection sensitivity.

A word about safety . . . . .

Thermal transient testing involves the application of precise, controlled test signals to the device under test. The nondestructive aspects of the test, and the safety implied, are closely related to the magnitude of the test signals and the characteristics of the test item.

As in any test involving potentially hazardous material, an element of danger is present when and EED is subjected to an electrical test signal. In the interest of safety, it is recommended that those using the equipment described herein thoroughly familiarize themselves with the contents of this manual prior to testing hazardous devices. In addition, hazardous test items should be placed in appropriate fixtures and protective enclosures (test chamber, barrier, etc.) during the time test signals are being applied.

PASADENA SCIENTIFIC INDUSTRIES

WARRANTY

Type 605 Thermal Transient Test Set is warranted against defects in materials and workmanship for one year from date of shipment. Our obligation is limited to repairing or replacing parts which prove to be defective during the warranty period. No other warranty is expressed or implied. We are not liable for consequential damages.

Pasadena Scientific Industries
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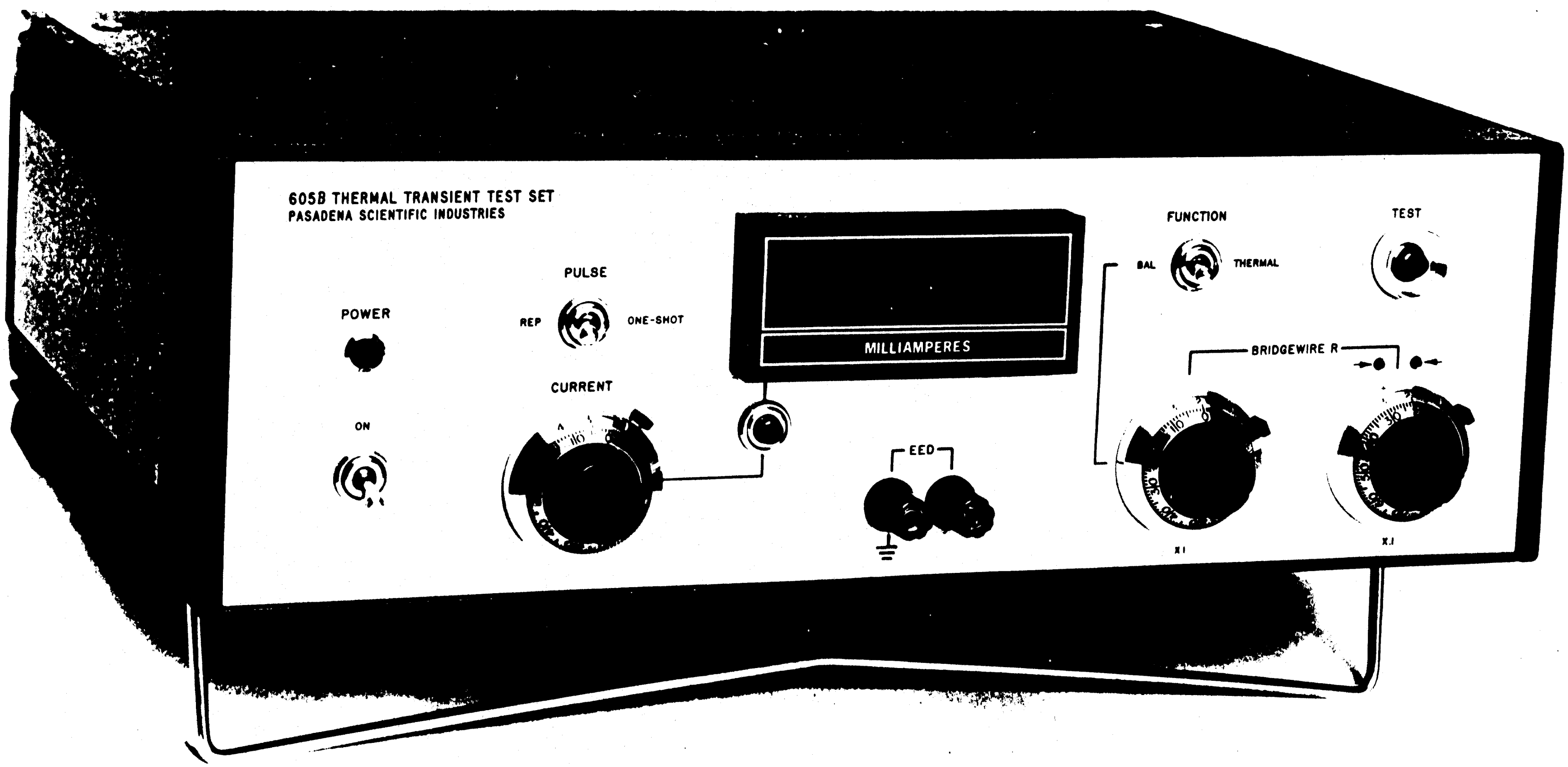


THERMAL TRANSIENT TEST SET - MODEL 605

SECTION I

THERMAL TRANSIENT TEST[1]

1.1 Introduction - The use of electroexplosive devices (EED's) in military, aerospace, and many commercial applications necessitates a high degree of reliability at a high level of confidence in each item. Commonly employed testing techniques rely heavily on destructive techniques. The thermal transient test is a nondestructive examination technique for facilitating inspection of the critical bridgewire-explosive interface. In essence, the test allows one to "look" inside the EED nondestructively and determine if certain failure conditions and/or abnormalities are present.

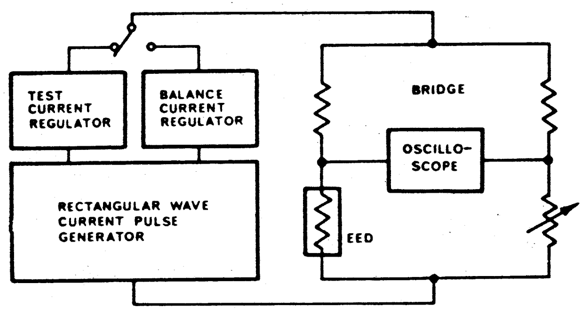
In addition to the nondestructive testing aspects, the thermal transient test offers unique and significant advantages for EED characterization. The test is particularly well-suited for quality assurance, development, and production control applications.

1.2 Test Concept - Application of a current to a hot bridgewire type EED causes the bridgewire temperature to increase. Some of this energy is dissipated from the bridgewire to surrounding explosive material. The temperature rise is accompanied by a corresponding increase in the resistance of the bridgewire material (it is important that the bridgewire material have a reasonable temperature coefficient of resistivity {TCR}). By carefully controlling and limiting the amplitude and duration of the current pulse, so that no chemical change of the explosive material occurs, the EED will return to ambient temperature with no discernible permanent change at cessation of the pulse. The pulse magnitude is selected to stress the bridgewire-explosive interface to the extent that its latent thermal characteristics become responsive. Pulse duration is chosen to produce interface thermal equilibrium. The rate at which the bridgewire changes, and the maximum value of the change, are determined by the interface characteristics. The signals generated by the changes are displayed on an oscilloscope for observation and analysis.

1.3 Test Capabilities - EED nondestructive test and measurement[2] capabilities include:

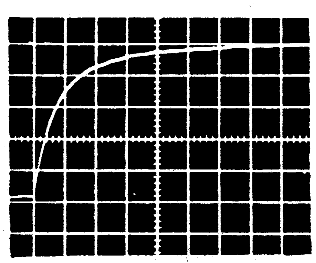
(a) Bridgewire weld quality
(b) Loading density
(c) Interface air gaps
(d) Explosive contamination
(e) Gas inclusion along bridgewire
(f) Thermal time constant
(g) Thermal capacity
(h) Bridgewire resistance
(i) Bridgewire temperature

1.4 Basic Test Circuit - An elementary form of the basic circuit for thermal transient testing is shown below.

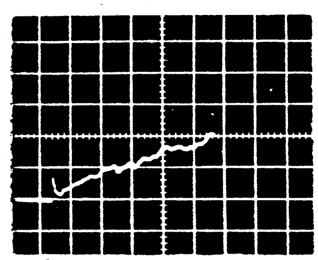


Current pulses of appropriate magnitude for bridge-balancing and thermal tests are derived from the pulse generator. The device-under-test (DUT) forms one arm of the Wheatstone bridge, with an adjustable resistor comprising the adjustable arm. Electrical output of the bridge is zero at balance. When a thermal test pulse is applied to the bridge the DUT resistance changes as the temperature increases, causing bridge unbalance and an output signal from the bridge characterizes the electrothermal condition of the bridgewire-explosive interface. The bridge output signals are displayed on a monitor oscilloscope.

Examples of two typical thermal response curves displayed on the monitor oscilloscope are shown below. Application Note AN-4 "Interpretation of Thermal Response Curves" covers representative examples of normal and abnormal curves likely to be encountered.



Normal EED



Defective Weld

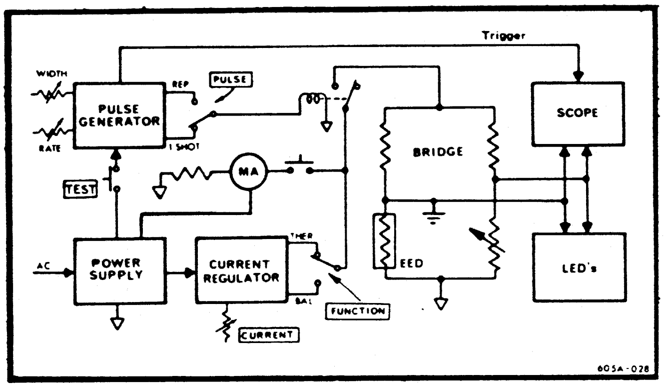
1 See Application Note AN-2 "Thermal Transient Theory"
2 See Application Note AN-3 "Calculation of Electrothermal Parameters"

SECTION II

DESCRIPTION - MODEL 605B

2.1 General - The 605B is designed to facilitate thermal transient testing of EED's within the constant current capacity and load resistance range of the Test Set.

2.2 Circuit Description - A simplified block diagram of the 605B is shown below. Refer to this diagram for general circuit information, and to the schematic diagrams in the "Maintenance & Parts List" section of this manual for circuit details.



2.2(a) Power Supplied - Three supplies (excluding the self-contained supply in the Digital Panel Meter DPM-100) provide power for the 605B. The main supply operates in a floating loop and furnishes power to the 605B bridge circuit (including the device under test) via a current regulator. The second supply provides regulated 24 volts DC to the pulse generator/mercury relay (K401) and control relays (K402, K403). The third supply is an integral part of Null Amplifier AM-500, furnishing power to the AM-500. A simplified schematic of the constant current loop is shown in Figure 2.1.

2.2(b) Constant Current Regulator - The constant current regulator provides test current to the 605B bridge circuit (including the load resistance connected to the 605B EED terminals). This resistance load is in the range of 0.10 to 10.50 ohms and consists of the device under test and the cable connecting the 605B to the test item. CURRENT control (R201) sets the test current level from 10 to 2,000 milliamperes. The constant current operating range is related to the load resistance (see Paragraph 4.6).

2.2(c) Pulse Generator/Mercury Relay - A triggered, monostable multivibrator generates drive signals for mercury relay (K401) and oscilloscope trigger pulses. Duration of the test current pulse(s) is set by R320, on the printed circuit board, and is adjustable from 10 to 70 milliseconds. Repetition rate of test current pulse(s) is set by control R313, also on the printed circuit board. Rate is adjustable over the range of 2.5 pulses per second to 9 pps (approx). A delay circuit delays start of the output pulse until relay K403 stops chattering. Delay is set by R305 and is adjustable from less than 5 to more than 100 milliseconds.

2.2(d) PULSE Switch - Repetitive or one-shot test pulse operation is selectable by the two-position PULSE switch (S202) on the front panel. The single shot mode is generally used for determining interface characteristics. Repetitive pulse operation is generally used for test effect studies. However, the choice between one-shot or repetitive operations is optional.

2.2(e) FUNCTION Switch - Switch (S204) configures the 605B circuits for either the balance or the thermal response test mode. With S204 in the BAL position repetitive, 10 milliampere pulses are applied to the bridge when the TEST switch is pressed. With the switch in the THERMAL position either single or repetitive pulses are applied to the bridge (depending on the position of PULSE switch) when the TEST switch is pressed.

2.2(f) TEST Switch - Two section, momentary pushbutton switch (S205) is on the front panel. One section (normally open) closes and applies power to relay K403, when actuated. The other section (single-pole, double-throw) terminates at AUXILIARY connector (J604) on the test set rear panel (see Paragraph 2.2(r)).

2.2(g) Digital Panel Meter - The 2000 count meter displays test or balance current level when METER switch S203 is pressed. Overrange (inputs greater than 1999 milliamperes) is indicated by a "1" followed by three blanked digits.

2.2(h) Oscilloscope - User-supplied oscilloscope monitors the output of the 605 bridge. A single channel scope with 1 millivolt vertical deflection factor is adequate for general purpose work. A dual beam, storage scope with camera will satisfy the most demanding requirements.

2.2(i) LED indicators - Two light-emitting-diodes (LED's) just above the BRIDGEWIRE R "X.1" multiturn dial supplement the oscilloscope as bridge balance status indicators during bridge balancing procedures. Their primary purpose is to indicate the direction to turn the BRIDGEWIRE R dials in order to reach the bridge-balance condition. At unbalance one LED will light when the bridge output exceeds approximately 1.5 millivolts. Polarity of the bridge output signal governs which LED will light. When balanced both LED's should appear dark when viewed in average ambient light. Arrows adjacent to the LED's indicate the direction to rotate the dials to achieve balance during the balancing sequence. The LED's may be considered a "coarse" balance adjustment, with final precise balancing using the oscilloscope trace.

The LED's function only during the balancing sequence (during which time the FUNCTION switch is in the BAL position); they are inoperative during the thermal response test mode (when the FUNCTION switch is in the THERMAL position).

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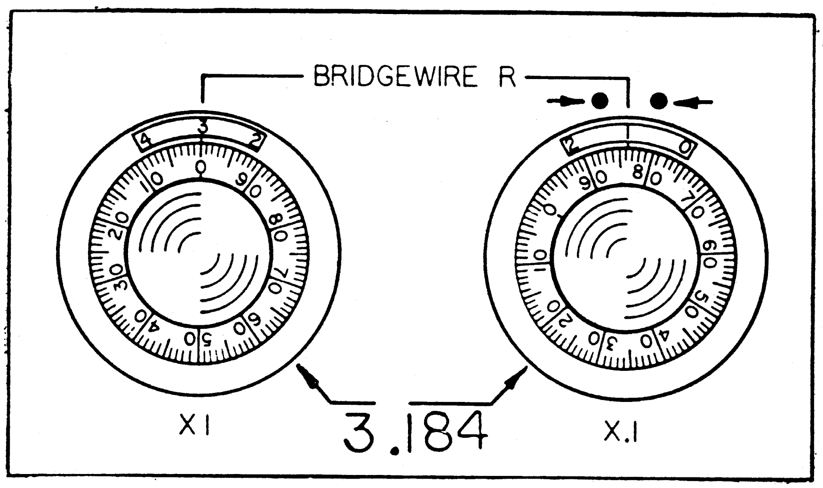
2.2(j) <u>BRIDGEWIRE R Controls</u> - Two 10-turn potentiometers (R202 and R203) from the adjustable balancing arm of the 605 bridge. The potentiometers, equipped with multiturn dials, are adjusted for essentially zero output of the bridge, as indicated by the oscilloscope and/or the LED's, described in Paragraphs 2.2(i) above. At balance the dial settings indicate the load resistance (±0.050 ohms) connected across the EED terminals.

Each graduation of the "X1" and "X.1" inner dial scales corresponds to load resistance of 10 milliohms and 1 milliohm respectively. At bridge balance, the total resistance across the EED terminals is read as the sum of the settings of the two dials. A resistance of 3.184 ohms is indicated in the example below.



2.2(k) <u>EED Terminals</u> - The device under test is connected to the 605 Test Set at the "EED" binding posts on the front panel. The "⏚" terminal is electrically connected to the oscilloscope ground through the BRIDGE OUT coaxial cable. The EED terminals are normally shorted by one section of relay (K403) as a safety measure. The short circuit is removed when K403 is actuated by pressing TEST switch (S205).

2.2(l) <u>AC Power Switch</u> - Switch (S201), on the front panel, controls the application of AC input power to the test set.

2.2(m) <u>Indicator Lamp</u> - Lamp assembly (DS201), on the front panel, indicates ON-OFF condition of AC power to the test set.

2.2(n) <u>Power Cord Receptacle</u> - Three-pin connector (J603) for AC power cord.

2.2(o) <u>Fuse</u> - (F601) provides overload protection of AC power input to the test set.

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2.2(p) BRIDGE OUT Connector - BNC type coaxial connector (J601), on the rear panel connects to the oscilloscope vertical amplifier by means of BNC coaxial cable assembly.

2.2(q) TRIGGER OUT Connector - BNC type coaxial connector (J602), on the rear panel connects the 605 to the oscilloscope trigger input by means of BNC coaxial cable assembly.

2.2(r) AUXILIARY Connector - Connector (J604) on the rear panel provides convenient connection to a set SPDT contacts on Switch S205. The contacts are actuated by closure of TEST switch (S205). Contacts may be used for control of auxiliary functions, i.e., test chamber interlock, test component shorting, test component grounding, test component disconnect, etc.

2.2(s) Null Amplifier - Designated A-500, the unit amplifies the bridge output signal during the balancing sequence. The A-500 output drives a pair of polarity sensitive light-emitting diodes to indicate the balance/unbalance status of the bridge (Par. 2.2(i)).

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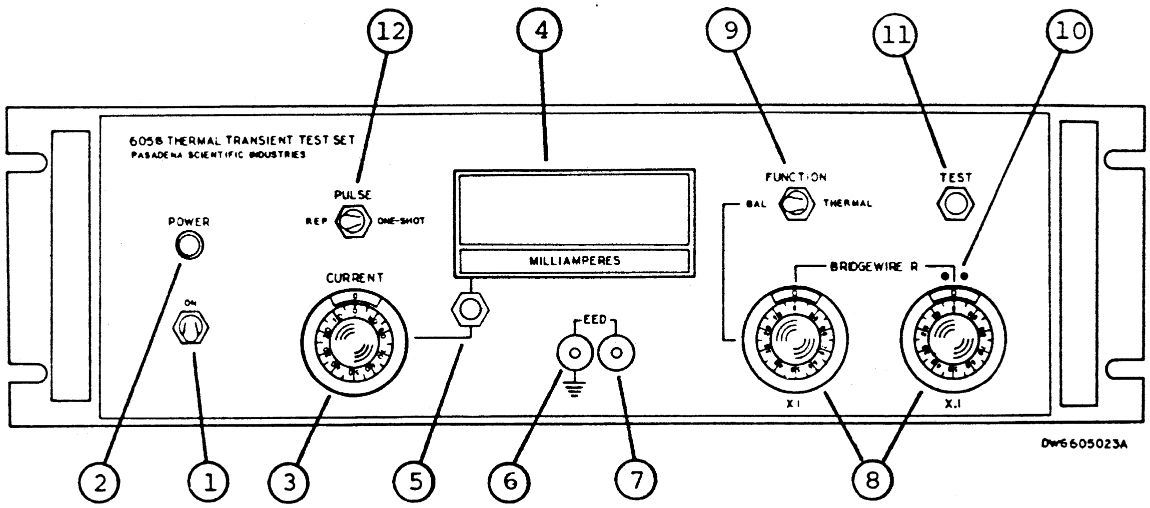


(1) AC power switch - Par 2.2(l)

(2) AC power ON-OFF indicator lamp - Par. 2.2(m)

(3) Test current control - Par 2.2(b)

(4) Digital milliammeter - Par 2.2(g)

(5) Meter switch - Par 2.2(g)

(6) Terminal for device under test; this terminal is the 605B circuit ground (connects to oscilloscope ground) - Par. 2.2(k).

(7) Terminal for device under test - Par 2.2(k)

(8) Bridge balancing potentiometers - Par 2.2(j)

(9) Balance/Thermal Test selector switch - Par 2.2(e)

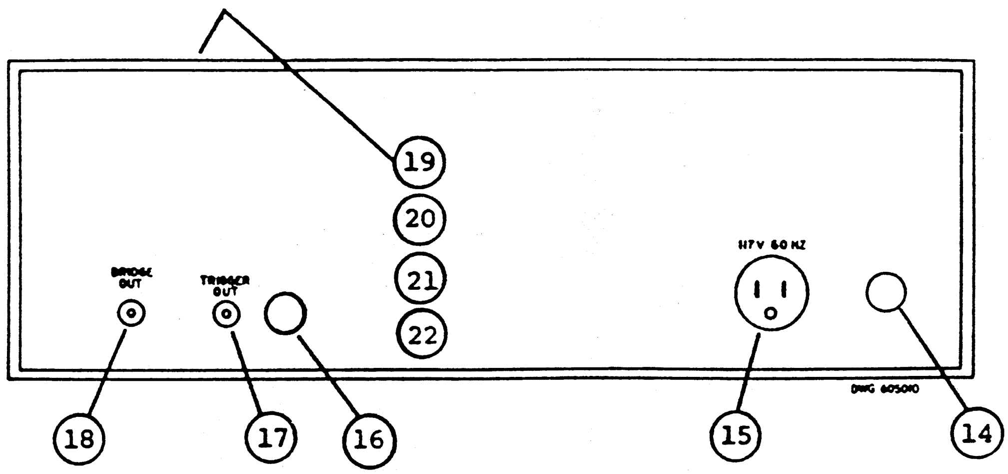
(10) Light emitting diodes - Par 2.2(i)

(11) Test switch - Par 2.2(f)

(12) Repetitive/One-Shot pulse selector switch - Par 2.2(d)

Figure 2.1(a)

Operating Controls and Terminals



14 AC power fuse - Par 2.2(o)

15 AC power cord receptacle - Par 2.2(n)

16 Auxiliary plug/socket - Par 2.2(r)

17 Trigger pulse connection to oscilloscope - Par 2.2(q)

18 Bridge output connection to oscilloscope - Par 2.2(p)

19 Pulse duration control - Par 2.2(c)

20 Pulse repetition rate control - Par 2.2(c)

21 Pulse delay control - Par 2.2(c)

22 Null Amplifier AM-500 - Par 2.2(s)

Figure 2.1(b)

Operating Controls and Terminals

SECTION III

INSTALLATION

3.1 General - The Model 605 is designed for bench or table top use. Optional adapters are available for rack mounting the enclosure. Installation consists of placing the instrument at a suitable operating position and making the cable interconnections to the AC power source, oscilloscope, and the device under test (including user-supplied test fixtures). The test set uses a mercury relay. It is therefore necessary to install and operate the instrument with its from panel within 30° of vertical.

3.2 Test Fixtures - User-fabricated test fixtures designed to accommodate the particular test components will usually improve the efficiency and safety of the test procedure.

AS A SAFETY MEASURE WE STRONGLY RECOMMEND THAT TEST ITEMS BE PLACED IN A SUITABLE TEST CHAMBER DURING THE TESTS.

User-supplied test fixtures should include provisions for electrically disconnecting the device under test from the test set "EED" terminals and shorting, and grounding, the bridgewire leads except during the application of balancing and test currents. It should be repeated that the test set "EED" terminals are shorted by one section of control relay K402; the short is removed during the time TEST switch (S205) is pressed.

3.3 Deleted

3.4 Connectors - High quality binding posts, terminals, switches, etc., are essential for noise-free test signals. Alligator clips and similar devices are to be avoided.

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NOTE: Particular attention should be given the following paragraphs if clean oscilloscope traces are to be obtained.

3.5 Power Requirements - The 605 is designed to operate only from an unbalanced-to-ground power source. The power line neutral (white or "identified" conductor) must be connected to the 605 neutral (unfused), and the power plug safety ground must return to ground through a different path than the power line neutral.

3.6 Grounds - The cabinet and chassis of the 605 are electrically connected to the power plug (PL602) safety ground pin.

The 605 circuit ground (⏚) is connected to earth ground (⏚) at the GROUND terminal of the oscilloscope amplifier input. If an earth ground connection must be made to the 605 circuit ground at a point other than the scope amplifier input, the earth ground connection must be removed during the time the TEST switch (S205) is actuated.

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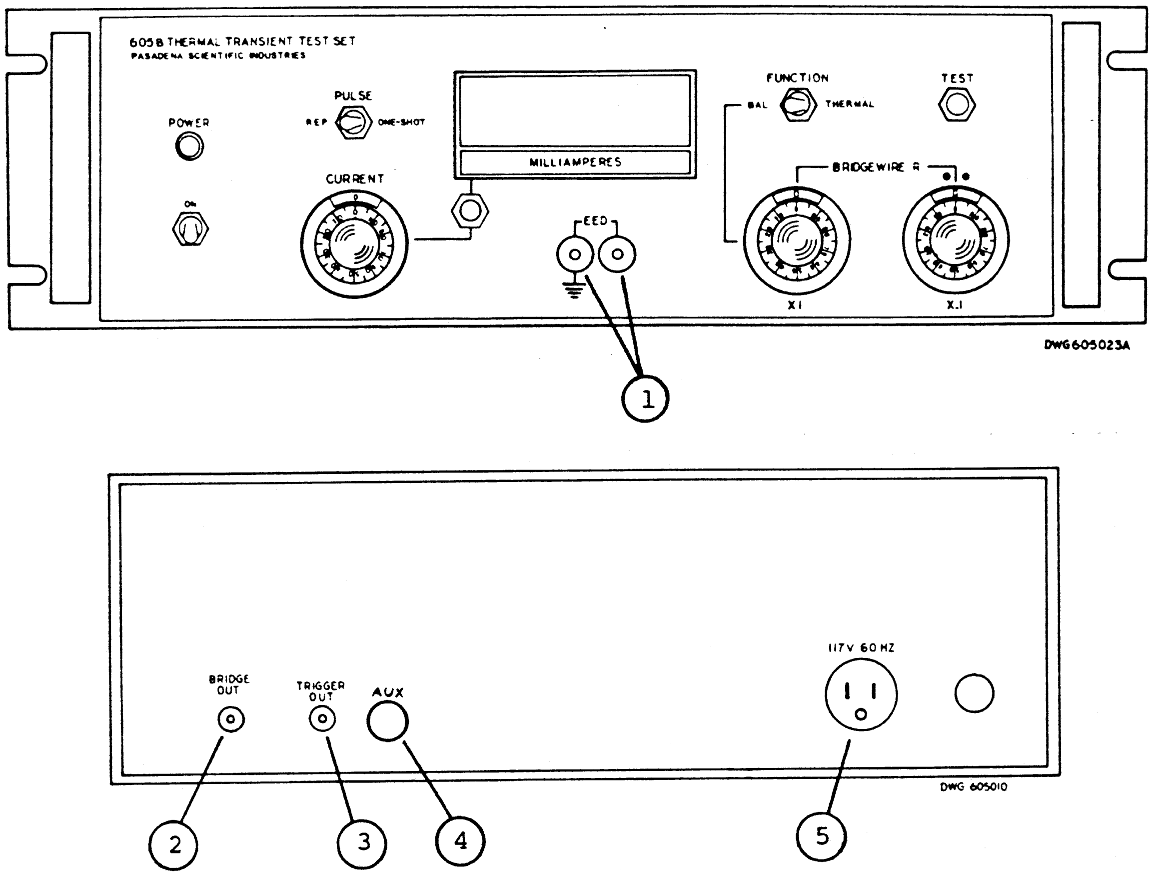


(1) Connect device under test to EED terminals; (refer to Par. 3.3) for 605/EED Cable details).

(2) Install coaxial cable assembly and connect to oscilloscope Vertical Amplifier input.

(3) Install coaxial cable assembly and connect to oscilloscope Trigger input.

(4) Connection is optional (refer to Par.2.2(r)

(5) Install AC power cord and connect to 105-125V, 50-60 Hz power.

Figure 3.1

Installation (Cable Connections)

SECTION IV

OPERATING INSTRUCTIONS

4.1 General - Instructions contained in this Section assume that the Test Set user is unfamiliar with the instrument and the test procedures. As the user becomes familiar with the various controls and their relationship to the test, it will become apparent that some procedure details, as outlined, may be modified or deleted.

For indoctrination purposes Reference Bridgewire RB101 is used as the device under test in the examples to follow. The RB101 is a thermally responsive resistor network whose electrothermal behavior is comparable to typical EED's. A full description of the RB101 will be found in Appendix D.

4.2 Operating Procedure - The test procedure consists of two parts: (a) balancing the 605 bridge, and (b) application of safe-level test current pulses to the device under test and observing its thermal response on an ancillary oscilloscope.

(a) Balance/Bridgewire Resistance - In this sequence the bridge is balanced by applying non-heating, low-current pulses to the bridge and adjusting the BRIDGEWIRE R pots for essentially zero signal as indicated on the oscilloscope connected to the bridge output terminals. Step-by-step instructions for this sequence are outlined in Figure 4.1.

(b) Thermal Response - In this sequence the device under test is pulsed with controlled, safe-level current; the electrothermal response of the bridgewire/explosive interface is detected and displayed on the oscilloscope for observation and analysis. Step-by-step instructions for this sequence are outlined in Figure 4.3.

4.3 Oscilloscope Controls - The following will serve as a general guide for setting the oscilloscope controls during the initial test period.

(a) Trigger: External "+"
(b) Sweep Rate: 5 milliseconds/centimeter
(c) Vertical sensitivity: Generally, the 1 millivolt/centimeter setting is used; however, settings of 2mv/cm or 5mv/cm may be advantageous in the early phases, then switch to lmv/cm

4.4 Selection of Test Current Level - The nondestructive aspects of the thermal transient test, and the safety implied, are related to the magnitude of the test current. Since bridgewire temperature is a function of bridgewire current, limiting the current to a safe level is of utmost importance. Obviously, the bridgewire temperature must be held to a value less than the ignition temperature of the explosive mixture. In practice, it is customary to limit the temperature rise at the bridgewire-explosive interface to a maximum of 100°C above ambient during the thermal transient test. Either of two approaches may be made in holding the temperature to a safe level.

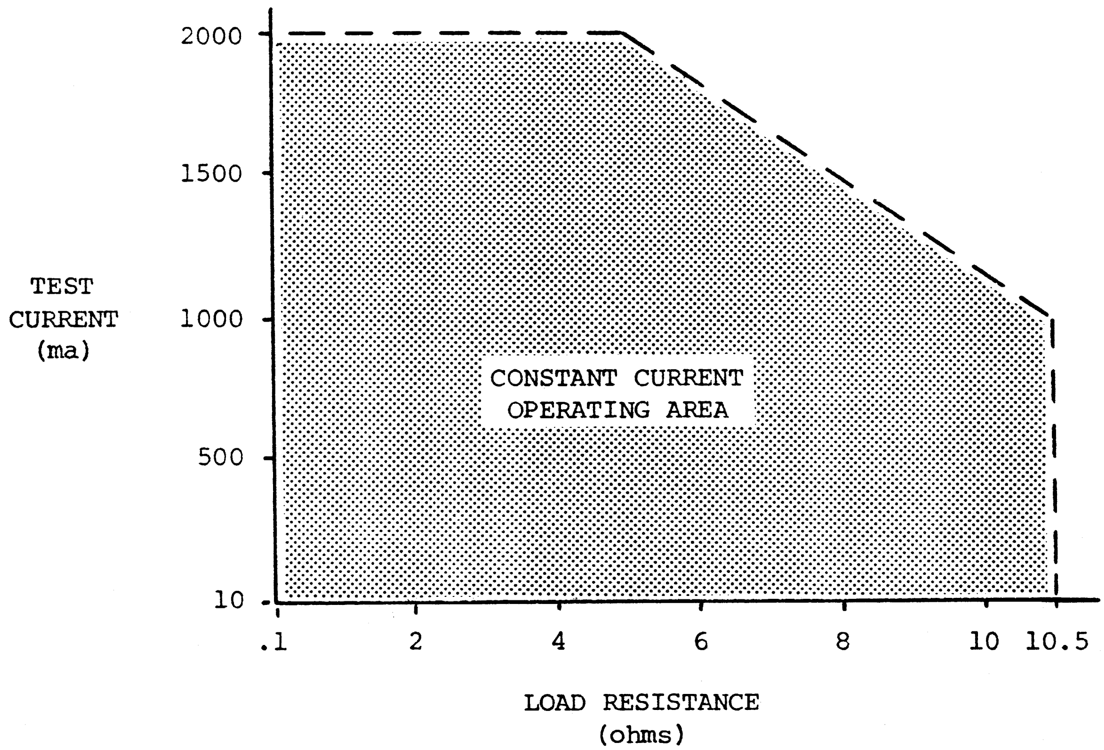
If the DC no-fire current value of a given design has been established (functional destructive testing), one approach is to limit the thermal transient test current to approximately 60% of the DC no-fire current.

Another approach may be used if the DC no-fire current level has not been established. This method involves calculating bridgewire temperature based on the signal developed across the bridgewire when the bridgewire is pulsed with a known current, and the Temperature Coefficient of Resistivity of the bridgewire material is also known. (See Application Note 3 "Calculation of Electrothermal Parameters"). In this instance the test current level is limited to a value resulting in a temperature rise of 100°C, maximum.

The thermal transient test concept requires that the bridgewire material have a 'reasonable' Temperature Coefficient of Resistivity (TCR), and that the TCR be known in order to generate a useful signal. Bridgewire materials having TCR's greater than about 50 parts per million/°C generally yield satisfactory signals at acceptable bridgewire temperatures. TCR's less than 50ppm/°C probably will require dangerously high bridgewire temperatures (above the 100°C figure) in order to generate a meaningful response.

4.5 Selection of Test Pulse Duration - Test current is generally applied to the device-under-test for a period of time sufficient for the bridgewire-explosive interface to reach thermal equilibrium. This usually requires several time constants. (Refer to Application Note 3 for Time Constant calculation). The 605 series Thermal Transient Test Sets are capable of generating current pulses of less than 10 milliseconds to over 70 milliseconds. Time constants of aerospace and military devices are typically in the range of 3 to 20 milliseconds, with low energy devices under 3 milliseconds. If the current pulse is too short (terminated before thermal equilibrium is reached) valuable thermal information may be missed since thermally induced abnormalities (bridgewire movement, air gaps, etc.) usually occur late in the thermal response cycle.

4.6 Test Current/Load Resistance - The 605B is capable of providing 2,000 milliampere (maximum) constant current test pulses to a load of 0.10 to 5.00 ohms. Loads in the range of 5.00 to 10.50 ohms require reduced maximum test current levels to ensure reliable constant current operation. The current/load relationship is shown below. It is essential that operation occur in the shaded area.



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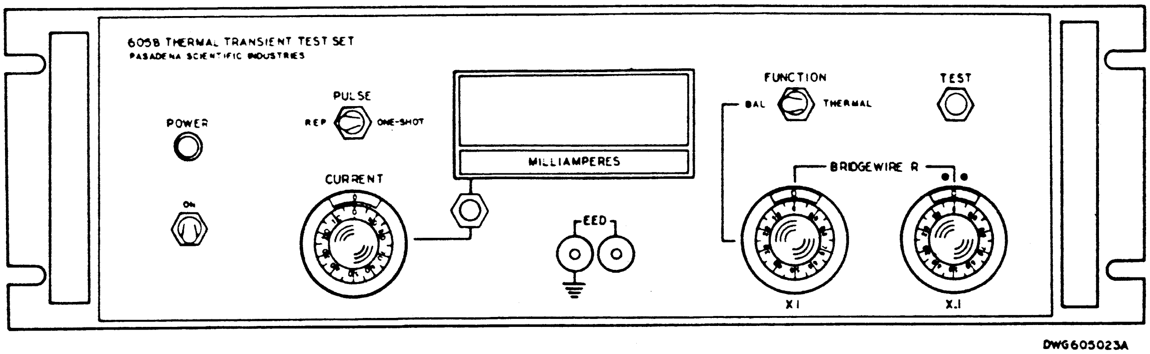


NOTE: The following step-by-step procedure assumes initial operation of the 605; see Par. 4.1.

(1) Turn on AC power to 605; allow 5 minute warmup.

(2) Plug Reference Bridgewire RB101 into EED terminals.

(3) Set FUNCTION switch to BAL.

(4) Set BRIDGEWIRE R "X1" dial to exactly 2.00; set the BRIDGEWIRE R "X.1" dial to approximately zero (00.00).

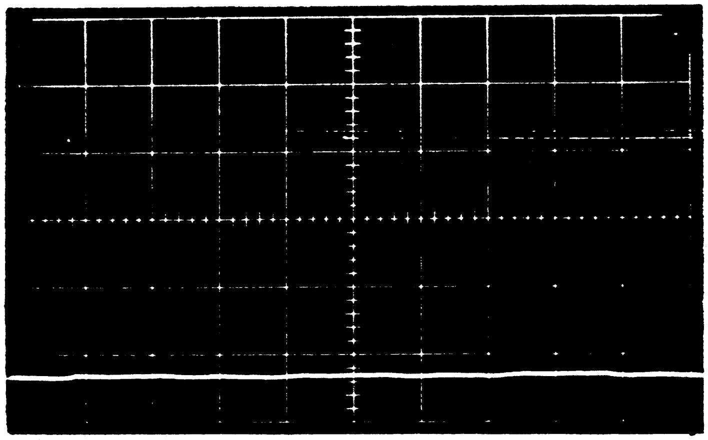
(5) Press the TEST switch while observing the oscilloscope and LED's and adjusting oscilloscope centering, intensity, etc., if necessary. The scope should show repetitive unbalanced traces similar to Fig. 4.2(B), and one LED should be pulsing.

Continue pressing the TEST switch and rotate the X.1 dial in the direction of the arrow next to the pulsing LED until the scope trace and LED's indicate bridge balance as in Fig. 4.2(A). Release the TEST switch.

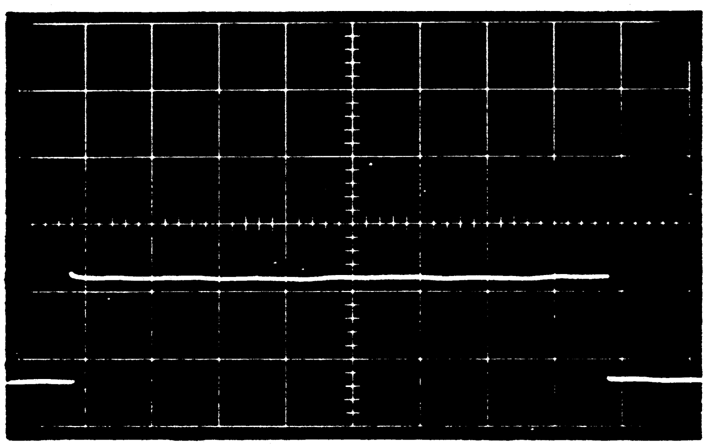
This completes the Balance/Bridgewire Resistance test sequence. Cold resistance (ohms) of RB101 is indicated by the sum of the X1 and X.1 dial readings. For familiarization, repeat the sequence several times using various initial settings of the X.1 dial.

Figure 4.1

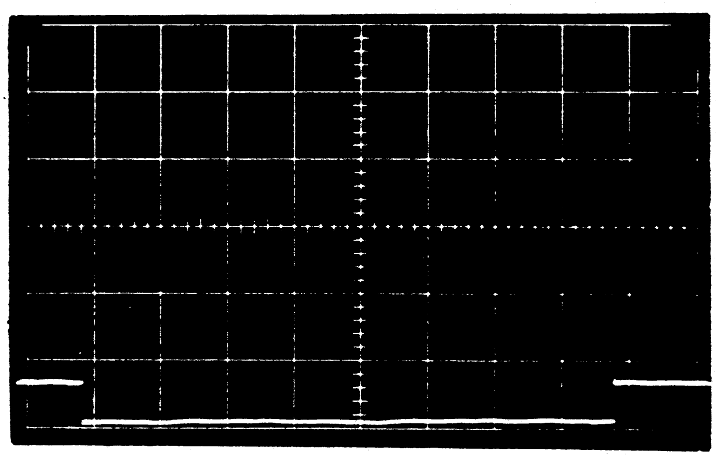
Operating Sequence
(Balance/Bridgewire Resistance Test)



(A) Balanced bridge



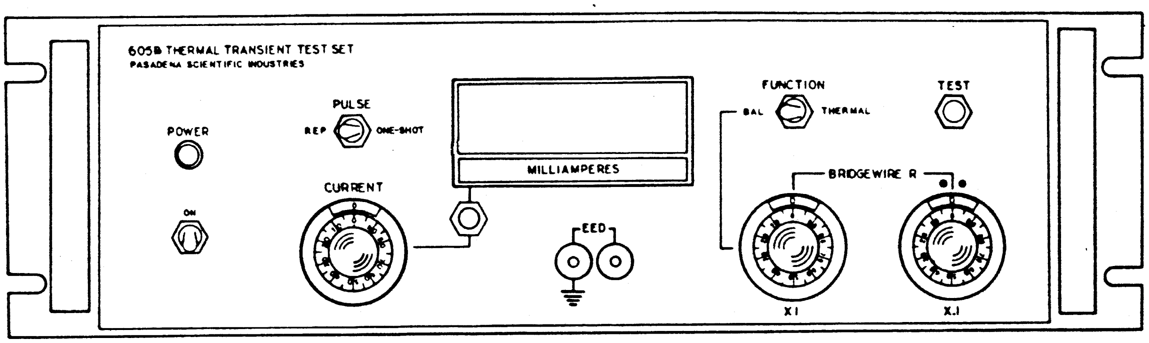
(B) Unbalanced bridge
(Positive unbalance)



(C) Unbalanced bridge
(Negative unbalance)

Device Under Test	:	Reference Bridgewire RB101
Bridgewire Current	:	10 milliamperes
Vertical (Bridge output)	:	1 millivolt/division
Horizontal (Sweep)	:	5 milliseconds/division

Figure 4.2
Typical Response Traces of Bridgewire
(Balanced Bridge and Unbalanced Bridge Conditions)



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NOTE: The following step-by-step procedure assumes initial operation of the 605 (Par. 4.1); and that the 605 is balanced per the preceeding sequence (Figure 4.1).

(1) Set FUNCTION switch to THERMAL.

(2) Set PULSE switch to ONE-SHOT.

(3) While pressing METER switch adjust CURRENT control for approximately 10ma meter reading. Release METER switch when 10ma setting is reached.

(4) Momentarily press the TEST switch while observing the oscilloscope trace. Compare scope trace with Fig. 4.4 at 10ma.

Increase test current to approximately 220ma by advancing the CURRENT control and noting meter reading. Release METER switch when 220ma setting is reached.

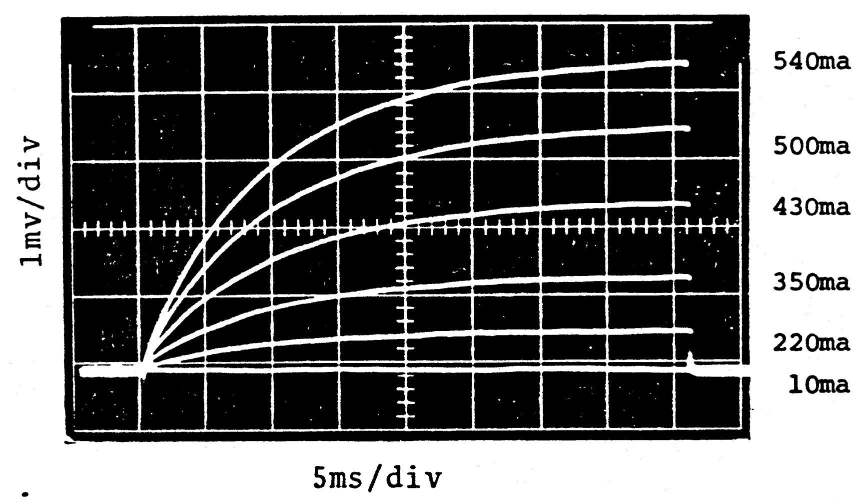
Momentarily press and release the TEST switch while observing the scope traces. Compare traces with Fig. 4.4 at the 220ma level. Tweak "X.1" dial if trace shows slight unbalance. Advance the CURRENT control while momentarily pressing and releasing the TEST switch; note the effect increasing the test current has on the amplitude of the thermal response curve. Compare the curves with those shown in Figure 4.4.

This completes the ONE-SHOT Thermal Response Test Sequence. For REPETITIVE operation, set PULSE switch (step 2, above) to REP and continue the test sequence as outlined.

Figue 4.3

Operating Sequence
(Thermal Response Test)

The figure below is a multiple exposure photograph of Reference Bridgewire RB101 thermal response curve at various test current levels*.



* Curves of different RB101 units may vary (i.e., slope, amplitude, etc) because of lamp filament TCR differences.

Figure 4.4

Reference Bridgewire RB101

SECTION V

MAINTENANCE

5.1 Component Numbering System - The component number of each resistor, switch, capacitor, etc., is showing in the schematic diagrams. The following chart lists the component numbering blocks and/or their respective area locations.

Numbers less than 100	Power Supply
100 Series	Power Supply
200 Series	Front Panel components
300 Series	Pulse Generator A-300
400 Series	Main chassis components
500 Series	Null Amplifier A-500
600 Series	Rear panel components
700 Series	Power Supply

5.2 Replacement of Components - Most components used in the 605 Series are standard electronic parts obtainable through normal electronic distribution channels. However, we will supply replacement parts at current net prices on out-of-warranty instruments; in-warranty instruments requiring parts will be serviced at no charge under our standard warranty.

We specially select some parts, whose value must fall within prescribed limits, by sorting through our regular stocks. The components so selected have standard REIMA color-code marks showing the values and tolerances of the stock from which they were selected; however, in general, they are not replaceable from dealer stocks.

Such selected parts, as well as the parts manufactured by PSI, are identified in the Parts List by appropriate notes or by our own stock or part numbers. Such parties are available from PSI.

A serial number is shown on the title page of this manual. This serial number is also the serial number of the instrument for which the manual was prepared. When ordering replacement parts be sure the manual number matches the instrument serial number.

5.3 Power Supply Adjustment - One section of the Power Supply provides closely regulated DC power for several 605 circuits. Normal output of this section is 24 volts ± 1 volt, measured across pins 2 and 10 of Relay K403 socket.

5.4 <u>Bridge Balance Current</u> - Zener diode D1 and resistor R2 set the test current level for the bridge balancing/bridgewire resistance procedure. Current level (typically, 10 milliamperes) is displayed on Digital Panel Meter M201.

5.5 <u>Pulse Rate Adjustment</u> - Screwdriver adjustable control R313 (on the Pulse Generator printed circuit board) sets the rate or frequency of test pulses. The rate is continuously variable over the range of less than 2 pulses per second to over 9 pps. Clockwise rotation of R313 increases the rate. The rate is set at approximately 2 pps when shipped from the factory.

5.6 <u>Pulse Width Adjustment</u> - Control R320 sets the width of test pulses over the range of less than 10 milliseconds to over 70 ms. R320 is a 15-turn, trimmer type, potentiometer on the Pulse Generator printed circuit board. Clockwise rotation of the screwdriver adjustable control increases the pulse width. A rate of approximately 40 milliseconds is set when shipped from the factor.

5.7 <u>Pulse Delay Adjustment</u> - R305 controls delay of the start of test pulses after relay K403 energizes. The delay is continuously variable from less than 5 milliseconds to more than 100 milliseconds. Clockwise rotation of R305 increases delay. Delay is set to approximately 50 milliseconds when shipped from the factory.

5.8 <u>A-500 Offset Voltage Adjustment</u> - Bridge balance status indicators (LED's DS202 and DS203) immediately above BRIDGEWIRE R "X.1" multiturn dial, should be unlighted when the bridge is in a balanced condition (with FUNCTION switch in BAL position). Integrated Circuits U501 and U502 may generate offset voltages causing the LED's to light when the bridge is balanced. This abnormal condition may be corrected by nulling the offset voltage as follows:

1. With power off and bottom cover removed, connect a DVM with a minimum of four digits between pin 10 (+) and pin 7 (-) on the A-500 connector. Set test set upright.

2. Turn on test set, balance with an external oscilloscope, and lock BRIDGEWIRE R dials at their balanced setting.

3. Remove relay K402 from its socket. Short pins one and three of socket XK402.

NOTE: Figure 5.1C shows position of R501 and R502 on the A-500 circuit board. Figure 5.1A shows access to R501 and R502 from top of cabinet and also shows position of relay K402.

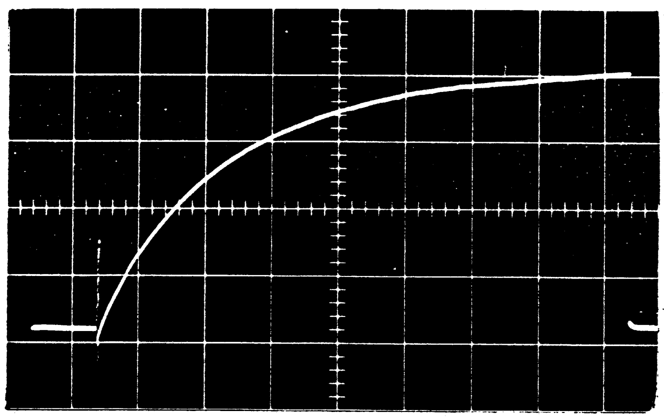
4. Adjust R501 until DVM indicates as close to .000 volts as possible. Adjust R502 until both LED's are extinguished. Leave R502 set to as near to the center of the deadband as possible.

5. Turn off power, reinstall relay K402, and disconnect DVM. Reinstall top and bottom covers.

5.9 <u>Switching Transients</u> - Under certain operating conditions (relatively high test current and/or high beam intensity of the oscilloscope) a narrow spike may be observed at the start of the heating curve. This is a normal condition caused by a combination of factors, i.e. - reactance of the bridge components and the BRIDGE OUT coaxial cable, power supply load change, and the frequency response of the oscilloscope vertical amplifier, etc.

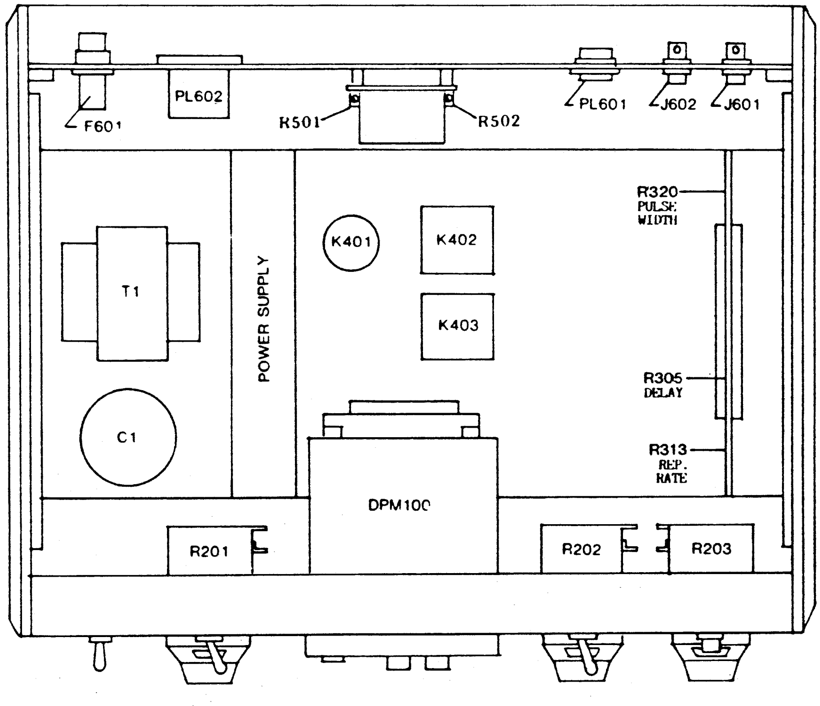
Also, a very small spike may be observed on the heating curve about 10 to 15 milliseconds prior to termination of the heating pulse. This spike is caused by the sudden de-energizing of the K401 coil.

Neither spike has any measurable effect on the test data or to the device under test. The transients in question are shown in the retouched photograph below.



5.10 <u>Digital Panel Meter M201</u> - Test current is measured as the "IR" drop across resistor R401 when METER switch S203 is pressed. To check meter M201 connect a digital DC voltmeter of known accuracy across resistor R401. Return the Test Set to its upright position and apply AC power. Warm up for a minimum of 15 minutes. Place FUNCTION switch (S204) in the THERMAL position. Press Meter switch (S203) and adjust CURRENT control (R201) for a 1.950 volt reading on the standard voltmeter. Meter M201 should indicate 1950.

The calibration of the constant current source and calibration of digital meter M201 in the Model 605B Test Set are functionally related. These are factory calibrations and as such should not be adjusted in the field.



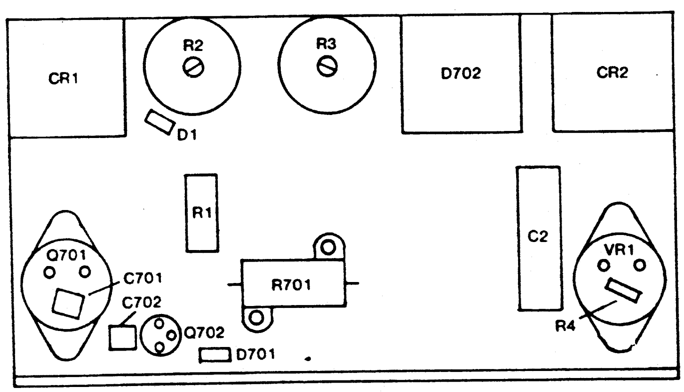


Figure 5.1A

TOP VIEW AND POWER SUPPLY

Application Note 1
March 1979

INTRODUCTION TO THERMAL TRANSIENT TESTING

Weapons Technology

New Test for EED's

Electroexplosive devices, storing and delivering large amounts of energy reliably and rapidly, have many applications in defense technology and now can be checked accurately and nondestructively

Arthur J. Murphy, Jr. • Vincent J. Menichelli
Jet Propulsion Laboratory, Pasadena, California

ELECTROEXPLOSIVE devices (EED's) are, of course, one-shot items and cannot be tested functionally prior to actual use, by which they are destroyed. However, items like EED's or electrical fuzes have for a long time been somewhat successfully qualified and tested on a small-sample statistical basis. That is, the functional reliability of such components as are destructively ground-tested simply is assigned to other identical units from the same manufactured lot.

The reliability—and, hence, the expected failure rates—of flight hardware of necessity have to be inferred. Testing or inspection of such critical components prior to actual flight usage typically is restricted to indirect examinations and various nondestructive tests, such as X-rays, leak checks, electrical resistance measurements, weights, etc.

It is the purpose of this paper to describe what is judged to be a new and more comprehensive nondestructive test or examination technique that presently is being employed by the Jet Propulsion Laboratory on flight-dedicated EED's. This technique can provide the EED user with more complete inspection information and acceptance/rejection criteria regarding the most critical failure area of EED's: namely, the bridgewire-explosive interface.

In essence, this technique allows one to "look" inside the EED nondestructively and determine if certain critical failure conditions exist. For example, the test will detect if the proper explosive material at its correct density is loaded on the bridgewire.

The use of techniques like this, which employs the critical initiation component, the bridgewire, to act as a transducer to signal potential faults and/or abnormalities, almost totally eliminates the possibility of fabricating, qualifying, or using faulty EED's.

This technique is based on a simple analysis of thermal sinking properties of EED's, a knowledge of specific failure modes and their effects, and, finally, on a "calibration test" program on individual squib designs. The test is fast, safe, and—for the EED's tested to date—completely nondestructive.

For approximately the last 12 years the increased interest in and consequently the increased exploration of the solar system by unmanned spacecraft has required the development of a new family of EED's designed to meet new space environments and unique spacecraft constraints.

For the most part, these newly developed devices possess no long history of successful performance upon which to establish functional reliability at failure rates as low as one in ten thousand. The need for alternative or, at the very least, complementary techniques to qualify this new generation of EED's economically and realistically was recognized.

Coincidentally, work was begun at the Naval Ordnance Laboratory, White Oak, Md.,[1] in 1959 for the purpose of developing new techniques for nondestructively examining what was recognized as the critical functional mechanism of these devices; namely, the bridgewire-to-explosive interface.

Prof. Louis Rosenthal of Rutgers University began experimentation[2] to take advantage of two well-known properties of nearly all such devices The properties were, first, that each of these devices had a known and reproducible firing energy vs. time-to-fire relationship and, secondly, that most of the high-resistance bridgewire material used in the fabrication of such devices had a reasonably high temperature coefficient of resistance.

Knowing that the most significant failure mechanisms (*i.e.*, condition of bridgewire weld and intimacy of contact between the bridgewire and pyrotechnic material) resided in the bridgewire/explosive/header interface, an electrothermal, nondestructive test technique for examining this critical area of the EED was developed.

Work has been conducted at the Jet Propulsion Laboratory[3] with a view toward developing techniques that would allow a nondestructive examination of the bridgewire header/pyrotechnic interface of the EED. As previously discussed, a particular EED design possesses a distinct and unique thermal capacity, thermal resistance, and thermal time constant. Changes or abnormalities in any one of these performance indicators provide information regarding the quality of the device under examination and the uniformity of lots of devices. →

For example, it has been determined that poor or marginal welds between the bridgewire and pin, imperfections in the bridgewire itself, incorrect loading pressure, movement of the pyrotechnic charge away from the bridgewire, and nonhomogeneity of the pyrotechnic charge change the effective thermal capacitance or resistance and consequently the thermal time constant of the squib.[4]

Instrumentation techniques allow for a determination of the thermal resistance, thermal time constant, thermal capacitance, and the cold bridgewire resistance of each EED.

Besides definite quantitative measurements being easily obtainable for each EED, a qualitative signature of each is obtained by photographing the heating curve. Irregularities on the heating curve have been investigated, and the relationship between these qualitative signals and faults that exist in the EED design or in manufacturing have been successfully determined.

The importance of this technique on the quality control of EED's, both to the manufacturer and to the user, is obvious. In the past, once an EED was completely assembled, little could be accomplished by way of examination of the bridgewire pyrotechnic interface. It is important to note that failure mode, effect, and criticality analysis (FMECA) conducted on various types of EED's has shown consistently that the most critical area of EED design and manufacture lies within this previously uninspectable area.

At the present time, the most important quality applications of this test technique are considered to be in the following areas:

1. The technique is extremely valuable as a developmental tool in the design and evaluation of new types of EED's. For example, new designs to provide improved welding configuration or methods and methods to improve low-temperature ignition characteristics or to increase heat-sink capability can be assessed quantitatively in a prototype configuration without building and destructively testing large numbers of units. Various manufacturing stages can be studied prior to the finished assembly.

2. Analysis of shelf life of conventional EED's can be greatly complemented by the use of this technique. Dependent on the EED design, long-term storage generally increases or decreases ignition sensitivity and/or energy capability. It is considered that these chemical-physical changes would be accompanied by corresponding changes in the thermal sinking properties. Degradation thus can be determined nondestructively and, more importantly, rates of degradation can be ascertained without firing large numbers of these devices destructively.

3. Both small and relatively large manufacturers of EED's can use these techniques, perhaps automated, to inspect in-process fabrication. Poorly built EED's could be rejected or reworked long before the unit is completely assembled. This would reduce costs due to individual-device attrition in final acceptance or due to complete lot rejection. It is considered that the use of this technique by a manufacturer as an in-process inspection tool would result in reduced fabrication and testing costs and in a higher quality, more uniform lot of EED's.

4. New device designs and new device applications are generally qualification tested by expending large numbers of EED's after subjection to various environmental and functional conditions. The use of this technique provides the test agency with a means to examine the internal portion of the EED after each test configuration. Continued testing into the next sequential condition can continue if no changes in the thermal characteristics are observed. This provides two advantages; namely, that fewer devices are required to obtain almost equivalent test information, and the environment or functional configuration that does indeed degrade performance can be isolated quickly. Test plans can be configured exclusively on a sequential environmental basis rather than one environment at a time.

5. Finally, and perhaps most importantly, this technique is considered a notable advance over the present method of selecting flight hardware. Typically, procurements of these devices are made in lots of several hundred. Perhaps 400 to 500 units might be randomly selected and expended in EED, assembly, subsystem, and system testing. The use of this technique allows a confident selection of the most uniform and fault-free devices for actual flight usage.

This technique for nondestructively examining a completely assembled EED is considered operational for EED flight applications at the Jet Propulsion Laboratory. At the present time the technique is being carefully introduced into the various phases of procurement, test, and flight usage. As experience with this technique increases, it is expected that firm acceptance and rejection criteria can be established both at the vendor fabrication level and during device qualification.

REFERENCES

[1] Rosenthal, L. A., "Electrothermal Equations for Electroexplosive Devices." NAVORD Report 6684, U. S. Naval Ordnance Laboratory, Silver Spring, Md., August 15, 1959. AD 230917.

[2] Rosenthal, L. A., "Thermal Response of Bridgewires Used in Electroexplosive Devices." *Rev. of Sci. Instru.*, Vol. 32, pp. 1033-1036, September 1961.

[3] Rosenthal, L. A., and Menichelli, V. J., Technical Report 32-1494, "Nondestructive Testing of Insensitive Electroexplosive Devices by Transient Techniques." Jet Propulsion Laboratory, Pasadena, Calif. July 15, 1970.

[4] Menichelli, V. J., and Rosenthal, L. A., "Interrelationship of Nondestructive Testing to Fault Determination." Seventh Symposium on Explosives and Pyrotechnics, Franklin Institute, Philadelphia, Pa. September 8-9, 1971.

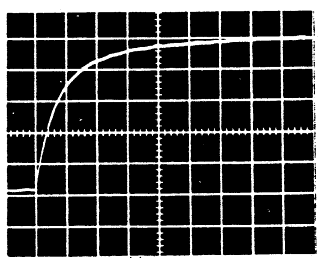
The source of the preceding application note is "ORDNANCE", published by the American Ordnance Association, 740 15th St. N.W., Wash. DC 20005

Application Note 2
March 1979

THERMAL TRANSIENT TEST THEORY

The Thermal Transient Test is a nondestructive means for characterizing the bridgewire-explosive interface of an electro-explosive device (EED). The test is based on the application of a current waveform to the device under test (DUT), and the examination of the signal developed across the bridgewire terminals. The response to the current pulse is a rise in bridgewire temperature and an increase in bridgewire ohmic resistance (ΔR). If the bridgewire cold resistance (R_o) and the bridgewire material temperature coefficient of resistivity (TCR), α, are known, the signal can be related to the bridgewire temperature rise such as in resistance thermometry.

The adjacent figure illustrates a typical electrothermal response of an EED under test as may be displayed on an oscilloscope in conjunction with a Pasadena Scientific Industries' Model 605A Thermal Transient Test Set. The horizontal axis is a time base from left to right. Vertical deflection represents the voltage developed across the bridgewire terminals. The specific shape of the analog is controlled by the bridgewire-explosive interface parameters, which are, thermal capacitance and thermal resistance. The initial slope of the curve is determined by thermal capacitance. The final amplitude by thermal resistance. The simple exponential curve can be seriously degraded by abnormalities at the interface†.



Test theory assumes that the interface electrothermal response, generated by the current waveform, is an exponential. On this basis, Rosenthal[1] derived equations to calculate the electrothermal parameters. Actually, testing of loaded units shows the analog to deviate from a true exponential. However, Rosenthal's equations are used since the primary object of the test is to compare units rather than obtain absolute values.

Treating the bridgewire-explosive interface as a lumped thermal system, we find the differential equation describing the temperature rise (Θ) to be:

$$\frac{d\Theta}{dt} + \gamma\Theta = P(t) \qquad (1)$$

† See AN-4, "Interpretation of Thermal Response Curves"

Equivalent heat capacity (C_p) is given in W·s/°C (or J/°C). Simple heat loss is represented by the linear thermal conductance term in W/°C. The reciprocal of thermal conductance is thermal resistance, which describes the temperature rise in °C/W dissipation. Power input P(t) as a function of time controls the thermal behavior of the system, and if we select a simple P(t) waveform, a recognizable and interpretable response results. The constant current (I) drive resulting in a power

$$P(t) = I^2 R_o (1 + \alpha\Theta) \tag{2}$$

provides a proper, convenient, and easily generated waveform. As the temperature rises, the $\alpha\Theta I^2 R_o$ component corresponds to thermal feedback; regenerative for a positive α.

The solution for (1) is

$$\Theta(t) = \frac{I^2 R_o \left[1 - \exp\left(-\frac{\gamma' t}{C_p}\right)\right]}{\gamma'} \tag{3}$$

The modified heat loss factor due to feedback is

$$\gamma' = \gamma - I^2 R_o \alpha \tag{4}$$

An apparent time constant is defined as

$$\tau' = \frac{C_p}{\gamma'} . \tag{5}$$

This time constant is responsive to the current or power wave form, whereas

$$\tau = \frac{C_p}{\gamma} \tag{5a}$$

is intrinsic to the device alone.

The signal, available as a voltage drop V(t) across the bridgewire, is obtained from V(t) = IR(t), where

$R(t) = R_o[1 + \alpha\Theta(t)]$. This results in

$$V(t) = IR_o \left\{1 + \frac{\alpha I^2 R_o}{\gamma'} \left[1 - \exp\left(-\frac{\gamma' t}{C_p}\right)\right]\right\} \tag{6}$$

It is apparent that the voltage appearing across the bridgewire is a step replica of the current waveform with an exponential rise superimposed as shown in the Figure below. The slope of the exponential portion of the heating curve at t = o is

$$\frac{dV(t)}{dt} = \frac{\alpha I^3 R_o^2}{C_p} \qquad (7)$$

and can be used to establish C_p/α, a device parameter. Note that the useful signal amplitude is $\alpha I^3 R_o^2/\gamma$ and that it varies with the cube of the current.

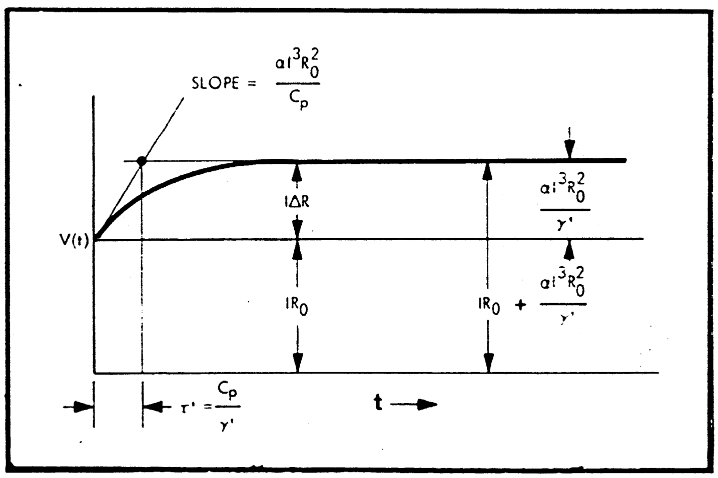


Fig.AN2-1 - Voltage drop across bridgewire

=0=

[1] L. A. Rosenthal, "Electrothermal Equations for Electro-explosive Devices", NAVORD Report 6684, U.S. Navy Ordnance Laboratory, Silver Spring, MD, 15 August 1959.

Application Note 3
March 1979
Rev: 9-79

CALCULATION OF ELECTROTHERMAL PARAMETERS

The thermal transient test provides quantitative data for calculation of interface thermal parameters, i.e., thermal conductance, thermal time constant, thermal capacitance, and bridgewire temperature rise. Data for the mathematical calculations are obtained from the test apparatus (605A Thermal Transient Test Set and associated oscilloscope). Bridgewire material temperature coefficient of resistivity (TCR), α, is obtained from handbook tables, manufacturer's data, or by experimental methods

The thermal parameters are calculated from the expressions below, where:

ΔV_m = maximum voltage change at bridgewire terminals
θ = temperature rise of bridgewire
I = test current
R_o = cold resistance (ohms) of bridgewire
α = temperature coefficient of resistivity of bridgewire
γ = thermal conductance
S = initial slope of heating curve (at t = 0).
C_p = thermal capacitance
τ = thermal time constant
$t_{1/2}$ = time at $\frac{1}{2}\Delta V_m$ value

<u>Temperature rise</u> θ, above ambient, at the interface is expressed in °C, and is determined by the definition

$$\theta = \frac{\Delta V_m}{I R_o \alpha} \qquad (1)$$

<u>Thermal conductance</u> γ at the interface is expressed in watts/°C, and is determined by the definition

$$\gamma = \frac{\alpha R_o^2 I^3}{\Delta V_m} \qquad (2)$$

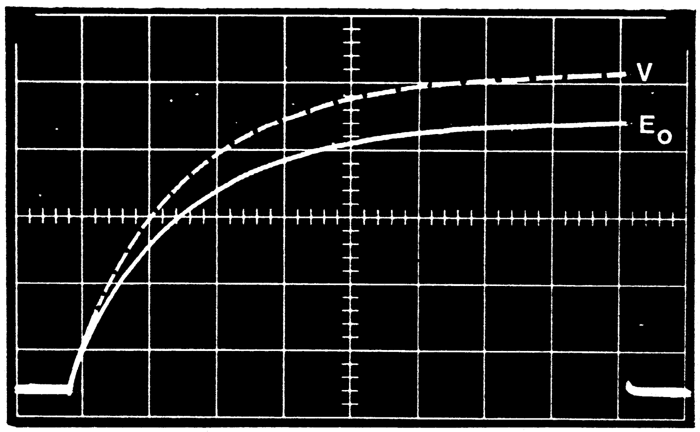
<u>Thermal capacitance</u> C_p is expressed in watt-seconds/°C is determined by

$$C_p = \frac{\alpha R_o^2 I^3}{S} \quad \text{or} \quad C_p = \gamma \tau \qquad (3)$$

<u>Thermal time constant</u> τ is expressed in seconds and is determined by the definition

$$\tau = \frac{t_{1/2}}{0.69} \qquad (4)$$

Voltage Correction - Measurement of voltage present at the bridge output terminals during application of test current pulses is basic to the resolution of bridgewire temperature (θ) and thermal conductance (γ). The voltage is measured by observing the amplitude of the thermal response curve on the calibrated oscilloscope CRT. The observed voltage will differ from the true voltage because of bridge signal-loss and nonlinearity. This difference is shown in the photograph below. The observed (uncorrected) curve is identified by the solid line "E_o" trace. The true (corrected) voltage curve is indicated by the dashed trace "V".



The magnitude of the correction is related to the ratio of the load resistance (R_L) and the bridge fixed-arm resistance (R_b). It should be noted that R_b is a 10 ohm resistor used in all Model 605 Test Sets. Load resistance R_L is determined by the Test Set resistance measurement. R_L values will be in the 0.10 to 10.50 ohm range. Corrected voltage "V" is determined by:

$$V = E_o + \left(E_o \cdot \frac{R_L}{R_b}\right)$$

Example: E_o is observed as 4 millivolts; load resistance R_L has been determined to be 2 ohms; R_b is a constant 10 ohms. Solving for corrected voltage V:

$$V = 4 + \left(4 \cdot \frac{2}{10}\right) = 4 + (0.8) = 4.8 \text{ millivolts}$$

=0=

Application Note 4
March 1979

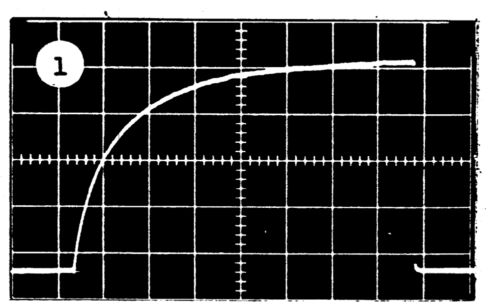
INTERPRETATION OF THERMAL RESPONSE CURVES

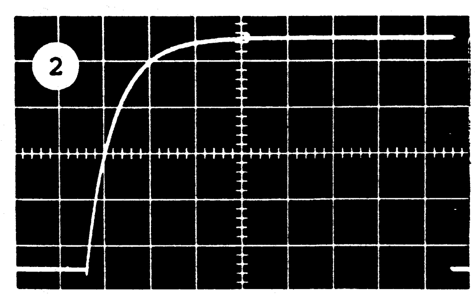
<u>Introduction</u> - Thermal response curves generated by the thermal transient test graphically describe the electrothermal character of the bridgewire-explosive interface under examination. The normal heating curve can be seriously degraded by interface faults; such as, defective bridgewire welds, bridgewire movement, incorrect compaction pressure, and other interface irregulatities.

With proper interpretation of thermal response curves, the test is capable of providing a great deal of inspection information and acceptance/rejection criteria of the interface. Each fault category generates a distinctive "signature", making curve interpretation and fault determination a reliable and fairly routine procedure.

This Application Note includes representative typical examples of normal and abnormal thermal response curves likely to be encountered†. The causes underlying the various abnormalities are discussed.

<u>Normal Curves</u> - Each EED, when properly fabricated, will generate a thermal response curve whose specific shape is controlled by the thermal capacity and thermal resistance inherent in the design of the EED. A normal heating curve is always smooth and continuous. In addition, normality of the heating curve will depend on its relation to other curves generated by EEDs of the same design in the test population.

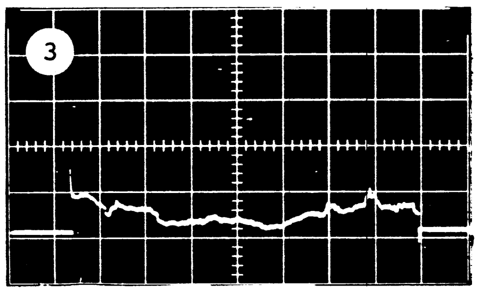


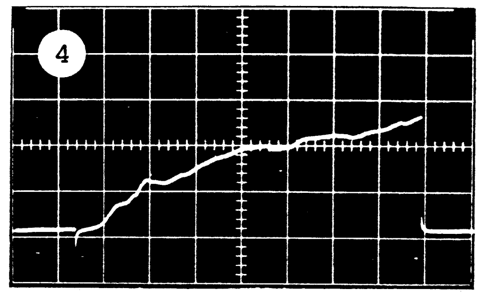


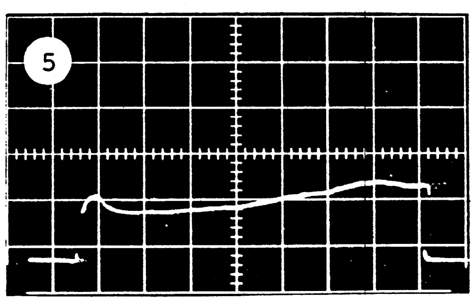
Figures 1 and 2, above, illustrate curves generated by EEDs of two different designs. Each curve is smooth and continuous. In addition, each is assumed to be within acceptable limits relative to other curves in their respective test populations. In summary, both curves appear normal in every respect.

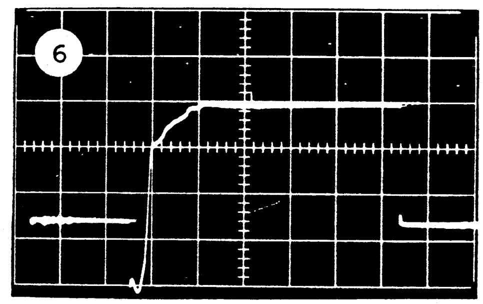
† Example curves made with Model 605A Thermal Transient Test Set

Bridgewire Welds - Defective mechanical fusing of bridgewire and posts, coupled with oxides and semiconductor products at the weld joint, combine to form a defective weld. The unstable mechanical and electrical character of defective welds generate a wide variety of erratic responses. Typical responses are shown in Figures 3 - 6, below. Abnormal welds generally manifest themselves early in the heating cycle (at the onset of the test current pulse).

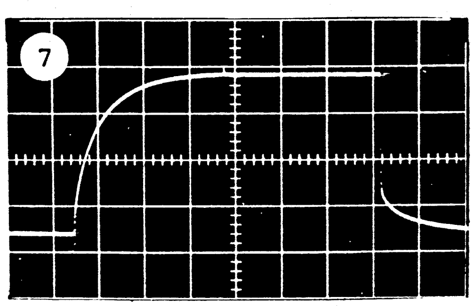


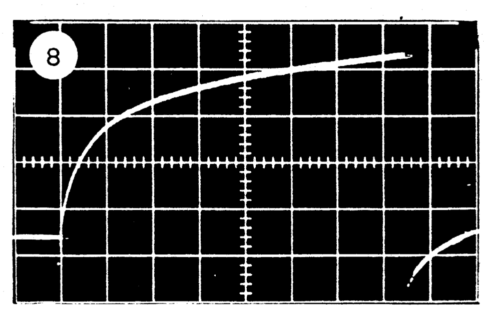




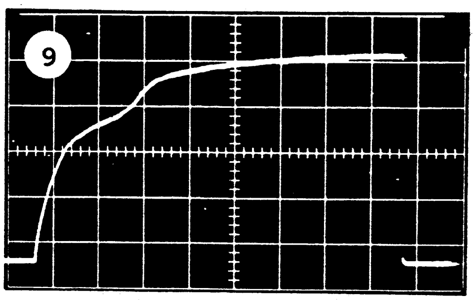


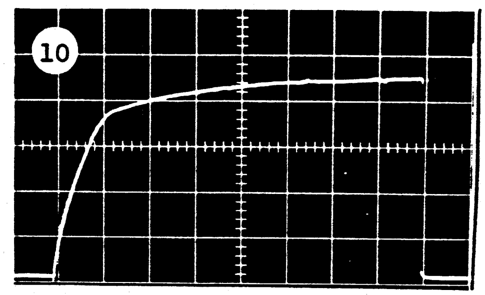
A bridgewire welded to each of two terminals creates a thermocouple junction at each weld. Bridgewire temperature changes generate thermal EMF signals across each weld. If the welds are equal, the two opposing EMF's cancel, with no discernable effect on the heating curve. However, if the welds are different, unequal EMF's generate a residual signal at the termination of the heating cycle as the bridgewire cools to ambient temperature. The decaying residual may be either positive (Figure 7) or, negative (Figure 8). A residual signal may be an abnormality to the extent that it is a possible indicator of a latent weld defect.



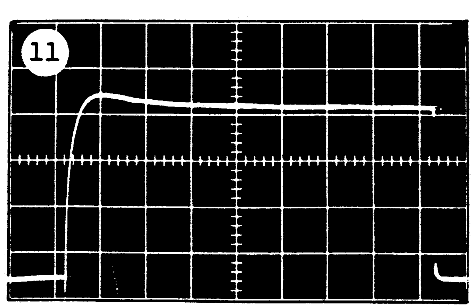


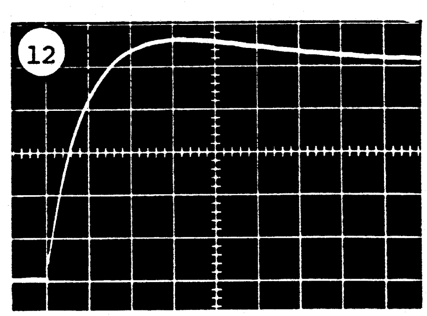
Bridgewire Movement - An air gap between the bridgewire and explosive material may permit bridgewire movement as the bridgewire expands and buckles, when heated. As the bridgewire moves, contact is made with the explosive material causing a change of rate of bridgewire temperature increase, creating a knee in the heating curve. Another potential cause of bridgewire movement is insufficient loading pressure. Bridgewire movement is minimized as the loading pressure is increased. Either air gaps, or insufficient compaction pressure may lead to bridgewire burnout before ignition is reached. Curves reflecting bridgewire movement are shown in Figures 9 & 10. Abnormalities related to bridgewire movement are thermally-induced, and occur well into the heating cycle; as indicated in the examples.



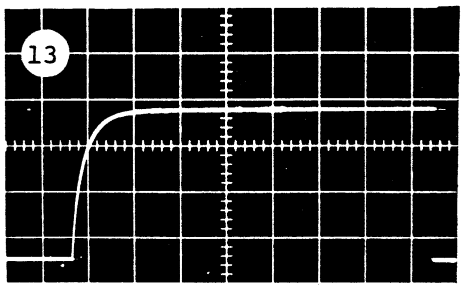


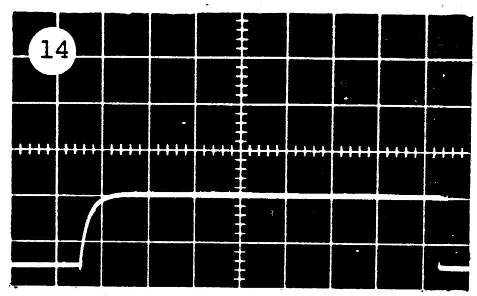
Phase Change - Acetone, MEK, and similar binder solvents, entrapped in explosive mixes can sink appreciable bridgewire heat as they undergo phase change (from liquid to gaseous state) at around 125°C, or so. The cooling effect of residual solvent is indicated in Figure 11, and Figure 12. Cooling starts immediately following the peak of the curves; as the curves begin to fall off. The implications of entrapped solvents are not generally appreciated; however, the condition may seriously affect control of EED sensitivity. It should be noted that the transient test is capable of detecting residual solvents in fully assembled units, as well as partially completed units.



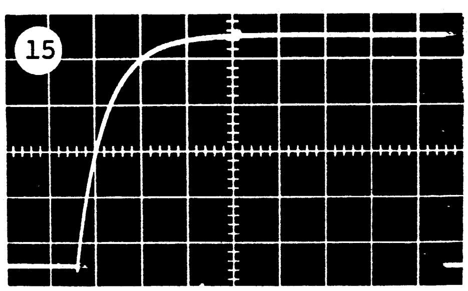


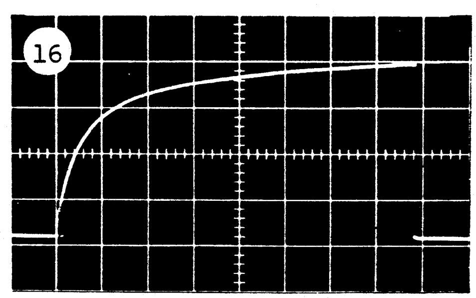
Loading Abnormality - The response of a bridged header without explosive is shown in Figure 13. A device of the same design, with explosive and tested at the same current level, is shown in Figure 14. Neither response is abnormal, as such. The intent is to illustrate the difference due to the absence of explosive. Absence of explosive must be defined as an abnormality in a population of assembled units.





Thermal Stabilization - Temperature rise of the interface tends to stabilize near the end of the primary response. A component with explosive pressed in intimate contact with the bridgewire will display little temperature rise, as in Figure 15. An assembly with lesser compaction will exhibit greater rise, shown in Figure 16. Whether a given rise is abnormal or not depends on its relation to other units of the same design in the test population.





Conclusions - The curves described in the preceding pages are typical, basic, and represent those most likely to cause functional problems. Not all possible faults have been covered. One should be alert to the possibility of multiple faults in a single test item. Items exhibiting abnormal responses should be viewed with suspicion and culled out. A knowledge of fault mechanisms and curve interpretation should lead to improved product reliability, and reduced development and production costs.

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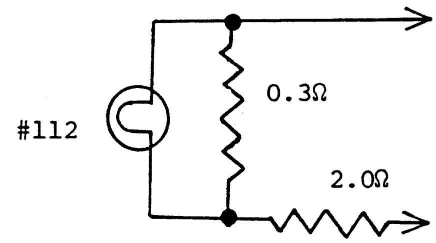
APPENDIX I

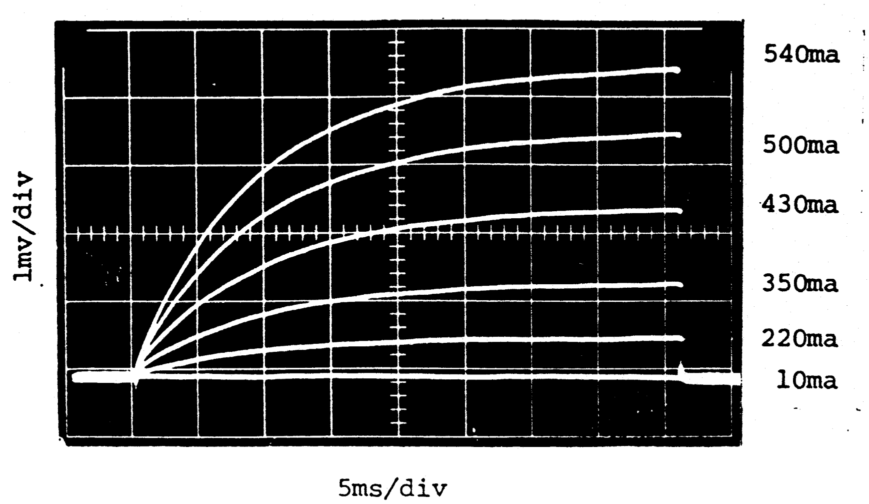
REFERENCE BRIDGEWIRE RB101

Reference Bridgewire RB101 is a thermally responsive resistor for use in checking the operation and performance of Series 605 Thermal Transient Test Sets. It also finds use as a training aid during 605 indoctrination and familiarization. In effect, the RB101 is a simulated bridgewire whose electrothermal response to test signals is similar to that of an operational bridgewire.

Components of the device include a #112 standard incandescent lamp in a two resistor network, shown below. Cold resistance (R_o) is in the range of 2.15 to 2.35 ohms. Maximum test current (I_{max}) is approximately 600 milliamperes. The device plugs into the 605 front panel "EED" terminals.



The figure below is a multiple exposure photograph of typical RB101 thermal response curves at several designated test current levels. Amplitude and slope of the curves of a particular RB101 may vary from the examples because of lamp filament material TCR and manufacturing tolerences.



APPENDIX A

CALIBRATION DATA

Figure A-1 is the Calibration Data Sheet for this unit.

Paragraph 1 gives the resistance of the current measurement resistor R401.

Paragraph 2 gives data on R202 and R203 to allow the operator to compensate for non-linearity of these controls by interpolation.

Paragraph 3 gives a remainder that the third decimal place of these measurements is unreliable.

Paragraph 4 gives the cold resistance of the detonator simulator RB-101 supplied with your test set as measured on both your test set and a Kiethley 191 meter.

CALIBRATION DATA SHEET FOR SERIAL #605-315

1. Resistor R401 in test set Serial #605-315 has a resistance of 0.968 ohms.

2. Resistance values of R202 and R203 are as follows:

For	Set X1 to
0.00 ohms	
1.00 ohms	0.980
2.00 ohms	1.970
3.00 ohms	2.961
4.00 ohms	3.940
5.00 ohms	4.940
6.00 ohms	5.940
7.00 ohms	6.917
8.00 ohms	7.915
9.00 ohms	8.920
10.00 ohms	9.950

Read X.1 (R203) directly and add to value in "For" column.

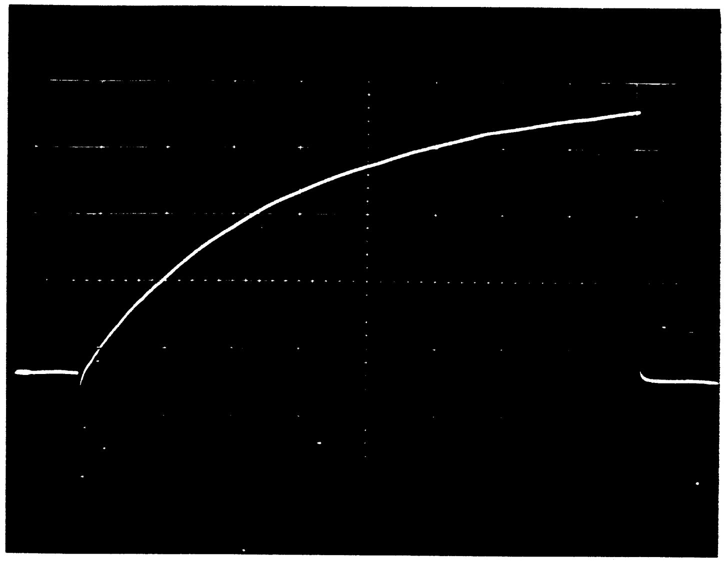
*The third decimal place in the setting of X1 is an "eye approximation" between the smallest divisions on the dial.

3. After nulling, add the indication of X.1 (R203) to the even ohm value set in paragraph 2 above.

   The third decimal place of an ohm is unreliable due to non-linearities and inaccuracies inherent in the test set. Round the final measurement to two decimal places.

4. RB-101 as measured on this Model 605B tester has a cold resistance of 2.220.

   RB-101 as measured on a Keithley 191 meter has a cold resistance of 2.225.



Measured on	Model 605B	SN315
RB-101 resistance	2.22 ohms	
Test Current	597 ma	
Vertical Scale	1 mv/cm	
Horizontal Scale	10 ms/cm	

CALIBRATION DATA SHEET FOR SERIAL #605B-332

1. Resistor R401 in test set Serial #605B-332 has a resistance of 1.005 ohms.

2. Resistance values of R202 and R203 are as follows:

For	Set X1 to	
0.00 ohms	0.037	
1.00 ohms	1.035	
2.00 ohms	2.041	
3.00 ohms	3.035	
4.00 ohms	4.037	Read X.1 (R203) directly and add to value in "For" column.
5.00 ohms	5.035	
6.00 ohms	6.029	
7.00 ohms	7.028	
8.00 ohms	8.029	
9.00 ohms	9.060	
10.00 ohms	-----	

*The third decimal place in the setting of X1 is an "eye approximation" between the smallest divisions on the dial.

3. After nulling, add the indication of X.1 (R203) to the even ohm value set in paragraph 2 above.

*The third decimal place of an ohm is unreliable due to non-linearities and inaccuracies inherent in the test set. Round the final measurement to two decimal places.

4. RB-101 as measured on this Model 605B tester has a cold resistance of 2.243 at a test current of 590 mA.

RB-101 as measured on a Keithley 197A meter has a cold resistance of 2.242.

! ! ! WARNING ! ! !

**OBSERVE APPROPRIATE SAFETY PRACTICES
WHILE PERFORMING THESE TESTS**