Bridgewire Temperature Estimation Using a Constant Current Supply

L. Weinman
Luna Tech, Inc., 148 Moon Drive,
Owens Crossroads, AL, 35763, USA

A brief description is presented of a means of measuring the *average* temperature of a bridgewire during firing using a constant current source.

Many functional tests of electroexplosive devices, such as electric matches, utilize a constant current power supply as part of the firing circuit, as this is the only way to comply with many specifications that call for functional testing to be done at a specified current. Frequently, if a constant voltage source is used, the change in resistance of the bridgewire during heating will put the current out of the specification tolerance. This is often the case when producing electroexplosive devices for the military and aerospace customers.

A simple constant current supply is shown in Figure 1. The operation of this circuit is as follows: When some reference voltage is supplied to the "+", non-inverting, input of the operational amplifier, A1, a voltage is produced at A1-Eout; this voltage produces a current in fixed resistor R1. This produces a voltage, referenced to ground that is fed back to the "–",

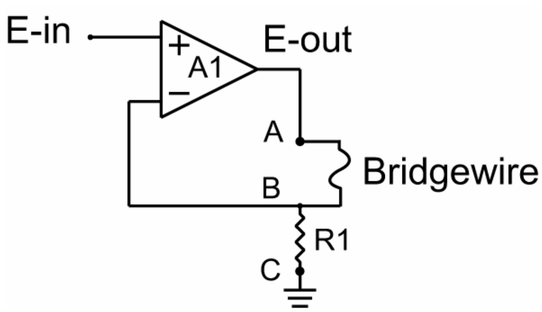

Figure 1. Basic constant current circuit.

inverting, input of A1. This "–" feedback input acts to maintain the output voltage, and thus current through R1, at a constant value. If the circuit and components are correct, the supply will accommodate a wide range of resistance in the bridgewire and still maintain a constant current through R1, and thus through the bridgewire. If the resistance of the bridgewire is not fixed but varies with temperature, the constant current supply must vary its output voltage to accommodate the total resistance of the load by maintaining a constant current through R1.

Figure 2 shows a more realistic circuit for bridgewire temperature measurements. Transistor Q1 serves to supply more current than would most operational amplifiers. Amplifiers A2 and A3 and their associated components will allow the nulling out of most of the testing voltage and then amplification of the portion of the voltage above the level that has been nulled out. Note that this circuit serves only to illustrate how these sorts of operations are performed. In the data presented, the author used a 12-bit digital oscilloscope, and a "simple" constant current supply. If, as an example, the voltage across the bridgwire had first been 1V, and then risen 6%, the range of the instrument would have to have accommodated approximately 1.06 volts. If some circuitry were to have been utilized that allowed nulling-out/subtracting the original 1 volt starting value, then the oscilloscope could have been set to accommodate only, perhaps, 0.1 volt. This would have allowed greater precision in the measurements taken.

Most materials used as resistors have some temperature coefficient associated with them. If they are made of the common "resistance" bridgewire alloys, such as the various platinum or Ni/Fe alloys, the resistance coefficient is positive. This results in the resistance of the bridgewire increasing as its temperature increases. Because the constant current supply depends on the resistance of R1, it is important that the resistance of R1 remain constant during testing. This may usually be accomplished by having the thermal mass of R1 be "large", or the temperature coefficient of resistance be very small. In practice, typically a 1 ohm, 10–20 watt power resistor will remain sufficiently constant during the occasional short and moderate amperage pulse used to function the typical hot bridgewire electroexplosive device, and it will provide a suitably stable feedback for the operational amplifier.

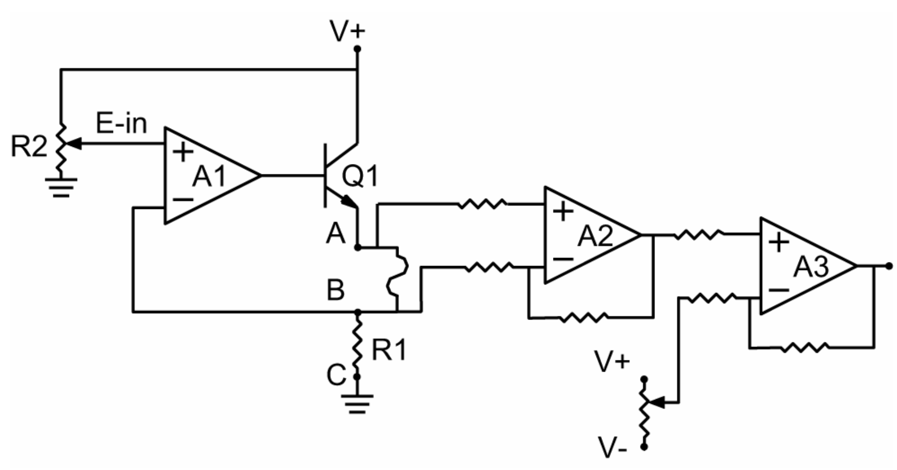

Figure 2. Example circuit showing high current, amplification, and nulling, capabilities

Because the resistance of R1 is constant and known, a voltage measurement from point B to point C can be used to calculate the current flowing in both R1 and the bridgewire. Similarly, a measurement of the voltage from point A to point B along with the known current allows one to calculate the resistance of the bridgewire. However, for the present purpose, using only the voltage will do, as it is proportional to the resistance of the bridgewire and therefore to the temperature of the bridgewire.

For most bridgewire materials, the resistance of the bridgewire is some reasonably smooth function of its temperature. Based on that fact, one can calculate the temperature of the bridgewire assuming the temperature prior to heating is known. The temperature will be determined from the ratio of the starting resistance (voltage) to the "final" resistance (voltage) plus the starting temperature.

Note that there are some potentially important factors that are extremely difficult to determine. There are, among others, thermal end effects, where the bridgewire loses heat to its contacts, and a possibly non-homogenous thermal environment caused by "bubbles" or non-uniform pressing, which may make the temperature change of any particular portion of the bridgewire difficult to determine with accuracy, since all that can actually be measured is the *total resistance change.*

Table 1 presents data for five electric matches taken near the beginning of the firing pulse and showing the voltage across the bridgewire. The first column shows the time, including some points prior to the onset of the firing pulse (shown as time 0.0000). The next five columns are voltages across the bridgewire for each of the matches. Then an average of these voltages is given, followed by the calculated temperature based on the average. The last column is the temperature smoothed using a Savitsky-Golay method. The temperature for each data point V_x is calculated by selecting the first low stable voltage reading (V_o) after the beginning of the firing pulse and before the bridgewire has heated significantly, then

$$T_x = T_0 + \left(\frac{V_x}{V_0} - 1 \right) \alpha$$

where, α is the temperature coefficient of the bridgewire material.

To avoid extreme artificial excursions caused by the smoothing algorithm, the values prior to V_o were set to ramp up to T_0 from zero. In data in Table 1, the time selected for V_o = 0.00006 (*), or 60 microseconds after the leading edge of the firing pulse which triggered the

Table 1. Data for Five Electric Matches Showing the Voltage across the Bridgewire.

Time s	Match 1 V	Match 2 V	Match 3 V	Match 4 V	Match 5 V	Average V	Temp. °C	Smoothed °C
–0.00004	–0.0002	–0.0000	–0.0000	–0.0001	–0.0000	–0.0001	0	1
–0.00002	–0.0002	–0.0000	–0.0000	–0.0001	–0.0000	–0.0001	0	3
0.00000	0.9773	0.0004	–0.0005	0.7679	0.6260	0.4742	5	6
0.00002	0.7618	0.8335	0.7659	0.7759	0.8085	0.7891	10	10
0.00004	0.7913	0.7859	0.7779	0.7959	0.8325	0.7967	15	14
0.00006*	0.7888	0.8074	0.7874	0.7919	0.8200	0.7991	20	19
0.00008	0.7868	0.8054	0.8014	0.7874	0.8145	0.7991	20	25
0.00010	0.7938	0.8019	0.7975	0.7914	0.8180	0.8005	32	28
0.00012	0.7968	0.7984	0.7919	0.7959	0.8225	0.8011	37	32
0.00014	0.7928	0.8035	0.7934	0.7939	0.8200	0.8007	33	35
0.00016	0.7913	0.8049	0.7984	0.7929	0.8200	0.8015	40	35
0.00018	0.7943	0.8014	0.7954	0.7924	0.8195	0.8006	33	37
0.00020	0.7928	0.8014	0.7944	0.7939	0.8200	0.8005	32	38
0.00022	0.7923	0.8059	0.7984	0.7949	0.8200	0.8023	47	39
0.00024	0.7958	0.8014	0.7954	0.7919	0.8215	0.8012	38	41

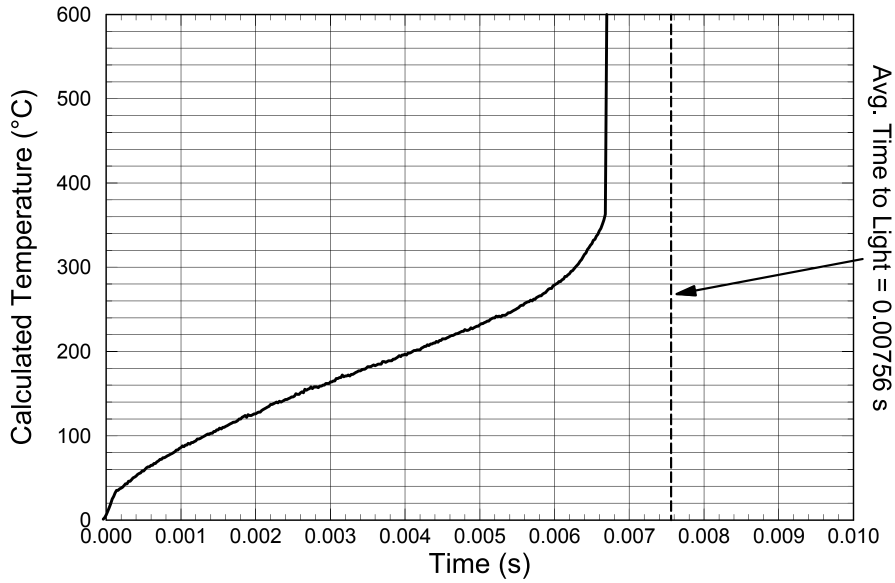

Figure 3. Test data for average of 5 electric matches.

oscilloscope to begin storing data (s = 0.0). T_o was selected by inspection of the unsmoothed average data prior to smoothing.

Tests 1 and 2 show the graphed results of tests using two different production lots of a potassium chlorate-based bridgewire composition. These lots differed, only slightly, in the method of application to the bridgewire.

In Test 1 (Figure 3), it appears that the thermal environment of the bridgewire was quite uniform and the composition adhered well to the wire. Notice that there is almost linear heating until about 275 °C when a change in slope occurs. This slope change may indicate either a decomposition of the nitrocellulose binder used or a thermal decoupling of the composition from the wire. At about 350 °C there is a very abrupt change in slope, which may indicate either a severe decoupling, or (fortuitously) the chlorate decomposition/reaction onset.

In Test 2 (Figure 4), the binder decomposition, or thermal decoupling, seems to begin at a somewhat lower temperature. There is a longer period of more rapid heating until about 425 °C and then another abrupt slope up.

Of course, in both cases, these are the present interpretations of the author and may not be necessarily correct.

The vertical dotted lines, in both figures, show the average time to light output indicating "function time" average for the electric matches as determined by a signal produced by a Schottky diode reacting to the light output from the match.

This general technique has also been used to determine the "goodness" of bridgewire attachment welds and to look for defects in the bridgewire, and is mandatory for some military and aerospace devices. In these cases, the stimulus is usually supplied in a short high current pulse, insufficient to cause firing, and the resultant heating causes an elongation and movement in the bridgewire which results in a "ragged" trace that may then be compared to known good traces.

One should not, at least under the test conditions used by the author, rely very much on the calculated temperature values being accurate. However, this general technique may prove useful in finding differences between items, and it adds another tool to the pyrotechnist investigators' armentarium.

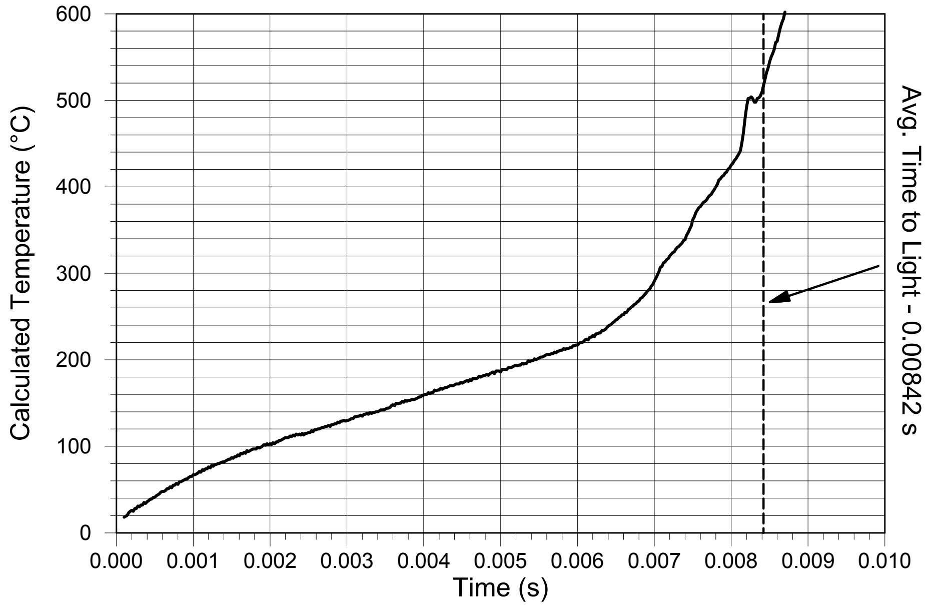

Figure 4. Test data for average of 10 electric matches.