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THE SPARK CALORIMETER

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1. INTRODUCTION

- 1.1 A spark calorimeter is an instrument used to measure the average spark energy (joules/spark) of an ignition system across the igniter gap.

2. THEORY OF OPERATION

- 2.1 "Energy" is defined as the capacity to perform work. In an ignition system the spark manifests itself as the rapid release of the stored or developed electrical energy at the igniter. This rapid energy release is in the form of thermal energy which the calorimeter measures.
- 2.2 When such an energy release (spark) is confined in a spark bomb, the heating component of the spark warms the bomb air which in turn is transferred by radiation, convection, and/or conduction to the bomb walls. If this bomb is enclosed by a perfect thermal insulator, the bomb wall temperature will rise proportionally to the thermal energy dissipated internally. All measurements are made when temperature equilibrium is reached within the bomb. If all the thermal characteristics of the components are known, it is possible to calculate the generated thermal energy. However, there are many aspects of the components and the calorimeter which make direct calculations impossible.
- 2.3 A practical method, which provides precision results, is to place a resistor in the bomb through which accurately measured current and voltage can be passed. This resistor is a heating element which causes the chamber to be heated in a similar fashion to that of the spark. Since the current and the voltage can be measured accurately, then the power or energy dissipated in the chamber can be calculated very easily and accurately. By comparing the temperature rise (measured by thermocouples and a potentiometer) due to the spark against calibration curves at various power levels, the energy released to give this rise can be determined. If the number of sparks providing this rise is known, then the energy per spark can be computed very accurately.
- 2.4 Assume that housed internally in the calorimeter is a spark bomb consisting of masses M1, M2, M3, M4, etc. and associated with each mass are their respective specific heats C1, C2, C3, C4, etc. When temperature equilibrium is reached, all components see the same temperature change (ΔT). The heat therefore absorbed to provide this change, ΔT , is then given by the equations:

$$Q = M1 \ C1 \ \Delta T + M2 \ C2 \ \Delta T + M3 \ C3 \ \Delta T + M4 \ C4 \ \Delta T + \dots \quad (1)$$

$$\text{or } Q = [M1 \ C1 + M2 \ C2 + M3 \ C3 + M4 \ C4 + \dots] \ \Delta T \quad (2)$$

In the above equations -

Q = quantity of heat in joules,

M_1 , etc. = component masses in grams,

C_1 , etc. = component specific heats in joules/grams C, and

ΔT = temperature change in C.

- 2.5 If all components are equally insulated from the outside, then equation 2 shows that it is of little importance which element produces the heat. When temperature equilibrium is reached, all masses are at the same temperature; therefore, this eliminates the consideration of which component produced the heat.
- 2.6 In actual spark bomb calorimeters all components are not equally insulated from the external surroundings. Under this condition, when heat is being produced, losses vary from component to component; therefore, errors will develop depending on which component is the heat producer. In most cases this error is considered negligible.

3. TEST METHOD

- 3.1 Figure I shows the calorimeter and associated equipment as used in spark energy measurements.
- 3.2 Figure II is a block diagram showing the arrangement of this equipment used in the measurements.
- 3.3 Figure III is a drawing of the calorimeter.
- 3.4 Figure IV is a cross sectional view of the calorimeter head assembly.
- 3.5 Figure V shows the assembled igniter spark bomb.
- 3.6 Figure VI shows a cross sectional view of a spark bomb.
- 3.7 Figures VII through XI are detail drawings of the bomb components.
- 3.8 Figure XII shows a typical calibration curve for a particular igniter tip configuration.
- 3.9 As described previously, the number of watts dissipated as heat energy may be accurately calculated if the amperage and voltage applied to the resistor is known.
- 3.10 A known quantity of heat energy, produced by the resistor, is compared with an unknown quantity of heat energy, produced by an ignition gap, provided conditions such as time of operation and characteristics of surroundings are unchanged.

- 3.11 The bomb, Figures V and VI, in this calorimeter contains a resistor which is used to provide a known amount of heat energy. In the bomb, near the resistor, is an appropriate igniter tip to be operated by whatever system is being tested. The bomb is insulated and placed in an insulating flask so that the thermal leakage is minimized. The flask also protects the bomb from sudden changes in temperature.
- 3.12 Supplying power to the resistor will result in an increase in millivolt reading of the two thermocouples located in the insulating flask. The "bomb" thermocouple, attached directly to the bomb, will show a fairly large increase in millivolt reading. The "ambient" thermocouple, attached to the inside of the insulating flask but out of contact with the insulated bomb, will show a much smaller increase in millivolt reading. Hereafter, "ambient temperature" will mean the ambient temperature of the flask, not the external temperature. This change in readings is proportional to the joules per second dissipated, or heat energy. As greater amounts of heat energy are released with increasing voltage and amperage, greater changes in millivolt readings will be produced. This fact is useful for measurements only when each run is performed in the same manner as all others.
- 3.13 This means cycles of the same length, and always the same number of cycles per run. As the millivolt reading is directly proportional to temperature, the larger the millivolt reading, the higher the temperature. Large changes in millivolt readings indicate large changes in temperature.
- 3.14 The calorimeter calibration is obtained by several normal runs. This calibration determines the change in millivolt reading that will be produced by a given amount of heat energy, or joules/second, over a certain time in the bomb. After several runs a graph (Figure XII) may be plotted which will show clearly the simple relationship between the heat energy in joules/second and the total change in "bomb" millivolt reading.
- 3.15 After the calibration graph has been completed, the test gap comes into the operation. The spark measurements are made with no change in the bomb. An ignition unit is connected to the gap and operated for the same length of time, in the same set of cycles, as the resistor was for all the calibration runs. Obviously, the spark will heat the bomb. The heat will produce a change in the "bomb" millivolt reading as the heat from the resistor did, and this change will be proportional to the energy released. At the end of the run, the total change in "bomb" millivolt reading is calculated and this change is compared with the curve on the calibration graph to determine the equivalent joules/second dissipated by the spark.
- 3.16 One run is made for each measurement. The only change which occurs is the spark rate. Other controllable quantities are held constant. For the purposes of uniformity and accuracy all test run cycles and periods are held constant.

4. STABILIZATION PROCEDURE

- 4.1 Before each run, the bomb and flask temperatures must be equal. If they are not, the warmer one will cool off and the cooler one will warm up. These changes cannot be separated from the changes produced by the spark gap and will produce erroneous results, especially for low spark energies.
- 4.2 If over a period of ten minutes the "bomb" and "ambient" millivolt readings remain unchanged within two microvolts, the bomb and flask are well stabilized. However, if not, the test results will be inaccurate by the resulting drift, and cannot be considered.
- 4.3 The detailed directions described here assume the use of the standard run, which consists of six cycles, each cycle consisting of a two-minute operating period followed by one minute off.
- 4.4 It is necessary that the calibration of the potentiometer be checked before each test run.

5. CALIBRATION PROCEDURE

- 5.1 Connect all associated apparatus; then set panel switch to calibrate.
- 5.2 Fill reference temperature vacuum bottle with cracked ice and water.
- 5.3 Adjust the rheostat for the required wattage, as read from the ammeter on the calorimeter panel. The first calibration run should be at 0.5 watt, later runs greater by 0.5 watt increments. For powers of over 6 watts use 1 watt increments. With the apparatus and operating cycle described, the calorimeter has a maximum power rating of 20 watts. This rating is derived from the temperature rise in the bomb, and the temperature gradient on the insulation and other fabricating materials.
- 5.4 Set the timer for the desired cycle of operation, normally two minutes on, and one minute off. Set to repeat cycles. Turn off the timer.
- 5.5 Allow 10 minutes minimum for "bomb" and "ambient" temperatures to stabilize. Flask must be closed and sealed. At the end of this period, the millivolt readings should agree within 2 microvolts.
- 5.6 Record bomb millivolt readings.
- 5.7 Set timer on "off" cycle, turn on heater power supply and switch.
- 5.8 Turn on all parts of the equipment, allow timer to start cycle.
- 5.9 At the end of a test run record the "bomb" temperature.

- 5.10 After this reading is completed turn off the timer and heater switches.
- 5.11 Bring temperature back to its initial value by circulating external air into flask.
- 5.12 Subtract from the initial millivolt reading the reading at the end of the test run.
- 5.13 Record the resulting temperature rise and calculate the wattage producing the rise.
- 5.14 Repeat steps 5.1 through 5.13 for other energy levels.
- 5.15 Develop a curve with power (or joules/second) as the axis of the abscissa and temperature rise on the ordinate axis from the data obtained in steps 5.1 through 5.13.

NOTE: A calibration curve is good only for the set of timer cycles used in the calibration runs. If the timing periods are changed, then an entirely new curve must be plotted.

6. OPERATION PROCEDURE

- 6.1 Connect all associated equipment, including the ignition system, to be tested. Set the timer switch to operate.
- 6.2 Follow Calibration Procedure exactly for steps 5.2 and 5.4 through 5.6.
- 6.3 Set timer on "off" cycle, turn on all equipment including the ignition system to be tested. Allow timer to start the first cycle.
- 6.4 Follow Calibration Procedure steps 5.9 and 5.10. Record number of sparks.
- 6.5 Using the calibration graph, determine the watt value corresponding to the measured temperature rise.
- 6.6 Calculate as shown in the following example:

As a typical example of spark energy measurements, assume that the temperature rise due to sparking is equivalent to 2.5 watts for 12 minutes of operation. The energy (J) expended in the calorimeter is