

Oscillographic Method for Measuring Spark Energy of Capacitor Discharge Ignition Systems

1. INTRODUCTION:

The efficiency of any electrical machine is the ratio of the output to input and is generally expressed in per cent. In the case of ignition systems the input power can be supplied from a battery, 115, volt, 400 cycle generator or an engine driven alternator which is integral to the ignition system. Regardless of the input power source, the ignition unit functions to form this power into a spark for the ignition of combustible mixtures. A spark between two electrodes (igniter plug electrodes) is the most acceptable way for igniting a combustible mixture. The wide variation of the combustible mixtures found in the region of the igniter plug electrodes compels manufacturers to provide a wide variation in ignition systems. The design parameters of the ignition system (spark rate per second, spark energy, duration of the spark) are generally arrived at by empirical engine testing. Thus it is very important that means be provided for testing the energy of the spark independent of the final system application.

Various methods can be utilized for testing spark energy. The method described herein has the following advantages:

- (a) It can be used in conjunction with a complete system where internal circuitry components are not accessible.
- (b) It measure the voltage across the igniter plug electrodes and the current which flows through the spark plasma, thus assuring an accurate spark energy measurement.

2. PROCEDURE FOR SPARK ENERGY MEASUREMENTS:

(a) Current Measurement

The apparatus is set up as per Figure 1 and Figure 2. Allow approximately 20 minutes warm up time for the oscilloscope to stabilize. Set the 'Vertical Amplifier A' to obtain the maximum vertical deflection of the waveform within the linear response of the oscilloscope.

Set the 'Triggering Mode' switch to 'A.C. Slow'.

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Set the 'Triggering Slope' control to positive, if the initial slope of the current waveform is positive. Negative, if it is negative.

Place the 'Stability' and 'Triggering Level' controls fully clockwise.

Rotate the 'Stability' control slowly counterclockwise until the sweep just ceases to appear on the oscilloscope screen.

Rotate the 'Triggering Level' control counterclockwise until the zero level of the leading edge for the current waveform is obtained. (Be sure it is the leading edge for the beginning of current flow).

Set the 'Time/cm.' and 'Multiplier' controls to allow all the current waveform to appear on the screen.

Take a picture of the resultant waveform including the screen grid lines. A minimum of 5 superimposed waveforms should be taken. See Figure 5A.

(b) Voltage Measurement

Change the apparatus setup to agree with Figure 3 and Figure 4 for the voltage waveform recording.

The oscilloscope 'Vertical Amplifier B' is now in use.

Keep the 'Triggering Mode', 'Time/cm.', and 'Multiplier' controls the same as during the current measurement.

Adjust the 'Vertical Amplifier B', 'Triggering Slope', 'Stability' and 'Triggering Level' controls as previously outlined.

Record the waveforms of the voltage drop across the spark. A minimum of 5 superimposed waveforms should be taken, see Figure 5B.

It is important to keep the zero voltage level of the sweep at the zero reference for all pictures taken.

(c) Power Curve Formation

Place the current waveform picture in the Opaque Picture Projector.

Project this picture of the current waveform onto 10 x 10 graph paper. (Deitzen No. 340A)

Line up the projector such that 1 cm. on the picture represents 1 inch on the graph paper.

Line up the current waveform vertical zero reference to a corresponding zero reference line on the graph paper.

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Line up the current waveform horizontal starting reference to a corresponding reference on the graph paper.

Trace the current waveform. The center of the width of the trace is followed in the tracing.

Remove the current waveform picture from the projector. Place the voltage waveform picture into the projector.

Line up the voltage waveform vertical zero reference with the corresponding zero reference of the current waveform on the graph paper.

Line up the voltage waveform horizontal position such that the voltage and current zeros must be coincident. If not coincident it indicates that the voltage or current measurements have not been properly made.

Trace the voltage waveform. Trace the center of the most prominent waveform. See Figure 5B and 6

Multiply the current and voltage waveform tracings together. Multiply vertical amplitude at each .1 inch time interval. The time intervals are in the horizontal direction.

Plot a volt-ampere (power) curve from the resultant data. See Figure 7.

(d) Calculation of Spark Energy

Integrate the area under the power waveform with the planimeter.

Calculate the energy per spark from the formula:

$$J = \frac{e_i e_v K_v A t}{R}$$

e_i = Amplifier 'A' calibration for the current waveform (volts/cm.)

e_v = Amplifier 'B' calibration for the voltage waveform (volts/cm.)

K_v = Voltage divider multiplying factor

t = Oscilloscope sweep setting (seconds/cm.)

R = Resistance of the Current Viewing Resistor Adapter (ohms)

A = Total square inches of area under the power curve.

Using the above formula and obtaining the respective information from the enclosed data:

$$J = \frac{2 \times .5 \times 100 \times 6.31 \times 50 \times 10^{-6}}{.00656}$$

$$J = 4.8 \text{ joules per spark}$$

3. SUMMARY:

A spark energy measurement procedure has been given which follows the formula:

$$J = \int_0^T V_g i dt$$

J = Joules/spark

V_g = Voltage drop across the spark

i = Current flow through the spark

T = Time in seconds

This method can be used with any present ignition system of the capacitance discharge nature which is currently being manufactured.

This method described above was found to agree very closely with the calorimeter and other methods of spark energy measurement.

4. REQUIRED INSTRUMENTATION:

The equipment necessary to measure spark energy consists of the following apparatus:

1. Oscilloscope
2. Voltage Divider
3. Current Viewing Resistor Adapter
4. Igniter Plug Voltage Measurement Adapter
5. Oscillographic record Camera
6. Opaque Picture Projector
7. Planimeter

5. DESCRIPTION OF THE APPARATUS:

1. The Oscilloscope: - A Tektronix type 531 oscilloscope which includes accurately calibrated vertical amplifiers and horizontal sweep circuits. The plug-in unit is type 53/54C.
2. The Voltage Divider: - This voltage divider is similar to the design in AIR NO. 84 with modifications. The attenuation ratio is 100:1. The input impedance is 1 megohm and 5 mmf. The rise time is approximately .3 microseconds. See Figure 8 for installation drawing.
3. The Current Viewing Resistor Adapter: - A variety of these adapters is shown in Figure 9. The purpose of the adapters is to permit the current viewing resistor (Figure 10) to be inserted into the discharge circuit between the igniter plug lead and the igniter plug. The resistor is coaxially constructed and is mounted in the ground return path of the ignition system. The impedance characteristic of this unit is flat and resistive up to one megacycle. (See Figure 11 for a simplified theoretical analysis). The only insertion effect that this adapter has on the discharge system is a slight increase of the igniter plug lead length.

4. The Igniter Plug Voltage Measurement Adapter: - This adapter (Figure 12) permits the measurement of the voltage drop across the igniter plug spark plasma. It makes contact to the center electrode and the shell of the igniter plug.
5. The Oscillograph Record Camera: - This is a DuMont type 302 using Polaroid film #44.
6. The Opaque Picture Projector: - This is a combination of a Viewlex slide projector and its opaque picture projector adapter.
7. The Planimeter: - This is a Keuffel and Esser 4236M. This integrates in square centimeters.

6. GLOSSARY OF TERMS:

Symbols:

a	- radius of the outer surface of the inner conductor
A_i	- cross sectional area of the inner conductor in square meters
A_o	- cross sectional area of the outer conductor in square meters
b	- radius of the inner surface of the outer conductor
C	- capacitance in farads
E	- voltage
f	- frequency in cycles/sec.
I_{in}	- input current
I_{out}	- output current
J	- joules per spark
K	- relative dielectric constant of region between inner and outer conductors. $K = 1$ for air.
K_s	- permeability and skin effect constant
L	- inductance in henrys
l_i	- length of the inner conductor in meters
l_o	- length of the outer conductor in meters
$P1, P2$	- potential pickup points for the current viewing resistor
R_{ac}	- effective resistance of the resistor with A.C. signal applied
R_{dc}	- resistance of the resistor with D.C. applied
R_i	- resistance of the inner conductor
R_o	- resistance of the outer conductor
T	- thickness of tubular conductor in inches
Z_t	- total impedance
P	- resistivity of the conductor material at any temperature
P_c	- resistivity of copper at 20 C (1.724 microhm-centimeter)
ρ	- resistivity of the conductor in meter-ohms
μ_r	- relative permeability of conductor material ($\mu_r = 1$ for copper and other non-magnetic materials)
ω	- $2 \pi f$

7. BIBLIOGRAPHIES:

- (1) Electric Transmission Lines - Skilling
- (2) Reference Data for Radio Engineers - Fourth Edition, International Telephone and Telegraph Corp.
- (3) Shunts and Inductors for Surge Current Measurements - John H. Park N.B.S. Research Paper RP1823
- (4) N.B.S. Reports Nos. 2158, 2451, 2705, 2871, 3066
- (5) Apparatus for Producing and Measuring High Energy Electrical Discharges - Charles J. Cook ASTIA-AD*100653

Cross Reference

AIR77, Spark Energy Measurements Using Oscilloscopic Methods

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