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AEROSPACE RECOMMENDED PRACTICE

ARP 1278

Issued June 1978
Revised

OSCILLOSCOPIC METHOD OF MEASURING SPARK ENERGY

PURPOSE This report provides specific information on instrumentation and procedure for the measurement of capacitance discharge spark energy using an oscilloscope.

SCOPE This report describes basic method for measurement of spark energy on all types of capacitance discharge exciters. Reference is made to other methods which may be used if limitations are observed.

1. INTRODUCTION

- 1.1 A spark between two igniter plug electrodes is the most common and accepted way of igniting a combustible mixture. Wide variations of the combustible mixture and its characteristics are found from combustor to combustor. The design parameters of ignition systems, particularly spark energy, are generally arrived at by empirical testing. Thus it is very important that a means be provided for testing and identifying the magnitude and characteristics of a particular spark.
- 1.2 The oscilloscopic method of measuring spark energy described in this report has been shown to agree satisfactorily with the spark calorimeter described in AIR 885. The oscilloscopic method in addition allows identification of the peak power, time duration and power envelope of the spark. Also test readings may be taken in a relatively short time.
- 1.3 It is sometimes desirable to periodically examine production or service exciters to determine their discharge energy capability. Recommendation is made that short circuit discharge current will provide the necessary information of exciter health.
- 1.4 There are several variations of the oscilloscopic method of measuring spark energy in use. While all of these provide relative spark energy data, most have limitations that preclude use on certain ignition circuits such as the "unipolarity discharge." To aid the occasional user and provide a base for definition, the sequential voltage and current measurement is presented as the general method.
- 1.5 Other methods such as the simultaneous and chopped mode measurements are identified and their primary limitations noted.
- 1.6 Instantaneous electronic multiplication of discharge current and voltage and the use of computer techniques are recognized as extensions of energy measurement technique. Such methods that can be shown to correlate with the results of paragraph 2. or AIR 885 may be used.

2. BASIC PROCEDURE FOR SPARK ENERGY MEASUREMENTS

The discharge current and igniter arc voltage are measured in separate setups to eliminate any possibility of ground loops or frequency response problems. The resulting sequential voltage and current traces are superimposed and the power discharge curve formed.

This Aerospace Recommended Practice was upgraded from an Aerospace Information Report by Committee action April, 1978.

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2.1 Discharge Current Measurement:

- 2.1.1 The apparatus is set up as per Fig. 1. Allow approximately 20 minutes warm-up time for the oscilloscope to stabilize.
- 2.1.2 Set the input amplifier channel selector to the channel being used and adjust the vertical amplifier to obtain maximum deflection of the waveform within the linear response of the oscilloscope.
- 2.1.3 Set the triggering mode switch to the most stable and sensitive position.
- 2.1.4 Set the "triggering" slope control to positive, if the initial slope of the current waveform is positive, negative if it is negative.
- 2.1.5 Place the stability control fully clockwise.
- 2.1.6 Place the "triggering" level control fully clockwise for positive going slopes and counter-clockwise for negative.
- 2.1.7 Rotate the stability control slowly counter-clockwise until the sweep just ceases to appear on the oscilloscope screen.
- 2.1.8 Rotate the triggering level control counter-clockwise if positive, clockwise if negative, until the zero level of the leading edge of the wave form is obtained.
- 2.1.9 Adjust the time/major division and multiplier controls to give maximum deflection of the waveform but keeping within the linear portion of the screen.
- 2.1.10 Take a picture of five consecutive traces of the resultant waveform including the screen grid lines. Refer to Fig. 2 for typical discharge current waveforms.

2.2 Arc Voltage Measurements:

- 2.2.1 The apparatus is set up as per Fig. 3. Allow warm-up time per 2.1.1 if necessary.
- 2.2.2 Follow procedures outlined in 2.1.2 through 2.1.9 with the following additions:
 - a. Use the same zero reference points and sweep setting as used for the current waveform.
 - b. Adjust, if necessary, the polarity of the waveform (normal-invert control) to produce an apparent 180° phase difference from the current waveform.
- 2.2.3 Recheck zero reference points and take a picture of five consecutive traces of the resultant waveform including the screen grid lines. Refer to Fig. 4 for typical arc voltage waveforms.
- 2.2.4 Current and voltage waveforms may be photographed on individual films or taken superimposed on the same film. Taking superimposed waveform pictures is a common procedure to those familiar with oscillographic technique.

2.3 Power Curve Formation:

- 2.3.1 Place the waveform picture in an opaque picture projector. This will have to be repeated if the current and voltage waveforms are on separate pictures. The zero level and zero time points at the leading edge of both waveforms must be carefully superimposed.

- 2.3.2 Project the picture of the waveforms onto 10-square-to-the-inch graph paper (Dietzgen No. 340A or equivalent).
- 2.3.3 Line up the projector such that one major grid line (usually on centimeter) on the picture represents one inch on the graph paper.
- 2.3.4 Line up the waveforms vertical zero and horizontal zero references to the corresponding zero reference lines on the graph paper.
- 2.3.5 Trace the waveform (both current and voltage). The center of the width of the consecutive traces is followed in the tracing.
- 2.3.6 Multiply the current and voltage waveforms together. Multiply vertical amplitude at each 0.1 inch time interval on the horizontal axis.
- 2.3.7 Plot a volt-ampere (power) curve from the resultant data.

See Fig. 5 for typical power curve data.

Note: Multiplication of the voltage and current curves and subsequent area calculation for energy may be accomplished by computer techniques directly from the photographs eliminating the projection step.

2.4 Calculation of Spark Energy:

- 2.4.1 Integrate the area under the power waveform with the planimeter.
- 2.4.2 Calculate the energy from the formula:

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

J = Arc Energy (Joules/Spark)

e_i = Amplifier Calibration for the Current Waveform (volts/major div.)

e_v = Amplifier Calibration for the Voltage Waveform (volts/major div.)

K_v = Voltage Divider Multiplying Factor

t = Oscilloscope Sweep Setting (second/major div.)

R = Resistance of the Current Shunt (ohms)

A = Total Area under the Power Curve

2.5 Description of Equipment:

- 2.5.1 **General:** Selection of oscilloscope, plug in unit, voltage adapter, voltage divider, and current shunt should be such that their combination, whether measuring discharge current or arc voltage, has a rise time which is 0.1 times the rise time to be measured and a band width which is at least ten times the frequency of the parameter being measured.

- 2.5.2 Oscilloscope and Amplifier: Tektroniz 530 or 540 series or equivalent which includes accurately calibrated vertical amplifiers and horizontal sweep circuits. The plug-in is type 1A1 or equivalent.
- 2.5.3 Current Shunt: The insertion of the current shunt should have minimum effect on the discharge circuit. A basic four terminal coaxially constructed resistor is satisfactory if the impedance characteristic is flat and resistive to one megacycle. Typical resistance value should be 0.005 ohms. Lower values such as 0.001 will eliminate any question of insertion loss in all cases.
- 2.5.4 Igniter Voltage Adapter: This adapter 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. The needle contact, contacting the center electrode must be enclosed in an insulating sleeve. Certain igniter tip configurations will give erroneous results due to disturbance of the arc. In these cases an igniter can be modified to obtain connection to the center electrode through the side of the plug. This connection should be as close as possible to the arc, preferably not more than one inch from the igniter firing tip.
- 2.5.5 Voltage Divider: The voltage divider must withstand the igniter ionization voltage (up to 25 KV) and yet measure the igniter arc voltage (approximately 75 volts). To accomplish this, isolation of 25 KV and an attenuation ratio of 100:1 or less is desirable. The 25 KV isolation is not necessary for low tension systems and clipping or other means of suppression may be used on high tension systems.
- 2.5.6 10 K Resistor: A 10 K resistor is often required on the input to the voltage divider to prevent ringing with application of steep wave fronts and resultant high frequency "fuzz" superimposed on the voltage waveform. The resistor should be composition film type capable of 15 kilovolts and 3 watts. IRC MVX-3 has performed satisfactorily.
- 2.5.7 Oscilloscopic Record Camera: Tektroniz C-27 or equivalent using Polaroid film 107 or equivalent.

3. OTHER SPARK ENERGY MEASUREMENT METHODS

- 3.1 Simultaneous Current and Voltage Measurement: The simultaneous method of spark energy measurement is very valuable as a time saver when used by a person well trained in the art of energy measurements. Limitations exist that preclude its use in certain cases and therefore make it undesirable to the occasional user.
- 3.1.1 Dual Channel Current and Voltage Display:
- 3.1.1.1 The typical setup is as depicted in Fig. 6. The current and voltage are traced simultaneously by the dual beams of the oscilloscope. An isolation transformer is required to prevent phase shift. Its insertion can, however, cause parasitic oscillations on the current waveform. The isolation transformer cannot be used if unipolarity discharge is being measured due to its blocking effect of the DC current component. This method must then be used without the isolation transformer and close watch kept for phase shift effect.
- 3.1.1.2 Most dual beam oscilloscopes are deficient in the amount and linearity of vertical deflection and/or tracking of the dual time bases.
- 3.1.1.3 If either phase shift, oscillations or non-linearity exist, the individual method of paragraph 2. should be used.
- 3.1.2 Chopped Dual Channel Current and Voltage Display:

- 3.1.2.1 A setup may be made as shown in Fig. 7 where a single beam oscilloscope is used with a plug-in operating in the chopped mode. This allows full deflection possibilities on the screen and eliminates the deflection problems of a dual beam scope. The resulting wave form will appear as dotted traces similar to the applicable waves of Fig. 2 and 4 superimposed.
- 3.1.2.2 This method can be used only where the natural discharge frequency is approximated 1/100.th of the chop rate of the oscilloscope amplifier.
- 3.1.2.3 The phase shift and oscillation problems associated with the use of a current isolation transformer are present and may preclude use.

3.1.3 Two Probe Isolation Current and Voltage Display:

- 3.1.3.1 Equipment may be set up as shown in Fig. 8. This method uses matched H. V. probes in the arc voltage circuit to isolate current and voltage waveforms. Typically a dual beam scope is used.
- 3.1.3.2 The use of the two probe method allows measurement of unipolarity systems without the problems associated with the current isolation method.
- 3.1.3.3 The H. V. probes must be very closely matched for response and kept as a pair for all measurements. The deflection limitations of the dual beam screen may also suggest reverting to the individual method in some cases.

3.2 Alternative methods of measuring spark energy are outlined in AIR 951.

4. EXCITER EVALUATION

- 4.1 It is often desirable to measure the discharge energy capability of an exciter unit to determine its variation from base line value. A common way this is done is to measure spark energy with a designated lead and plug.
- 4.2 This technique encompasses the problems of igniter arc voltage variation, multiple vendors and maintaining "standard" leads and plugs. These conditions can result in considerable confusion and make true quality measurements of the exciter impossible.
- 4.3 The discharge waveforms in this report are typical of nearly all exciter units in the following way. The peak power is relative to peak current, time duration of power waveform is relative to current duration and spark energy is relative to current waveform.
- 4.4 Capacitance discharge exciters basically apply the energy stored in a capacitor at a predetermined voltage to a load including the igniter arc gap. The igniter arc gap is known to vary over rather wide limits from spark to spark or igniter to igniter. Therefore when making discharge capability measurements to evaluate the exciter, it is highly desirable to eliminate the igniter plug.
- 4.5 Short circuit discharge current from a typical exciter varies only slightly from that when firing an igniter. It further has the characteristic of being stable from discharge to discharge.
- 4.6 It is recommended that short circuit current be used as a means of determining the discharge capability of capacitance discharge exciters. This can be accomplished by making a short circuit record of an exciter that provides the desired spark energy with a complete system by replacing the igniter with a current shunt as described in 2.5.3.