SAE The Engineering Society For Advancing Mobility Land Sea Air and Space®
INTERNATIONAL
400 Commonwealth Drive, Warrendale, PA 15096-0001

AEROSPACE INFORMATION REPORT

SAE AIR951 REV. A

Issued 1968-06
Revised 1998-08

Submitted for recognition as an American National Standard

Spark Energy Measurement, Alternative Methods

FOREWORD

This revision contains format/editorial changes only.

INTRODUCTION

The subject of spark energy measurement for the user of gas turbine engine ignition systems has been cautiously approached in that no one method has been developed that is readily usable outside the system designer's laboratory. Also, there is a lack of agreement as to the most desirable and informative method or methods to be used in establishing the system integrity except that it will effect an engine start when called upon. Periodic inspections during the used life of the ignition system crudely consist of (a) visual evidence of a spark and (b) sound level of the spark resounding within the caverns of its operating environment. Both of these depend primarily on human judgment which varies considerably with the individual.

This document is prepared in an effort to acquaint and summarize, for the user, the available methods, over and above those stipulated for overhaul agencies, for possible refinement and use as periodic inspection media.

1. SCOPE:

Parameters to consider and various methods of measuring spark energy of aviation ignition systems.

2. APPLICABLE DOCUMENTS:

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

QUESTIONS REGARDING THIS DOCUMENT: **(724) 772-8510** **FAX: (724) 776-0243**
TO PLACE A DOCUMENT ORDER: **(724) 776-4970** **FAX: (724) 776-0790**
SAE WEB ADDRESS: **http://www.sae.org**

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

See Appendix I.

3. SPARK DISCHARGE AS RELATED TO IGNITION:

At the present time there is little agreement on what characteristics of spark discharge are critical to ignition of various fuel-air mixtures. Spark discharge parameters which are known to affect ignition include:

a. Peak temperatures created by the spark,
b. Time vs. power of the spark,
c. Spark rate,
d. Spark shape (resulting from electrode shape and gap geometry),
e. Temperature, pressure, and velocity of the ignitable mixture,
f. Type of spark igniter, i.e., air gap, surface gap, shunted surface gap,
g. Total energy discharged per spark.

The above parameters are all controllable by the ignition system designer, or (item e) are capable of reasonable reproduction. Not included as spark discharge parameters are such engine parameters as spark location in the combustor, spark location vs. fuel spray quality, etc.

3.1 Peak Temperatures Created by the Spark:

Every commonly used hydro-carbon fuel has what is known as a spontaneous ignition temperature. This temperature is the lowest at which ignition will occur in an environment where temperature is the only variable. The spontaneous ignition temperature may vary as a value depending on the particular test method and fuel or fuel mixture used. It is generally accepted that the temperature created by the spark must exceed a certain value which either is or is related to the spontaneous ignition temperature of the mixture to be ignited.

3.2 Time vs. Power of the Spark:

With continuing advancement in engine and ignition technology, it has become common practice to measure and sometimes specify spark duration, peak power, and total discharge energy of a spark. (See Reference 1, Appendix I). Average spark power is also of some interest. It should be noted that peak spark temperatures are related to the power vs. time function.

3.3 Spark Rate:

There are at least two functions of spark rate related to successful ignition. One of these is to provide a spark at the proper time to coincide with earliest ignitable fuel-air mixtures. Another function of spark rate may be to control the rate of energy transfer to the ignitable mixture, in a manner allied to that provided by spark duration.

3.4 Spark Shape:

This parameter relates to the physical shape of the luminous part of the spark, or plasma. Spark shapes may, through constriction of the arc, be related to peak temperatures developed. Many interesting spark shapes can be recorded photographically, and for a particular design ignition system these shapes are quite similar. The spark shape results primarily from electrode size, shape, and gap geometry of the spark igniter, but can also be influenced by the system energy level.

3.5 Temperature, Pressure, and Velocity of the Ignitable Mixture:

These parameters, while basically a function of engine design, influence the discharge characteristics of a spark. In can be readily demonstrated that an inductive type spark changes in color and intensity as a function of pressure and velocity. Increasing ambient pressure will tend to reduce the effective arc length of a capacitive spark to a minimum. Temperature and pressure variations influence the ionization voltages necessary to produce a spark, and depending on the spark igniter, these variations may result in a significant portion of discharge energy being consumed as heat loss internal to the igniter.

3.6 Type of Spark Igniter:

Air gap, surface gap, shunted surface gap (See Reference 2, Appendix I) - The effect on ignition of type of spark igniter is related to both the ease of creating a spark (voltage level) and the resistance to fouling (discharge energy losses). Shunted surface gap igniters are generally more resistant to external fouling than other types, but may incorporate semiconductor materials which in themselves tend to be too conductive and dissipate significant discharge energy as internal losses.

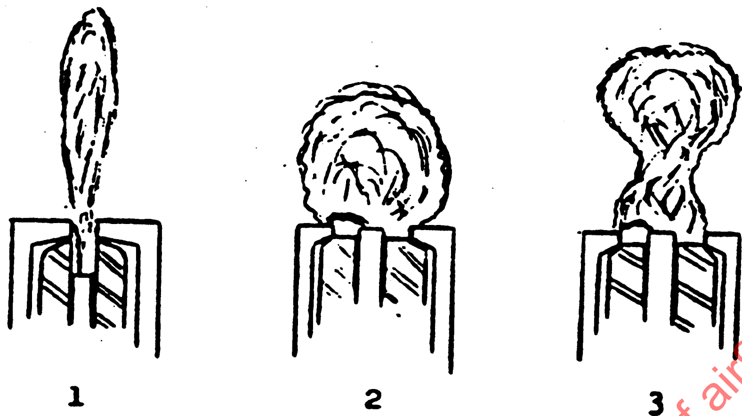
3.7 Total Energy Discharged per Spark:

This definition may be interpreted in two ways: (1) stored energy of the ignition system at the instant prior to discharge, and (2) energy dissipated at the spark igniter electrode location. This AIR is concerned with the second definition. The term, “total spark energy”, is a better definition, but not consistently applicable among the various measurement methods to be discussed.

4. OPTICAL METHODS:

A measurement of the light produced by a jet igniter spark discharge has a relationship to the corresponding electrical measurement of spark energy made by oscilloscopic methods. Optical methods have the advantage of simplicity, and can be done in a very small fraction of the time required to accomplish referenced oscilloscopic methods.

4.1 One optical method of spark energy measurement is to take time exposure pictures of the spark discharge. This method provides a good comparative evaluation of competing igniter designs on a total discharge energy basis. The results, of course, depend on the sensitivity of photographic film and equipment. Some typical results relative to spark shape are shown in Figure 1.



1. Recessed gap igniter
2. Radial gap igniter
3. Radial gap igniter with higher energy system

FIGURE 1 - Some Typical Spark Plasma Shapes from Photographic Measurements

4.2 Another optical method of spark energy measurement, designated as the photoelectric method, consists of sensing the light output of the spark discharge with a photocell or light sensitive device. By reading the output of such a device on an oscilloscope, a relationship of light emission vs. time may be established. Figure 2 illustrates a circuit and set-up as practiced by one igniter manufacturer. The instrumentation used in this method consists of a special photo-electric fixture as illustrated, and a stable calibrated cathode-ray oscilloscope of average sensitivity. Peak light measurements have proven most consistent, but measurements of duration and area under the curve may also be of interest. Figure 3 illustrates typical response. It will be seen that the shape of the energy waveform is quite similar to that obtained by oscilloscopic methods in References 3 and 4 of Appendix I.

Calibration of the light signal in terms of electrical energy has not yet been done, but the method has been particularly useful in making direct comparisons where absolute values of energy are not required. For example, igniter design changes have been quickly evaluated to determine their effectiveness.

5. PRESSURE METHODS:

Pressure methods of spark energy measurement, which have been attempted, are designed as total pressure measurement, peak pressure measurement, and instantaneous pressure measurement.

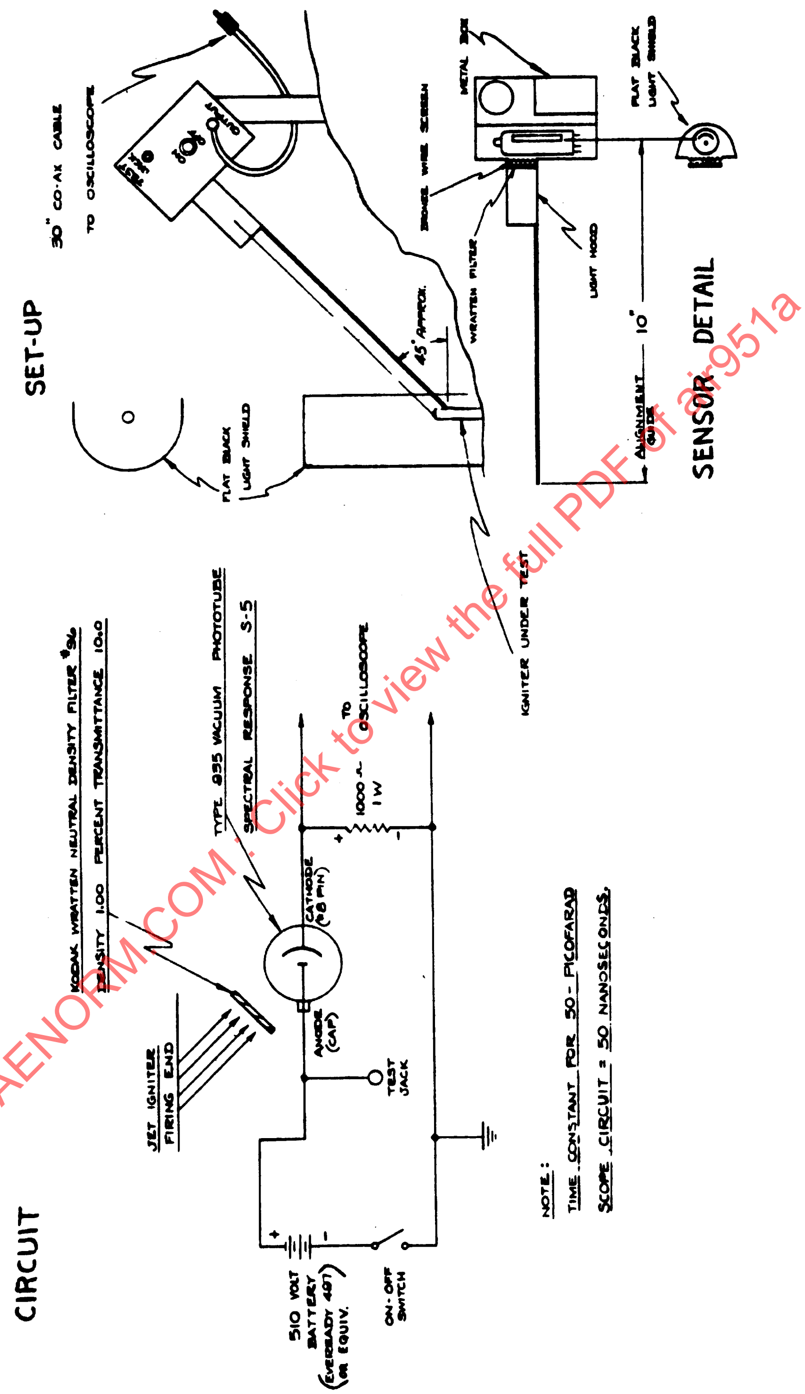
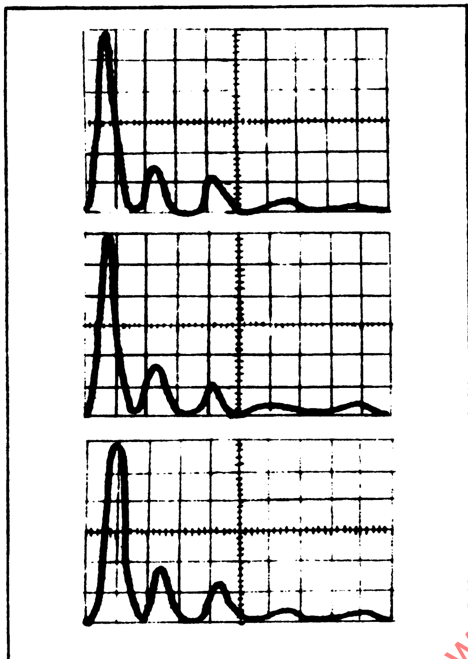


FIGURE 2 - A Test Set Up for the Photo Electric Method



Single

Discharges

Amplitude: .2 volts/cm

Sweep: 10 sec/cm

System: 4 joules (stored)

FIGURE 3 - Typical Waveforms form Set Up of Figure 2 (Photo-Electric Method)

5.1 Total Energy Method:

The term total energy as used herein designates a net effect relation, irrespective of time. Total energy pressure method is based on theoretical relations of perfect gases which state that,

$$\Delta E = \frac{V}{\gamma - 1}(\Delta P) \qquad \text{(Eq. 1)}$$

ΔE = Change in total energy at constant volume
V = Chamber volume
γ = Ratio of specific heats
ΔP = Change in maximum pressure

By confining the spark in a closed volume container of low thermal conductivity, it can be seen that an increment of energy added by a spark will produce a corresponding rise in temperature and pressure of the confined gas. The quantity and duration of the pressure rise are dependent on the gas tightness and thermal loss characteristics of the container and igniter assembly, and on the number of energy increments (sparks) added.

Experimental programs have yielded good correlation between total energy measured by the pressure pulse method and that measured by oscilloscopic methods. (See Reference 5, Appendix I). Figures 4 and 5 illustrate one construction of the pressure bomb and the type of pressure output response obtained. It will be noted that the bomb type of construction is closely akin to that utilized in a calorimeter type measurement. (See Reference 6, Appendix I). It is conceivable that a single vessel could be constructed to serve both types of measurements.

5.2 Peak Pressure Method:

The peak pressure method is actually a kind of acoustic energy measurement, i.e., how big a "bang". At least two variations of this method have been used with some degree of success.

5.2.1 One peak pressure measurement method has been demonstrated using a microphone pick up positioned at a fixed distance from the igniter. The result is read on a meter, as with a circuit described in Figure 6.

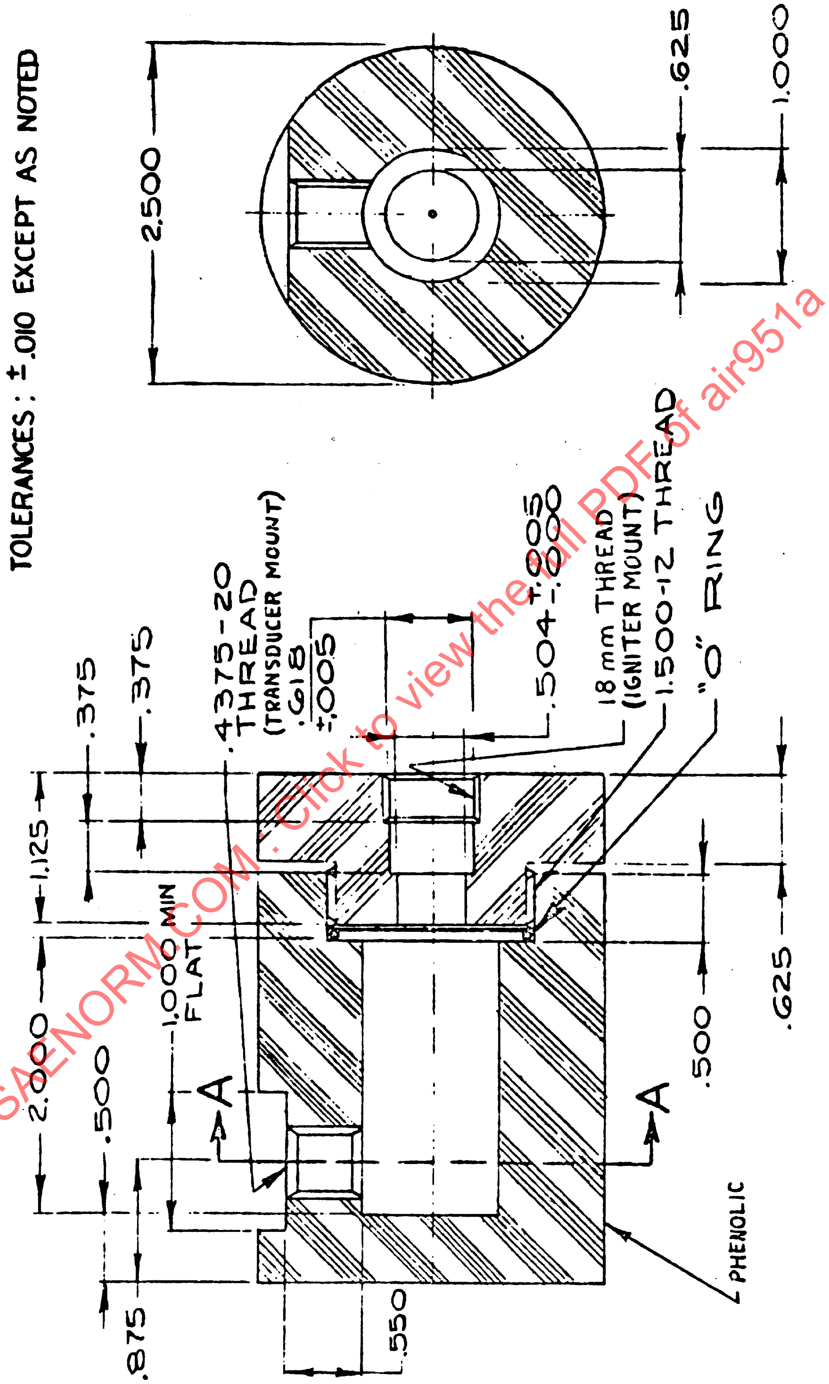


FIGURE 4 - Typical Pressure Bomb Construction for Spark Energy Measurement

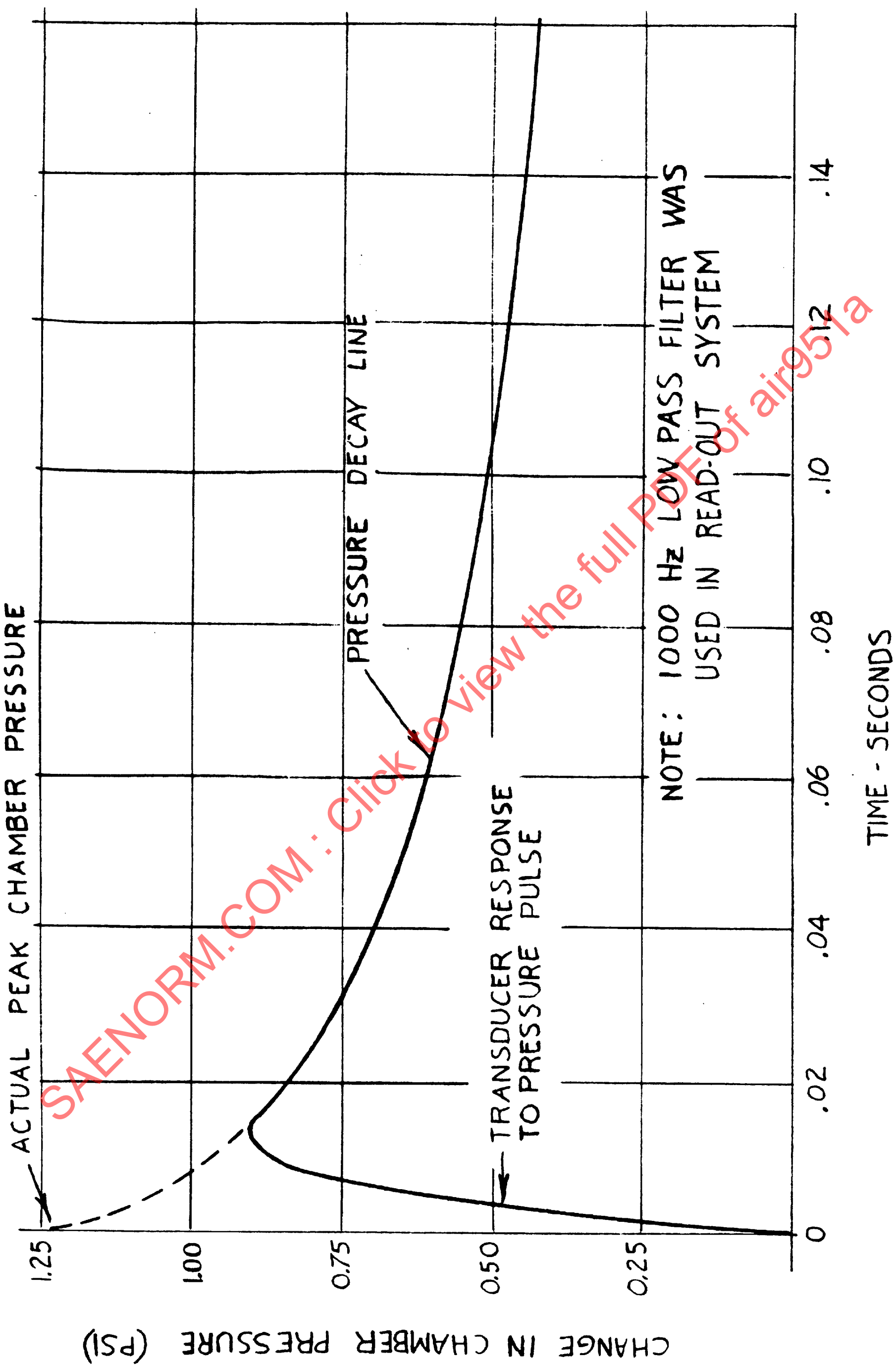


FIGURE 5 - Typical Pressure Response Curve from Bomb of Figure 4

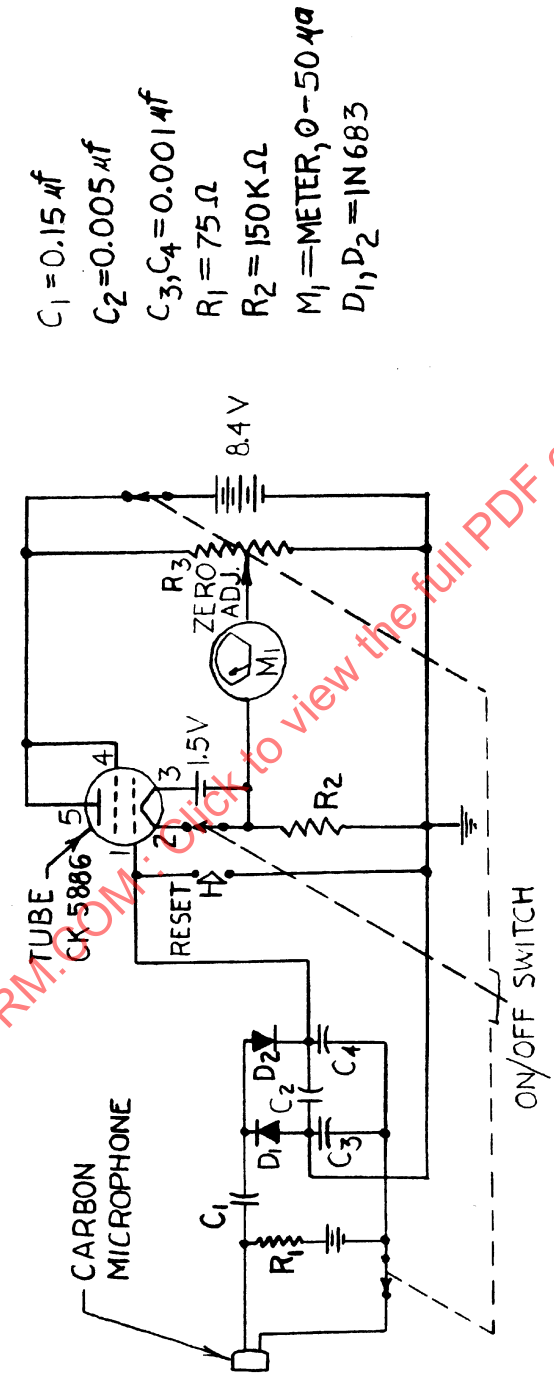


FIGURE 6 - A Circuit for Acoustic Spark Energy Measurement Using Microphone Pick-Up

5.2.2 Another spark energy pressure method has been devised based on the impact force generated by the spark shock wave. In this method the spark is confined in a very small container, at least one wall of which is movable with application of a certain force. The size of the container is established experimentally so that the force of the shock wave will lift off the movable weight and move it through a finite distance. The work thus performed is proportional to spark energy. The mass moved can be connected to a dial indicator of various types; for direct read-out.

Repeatable results have been obtained with this method, and the method will differentiate between systems of various energy levels. It is important with this method that no air leakage exists between the igniter shell and the movable weight prior to firing. This necessitates an accurate self-return feature and soft but firm gasket material at the interface. Figure 7 illustrates the concept.

6. OSCILLOSCOPIC METHOD IMPROVEMENTS:

Chief among objections to electrical energy measurements based on voltage-current relations (See References 3 and 4, Appendix I) are the expense, time, and attendant operator inaccuracies involved in reducing the data obtained as photographic voltage and current waveforms. Instantaneous electrical multiplication and integration of voltage and current waveforms have been accomplished. (See Reference 7, Appendix I). By use of appropriate digital read-out equipment, immediate results of improved accuracy can be obtained. As the art of solid-state devices advances, the economic and physical size aspects of equipment necessary for such operations are expected to improve.

7. OTHER POSSIBLE METHODS:

The foregoing sections of this document have covered methods of energy measurement which have yielded, at least experimentally, results of some value. The foregoing methods are all based on forms of energy release which are generally regarded as having possible effect on ignition. There are additional measurement method possibilities which may or may not be of value.

7.1 It has been observed that for an exciter and lead of a particular design, arc current is relatively constant regardless of spark igniter design. Thus, when oscilloscopic energy measurement is used, igniter energy evaluation for a particular exciter and lead design can be based largely on measurements of arc voltage.

7.2 Other measurement methods might be based on one or more of the following phenomena associated with spark discharge: electric and magnetic fields, wave length spectra of luminous discharge, peak temperature of the arc.

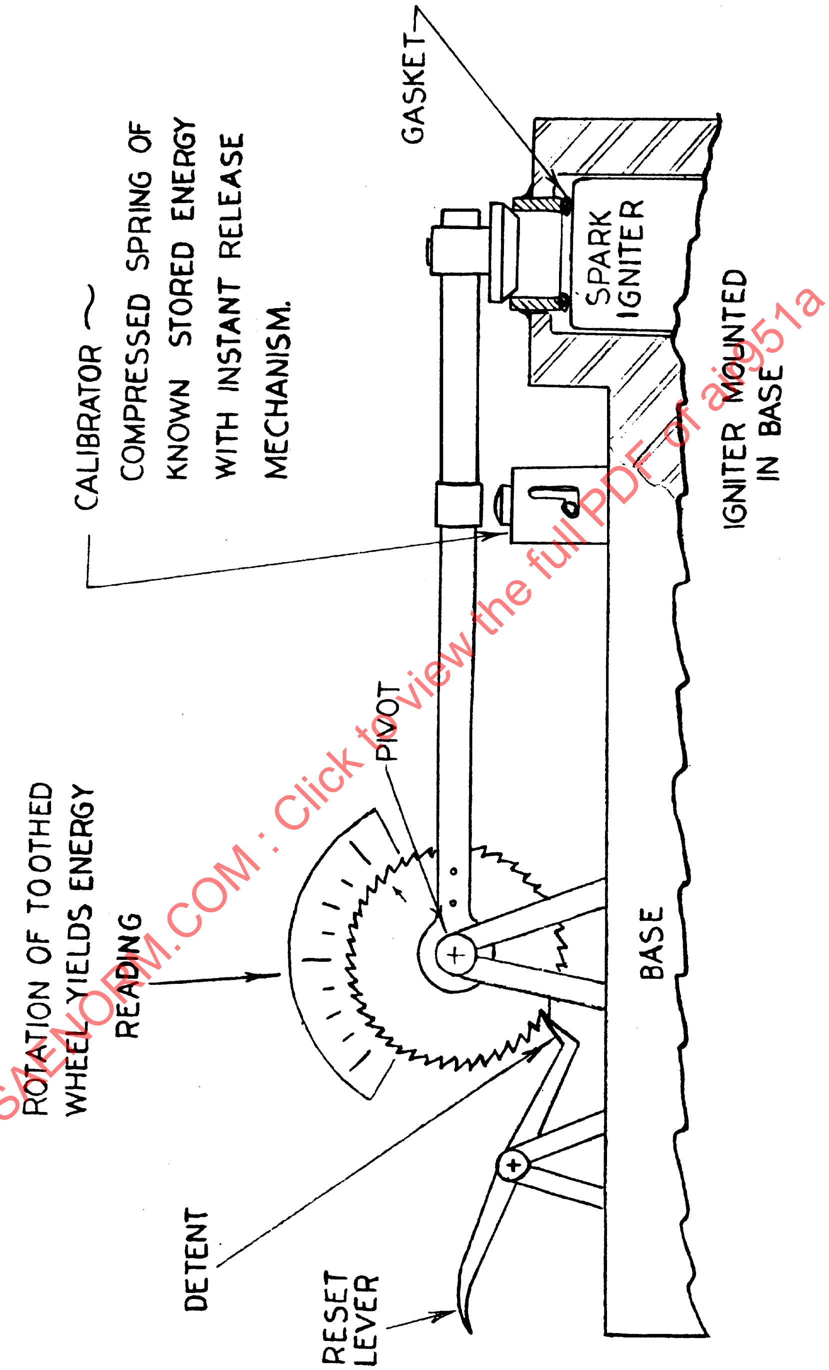


FIGURE 7 - Spark Shock Wave Measurement Device