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# INTERRELATION OF ENGINE DESIGN AND BURNER CONFIGURATION WITH SELECTION AND PERFORMANCE OF ELECTRICAL IGNITION SYSTEMS FOR GAS TURBINE ENGINES

## 1. PURPOSE

1.1 To provide the designer of gas turbine engines with a working knowledge of the interrelation between engine performance objectives and the part played by ignition in meeting the objectives.

1.2 To present a definitive collection of standard references, nomenclature, and descriptive terminology sufficient to provide a basis for design approach in specification of gas turbine ignition systems.

1.3 To stimulate further work necessary in the development of knowledge of the unknown, interrelated parameters.

## 2. SCOPE

2.1 To describe typical ignition systems in general usage and their parameters that warrant consideration during the development of a gas turbine engine.

2.2 To describe those parameters in gas turbine engine design and, in particular, burner configurations that influence the type selection and performance of the ignition system.

2.3 To indicate the areas where future work may uncover important effects having a direct bearing on certain interrelated parameters, with resultant benefits to both the engine and ignition designers.

## 3. GLOSSARY OF TERMS

3.1 Spark Igniters:

3.1.1 High Tension: Defined as, "An item incorporating an electrode (s) across which an electric spark is discharged to ignite a combustible mixture in a continuous burning cycle engine," by AS 341 and categorized by "H. V. air gap, H. V. surface gap, and H. V. air surface gap" by ARP 484. This type requires more than 5 KV potential to create a spark between the electrodes.

3.1.2 Low Tension: Defined same as above and categorized by "Shunted surface gap" in ARP 484. This type requires less than 5 KV potential to create a spark between the electrodes. General practice dictates that a "new" spark igniter shall spark when 1000 volts is applied.

3.2 Ignition Leads:

3.2.1 High Tension: Defined as, "A definite length of electrical cable having at least one end terminated in a single, common fitting," by AS 341. Its construction, materials used, etc. must be such as to conduct the discharge energy from a high tension ignition exciter (in excess of 5 KV) to a high tension spark igniter.

3.2.2 Low Tension: Defined same as above, but designed to conduct the discharge energy from a low tension ignition exciter (less than 5 KV) to a low tension spark igniter.

3.3 Ignition Exciter: An assembly of component parts which provides a means of changing low voltage alternating current or low voltage direct current to a condition suitable to provide (with or without additional devices) a spark discharge for ignition purposes. (Per AS 341)

3.4 Capacitor Discharge System: An ignition system in which the spark energy is primarily the result of a capacitor discharge. (See Sections 4.1, 4.2, 4.5, for illustrations of typical system circuits.)

3.5 Inductive System: An ignition system in which the spark energy is primarily the result of a rapid variation in magnetic flux in an induction coil. (See Section 4.3 for illustration of a typical system circuit.)

3.6 Spark Energy: The energy (Joules) released between electrodes of the spark igniter.

3.7 Spark Rate: The number of spark discharges per unit time occurring at the spark igniter under a given set of conditions. (Example - 2 sparks per second minimum at room temperature and 24 V DC input.)
Ø "Usually the spark rate is specified as a minimum figure at the lowest input voltage to control the minimum number of sparks in the worst case condition and a maximum value at the highest input voltage to control the life of the spark igniter."

3.8 Spark Duration: The length of time usually expressed in micro-seconds, required to dissipate the total energy of any one spark discharge occurring between the electrodes of a spark igniter.

3.9 Stored Energy: The energy (Joules) stored in the tank or storage capacitor of a capacitor discharge system ($1/2\ CE^2$), or in the inductance coil of an inductive discharge system ($1/2\ LI^2$).

3.10 Duty Cycle: The operating cycle required of the ignition system. It is expressed as a function of time ON and time OFF or continuous, as applicable, and is generally associated with the ignition exciter specification.

3.11 High Tension Systems: Ignition systems capable of delivering voltages in excess of 5 KV to the firing tip of the spark igniter.

3.12 Low Tension System: Ignition systems capable of delivering voltages up to 5 KV inclusive to the firing tip of the spark igniter.

3.13 Self Contained System: Ignition systems meeting one or more of the other definitions herein which,
Ø in addition, are designed to operate from a power source which is engine supplied equipment.

4. TYPICAL IGNITION SYSTEM CIRCUITS

The following simplified ignition circuits are shown to illustrate the basic components that establish the system limitations. These are to assist the engine designer in the realization for the need of zoning the system components on the engine in regard to temperature, vibration, distribution efficiency, etc.

4.1 D. C. Capacitor Discharge System, High Tension:

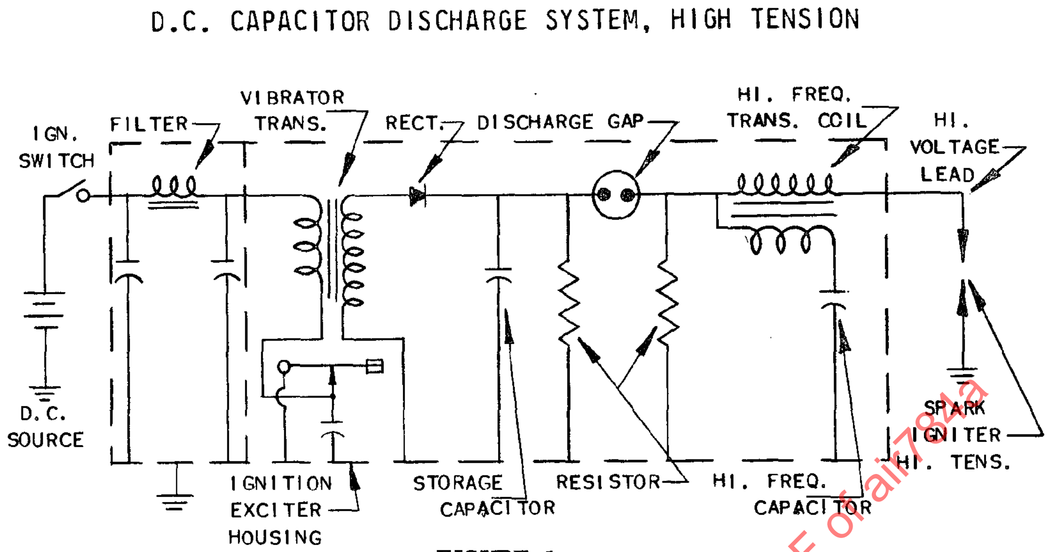


FIGURE 1



Comments:

The high tension capacitor discharge system produces an initial ionizing voltage of a magnitude as large as necessary (within design limits) to ionize the gap of the high tension spark igniter. This ionizing voltage usually has the waveform of a very short duration pulse or "spike" (above 5 KV) as compared with the remainder of the discharge voltage (0-500 volts). Because of the high magnitude of the ionizing voltage, a wide variety of spark igniter gap geometries are compatible with this system. The ionized spark igniter gap provides the necessary low impedance path for the discharge of the energy stored in the storage capacitor, through the ionized spark discharge gap, secondary winding of the high frequency transformer coil, high tension ignition lead, center electrode of the spark igniter, and arc to ground. Because relatively large amounts of energy are thus expended in the resulting spark in a matter of microseconds, the heat release and the accompanying shock wave to fuel-air mixtures is sufficient to produce ignition over a wide range of combustion conditions. Detailed explanations of the electrical phenomena of ignition circuits such as illustrated above are available in many publications and in manufacturer's literature.

For the purposes of this document, the following observations are made concerning the high tension version of the capacitor discharge system:

1. It is usually the heaviest, and largest, of the three basic ignition circuits discussed in this document, due to the incorporation of the high frequency transformer coil and its high frequency capacitor.

   The high frequency transformer coil itself causes certain energy losses and alters the time duration and peak power level of the spark from that which would be obtained if the coil were not present. Use of such a coil may therefore necessitate higher stored energy requirements.

2. The high voltages demanded by the spark igniter under extremes of high pressure and electrode erosion, must be considered in the determination of acceptable ambient temperatures and altitudes, lead lengths, terminal configuration, cable insulation, and the design of the spark igniter.

4.2 **D. C. Capacitor Discharge System, Low Tension:**

D.C. CAPACITOR DISCHARGE SYSTEM, LOW TENSION

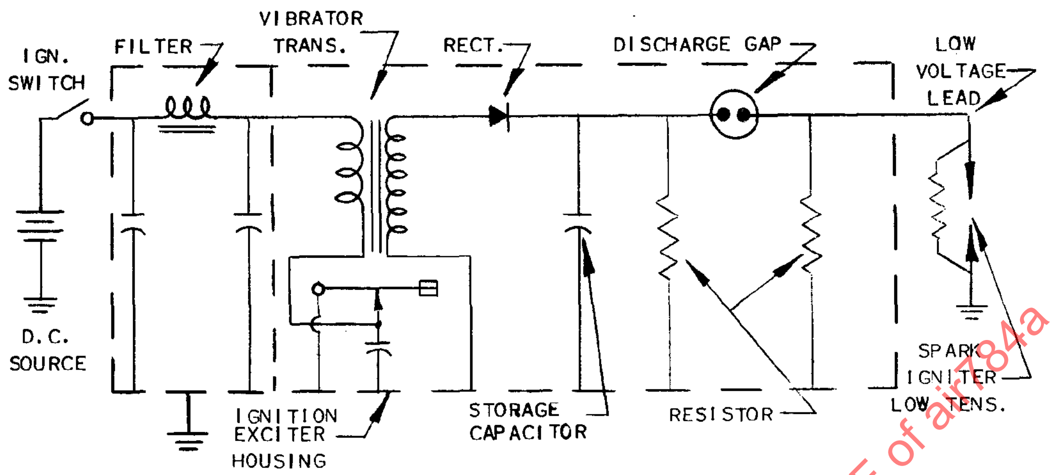


FIGURE 2

Comments:

The low tension capacitor discharge system produces sufficient voltage to cause current to flow across a semi-conductive surface in intimate contact with the center electrode and ground shell of a low tension spark igniter.

This initial flow of current ionizes the air between the center electrode and the ground shell so that the energy stored in the storage capacitor discharges through the ionized spark gap, the low tension ignition lead, the center electrode of the spark igniter, to ground. Because relatively large amounts of energy are thus expended in the resulting spark in a matter of microseconds, the heat release, and the accompanying shock wave, to fuel-air mixtures is sufficient to produce ignition over a wide range of combustible mixtures. Detailed explanations of the electrical phenomena of ignition circuits such as illustrated above are available in many publications and in manufacturer's literature.



For the purposes of this document, the following observations are made concerning the low tension version of the capacitor discharge system:

1. Because the low tension spark igniter firing tip contains its own shunted surface (semi-conductor body), contamination of the electrodes by fuel, carbon, or other combustion residues has little effect on the generation of a spark. For the same reason, higher burner pressures may be ignited than is feasible in the air gap or surface gap types of high tension spark igniters.

2. Lacking the inductance of a high frequency transformer coil in the discharge circuit, the spark duration is shorter and the peak power of the first pulse on the spark train is higher. This concentration of heat in the spark is more effective under some combustion conditions, which could result in lower stored energies and resultant decreases in the system weight, and size.

3. Lower discharge voltages permit smaller cable insulation, lighter leads, and are more easily controllable under extremes of ambient temperature and altitiude.

4. Because the functioning of the entire system depends on the condition of the semi-conductor surface required in the firing tip of the spark igniters, they may be influenced by engine burner conditions and may require more frequent replacement than do air gap or surface gap types of high tension spark igniters. The necessity of maintaining intimate contact between the electrodes and the semi-conductor material, requires that particular attention to be given to the extremes of temperature to which the firing tip is subjected. Each system application must be studied for its peculiar conditions.

4.3 Inductive System:

D.C. INDUCTIVE SYSTEM, HIGH TENSION

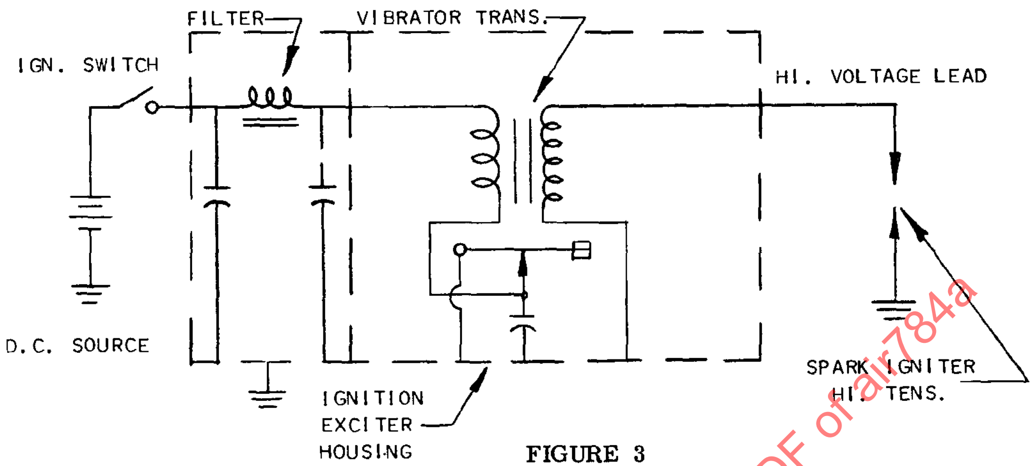


FIGURE 3

Comments:

The inductive discharge system is similar in performance to the magneto or battery timer ignition used on reciprocating engines. It is usually the lightest, smallest, and least expensive of all three basic circuits considered in this document. It produces a high voltage inductive spark shower in frequency with the rate of opening of the contact points. For the purpose of this document, the following observations are noted:

1. It contains fewer electrical components than are necessary in the other ignition system types discussed herein, and therefore offers potential advantages in size, weight, and cost. These advantages are particularly apparent when very low spark energies can be tolerated (in the millijoule range).

2. It has three main disadvantages:

   a. Low spark peak power capable of igniting only the more easily ignitable fuels, and within narrow fuel-air ratio limits.

   b. Inductive sparks may be more readily quenched by fuel or moisture wetting, and shorted by carbon fouling or other products of combustion.

   c. High voltage output must be considered in the determination of acceptable ambient temperatures and altitudes, lead lenghts, terminal configuration, cable insulation, and the design of the spark igniter.

4.4 Comments on D. C. Powered Circuits:

The circuits illustrated above are shown as deriving their electrical power from a D. C. source. Also, the power portion of the circuits illustrate a vibrator-transformer used to interrupt and transform the D. C. input to a pulsating current sufficient to charge the storage capacitors of 4.1 and 4.2, or to produce the inductive spark of 4.3. Another variation substitutes a transistorized circuit for the vibrator, with the rest of the ignition circuit remaining as illustrated. The vibrator, being an electro-mechanical device with moving parts, and contact points, may have the lowest operation life of any power circuit herein considered. "Today's transistor technology and availability allow the use of solid state components in applications of the same general temperature range as the vibrator at lower costs. At the same time, operating life has increased many times that of the mechanical vibrator design, making continuous duty capability practical.

4.5 A.C. Powered Circuits:

A.C. CAPACITOR DISCHARGE SYSTEM, HIGH TENSION

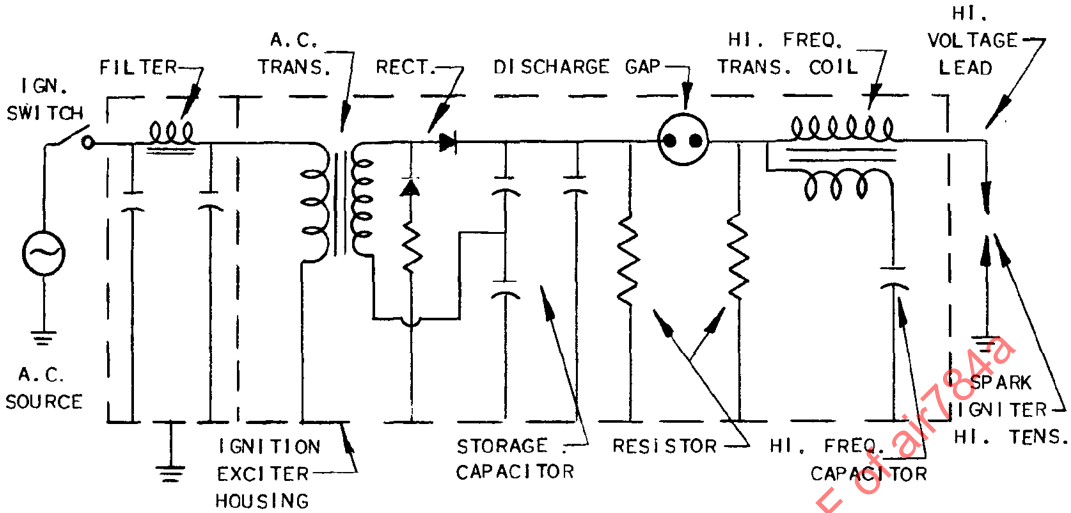


FIGURE 4

Figure 4 illustrates a typical A. C. powered capacitor discharge, high tension system. Comparing it with the D. C. powered circuit of 4.1 (See Fig. 1), it will be observed that the two are identical except for the power portion, after the filter and ahead of the storage capacitor. The same substitution can be made to change circuit 4.2 into an A. C. powered system, and the A. C. transformer can be substituted for the vibrator transformer in circuit 4.3.

Generally speaking, A. C. circuits may have one or all of the following advantages over D. C. powered circuits:

1. Increased reliability
2. Less cost
3. Lighter weight
4. Smaller size
5. Longer operation life before overhaul
6. Most adaptable to extreme ambient temperatures

It is obvious, therefore, that A. C. should be specified for ignition power whenever it is possible.

4.6 Dual Ignition and General Comments:

In each of the above ignition circuit diagrams, a single discharge system is illustrated, or one that fires only one spark igniter. There are several accepted procedures for firing two or more spark igniters:

4.6.1 Two Independent Single Systems: Use of two complete single exciter units will, of course, double the reliability of firing one igniter although at the penalty of twice the weight, size and cost. These factors can be decreased slightly by packaging the dual circuitry into one common housing.

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4.6.2 One Single System with a Spark Splitting Discharge Circuit: Figure 5 shows a typical circuit although many variations are optional with the spark splitting concept.
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Spark Splitting Discharge System

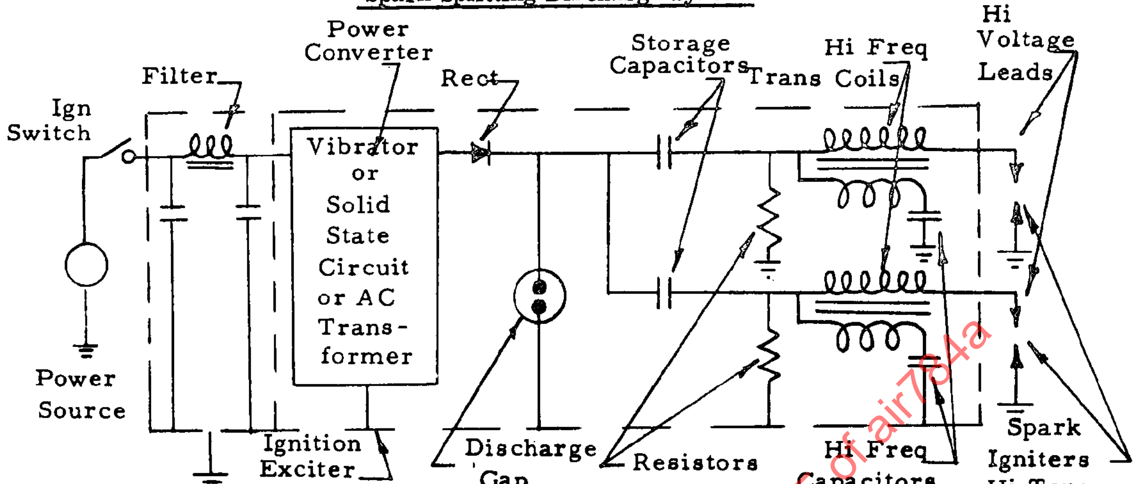


FIGURE 5

There is no increase in discharge efficiency over the single circuit concept, therefore both storage capacitors are the same value as found in two single units. Some weight, size and cost reduction over two single exciters is achieved due to the common primary circuit, high voltage rectifier and discharge gap. This circuitry can be used as a low tension system by eliminating the high frequency components.

4.6.3 One Single System with a Series Discharge Circuit: To further reduce weight, size and cost of a dual exciter unit, the series discharge curcuit shown in Fig. 6 is being used extensively in the gas turbine engine industry.
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Series Dual Discharge System

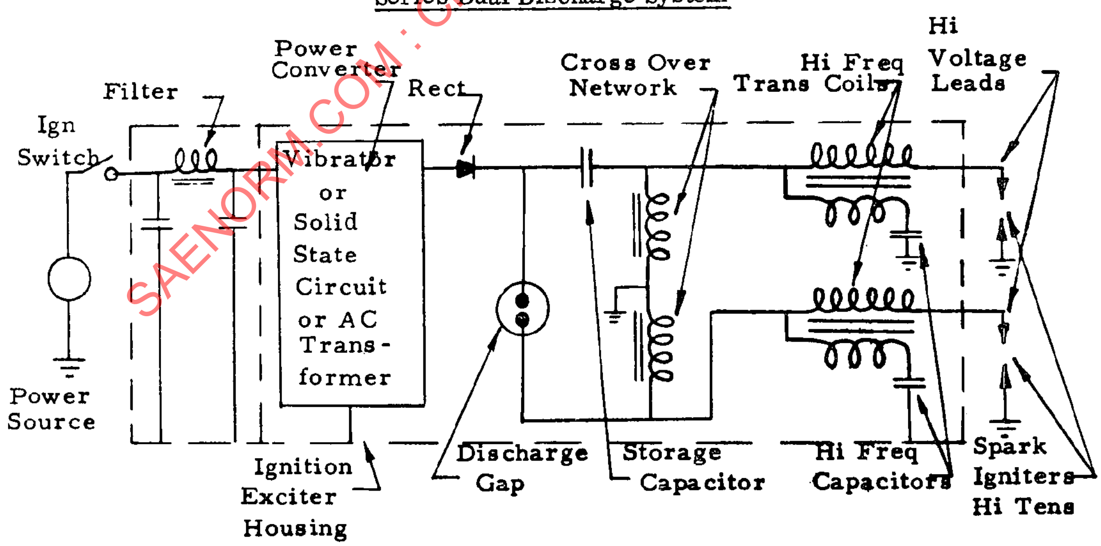


FIGURE 6

4.6.3 (Continued)

This concept offers dual capability with the least amount of weight and size. The series discharge circuit has a greater discharge efficiency, therefore weight, size and cost of the storage capacitor is decreased over that found in two single exciters in order to assure the same energy at the igniters. In case one igniter or output lead should become open or short circuited, the remaining igniter will continue to fire with approximately the same spark energy. Here again, variations of this type of circuitry appear and are controlled by specific applications.

4.6.4 General: Each approach to the solution for dual ignition has its own merits, depending on the situation being considered. It is recommended that the engine designer and ignition manufacturer study the situation and arrive at a decision based on all factors involved, such as reliability, failure analysis, etc.

It should be understood, also, that although the preceeding schematic diagrams illustrate the ignition exciter components physically located in one housing requiring an ignition lead to conduct the energy output to a remotely situated spark igniter, it is entirely feasible to relocate the components to meet specific conditions. Relocation possibilities extend to the extremes of mounting the entire system as an integral part of the spark igniter or separating the components into separate, lead connected housings throughout the engine installation. Each of these situations offers advantages and disadvantages and require due consideration by the engine and ignition system designers.

4.6.5 Ignition Monitoring: In some cases the ignition system user may wish to monitor the ignition system in order to trouble-shoot a malfunction or to analyze the life condition of the ignition system. Any desired electrical parameter may be made available for measurement through use of voltage/current
ø sensing elements and appropriate connectors. It should be noted that the only practical guarantee of a spark occuring in the proper location is through some optical detection means.

4.7 Unidirectional Discharge Circuit: A unidirectional capacitance discharge circuit can produce discharge efficiencies of 20% to 60% rather than the 10% to 30% mentioned in 7.1.1. The unidirectional discharge circuit provides a non-oscillatory discharge current. The conventional oscillatory discharge circuit has become a basic ignition system standard and improving its efficiency seems to be reaching a point of
ø diminishing return. The unidirectional discharge circuit is similar to the conventional circuit except for the inclusion of a "free wheeling" diode connected from the outside of the discharge gap to ground. It is suitable for use either in low tension or high tension circuit. The diode provides a low impedance path for the current produced by the energy stored in the inductance of the high frequency transformer or an inductance coil and maintains a unidirectional flow. This low impedance path by-passes the storage capacitors and the spark gap, thereby considerably increasing the energy dissipated at the spark igniters. The increase in energy results from the elimination of the circuit resistance associated with these two components.



The unidirectional discharge provides a continuous positive decaying power curve, Fig. 17, rather than an oscillatory wave form shown in Fig. 8 through 13. Advantages of the unidirectional discharge are as follows:

a. Increased discharge efficiency

b. Reduced exciter size and weight for a given igniter energy

c. Reduced input power requirement (an added advantage when working with a self-contained (alternator) power system)

d. Improved life of the exciter unit's discharge components

4.7 (Continued)

Limitations of this type of circuitry are:

a. Limited availability of high surge current and high temperature diodes.

b. Effects of this type of discharge on engine starting are not generally known.

c. Reliability unknown at this time.

d. Exciter cost is likely to be higher except for specific cases.

UNIDIRECTIONAL DISCHARGE CIRCUIT

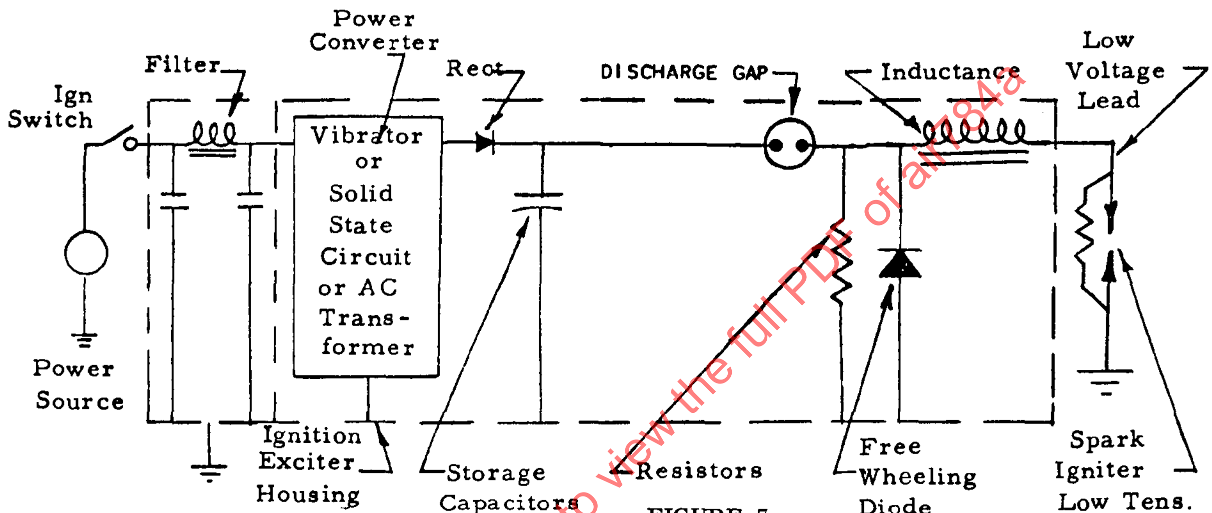


FIGURE 7

5. PERTINENT MILITARY SPECIFICATIONS AND AS, ARP, AIR DOCUMENTS:

MIL-STD-461 Electromagnetic Interference Characteristics Requirements for Equipment
MIL-STD-462 Electromagnetic Interference Characteristics, Measurement of
MIL-STD-704 Electric Power Aircraft, Characteristics and Utilization of
MIL-STD-810 Environmental Test Methods
MIL-STD-826 Electromagnetic Interference Test Requirements and Test Methods

MIL-E-5007 Engines, Aircraft, Turbojet, General Specifications for
MIL-E-5009 Engines, Aircraft, Turbojet, Qualification Test for
MIL-E-8593 Engines, Aircraft, Turboprop, General Specifications for
MIL-E-8597 Engines, Aircraft, Experimental Turboprop Preliminary Flight Rating Test for
MIL-E-8595 Engines, Aircraft, Turboprop, Qualification Test for

MIL-P-8686 Power Units; Aircraft Auxiliary, Gas-Turbine Type, General Specification for

AN-I-27a Interference Limits; Aircraft and Vehicular Engine Radio

MIL-I-6181 Interference Limits, Tests and Design Requirements, Aircraft Electrical and Electronic Equipment

MIL-I-26600 Interference Control Requirements, Aeronautical Equipment

5.2 Society of Automovite Engineers Publications:

| | |
|---|---|
| AS 341 | Drawing Titles Rules and Nomenclature for Aircraft Engine Parts |
| AS 422 | Spark Igniter Outline Right Angle Flange Mounting |
| AS 423 | Spark Igniter Outline Flange Mounting |
| AS 453 | Gasket |
| AS 692 | Igniter, Spark, Aeronautical Engine (High Tension) |
| AS 803 | Igniter, Spark, Aeronautical Engine (Low Tension) |
| AS 814 | Spark Igniter Outline - .750-20 Threaded Mounting |
| AS 815 | Spark Igniter Outline - .500-20 Threaded Mounting |
| ARP 294 | Terminal, Lead, Low Voltage Igniter Plug |
| ARP 295 | Terminal, Well, Low Voltage Igniter Plug |
| ARP 424 | Spark Igniter Outline Threaded Mounting |
| ARP 484 | Nomenclature for Spark Igniters |
| ARP 494 | Terminals - Input - Ignition Exciters |
| ARP 504 | Ignition System Testing Metering and Power Supply Regulation |
| ARP 670 | Terminal, Aircraft Ignition |
| ARP 841 | Leads, Flexible, Shielded, High Energy Ignition |
| ARP 846 | Low Tension Spark Igniter Sparking Voltage Test |
| ARP 937 | Jet Engine Electromagnetic Interference Test Requirements and Test Methods |
| AIR 77 | Spark Energy Measurement Using Oscilloscopic Methods |
| AIR 84 | Ignition Peak Voltage Measurement |
| AIR 85 | The Calorimetric Method of Ignition Spark Energy Measurement |
| AIR 801 | Oscillographic Method for Measuring Spark Energy Capacitor Discharge Ignition Systems |
| AIR 885 | The Spark Calorimeter |
| AIR 1090 | Ignition Exciter Output Voltage Pulse Measurement Using a Pressurized Ball Gap |
| AIR 1091 | High Voltage Pulse Generator |
| AIR 1092 | High Tension Exciter Output Voltage Measurement Using Cathode-Ray Oscilloscope |

6. DATA NEEDED BY THE IGNITION SYSTEM MANUFACTURERS

6.1 Application: The application of the system should be specified to permit future identification by common terms and allow the ignition system manufacturers to draw upon experience acquired in similar applications.

6.2 Type of System: The type of ignition system desired should be specified if known.

6.2.1 Capacitor discharge, high tension.

6.2.2 Capacitor discharge, low tension.

6.2.3 Inductive

6.2.4 Single or dual ignition.

6.3 Electrical Requirements:

6.3.1 Input Requirements and Limitations:

a. The nominal voltage plus maximum and minimum.

b. For AC systems, the nominal frequency plus its maximum and minimum variation.

c. Current limitations if any.

d. Any electrical transient conditions must be specified.

6.3.1 (Continued)

e. For self contained system, complete characteristics of the power source; i.e., voltage, source impedance frequency and spark rate vs. engine operating RPM. Method of turning exciter circuits on and off should be specified if applicable. Ø

f. Electromagnetic interference requirement, the typical circuits shown herein show filtering on only Ø one input line. Sophisticated EMI requirements may dictate more complete isolation.

6.3.2 Spark Rate: The spark rate required should be specified. The maximum and minimum should be specified at the input power limits.

6.3.3 Energy: The critical energy parameter insofar as system performance is spark energy as defined by a wave form of instantaneous power vs. time. For capacitor discharge systems, the energy stored in the capacitor of the ignition exciter is also required. The minimum energy that is acceptable should be specified. Where separate specifications are prepared for individual ignition system components, i.e. exciters, leads, spark igniters, the spark energy requirements of the entire system should be stated in each component specification, with cross references to all other system component definitions.

6.3.4 Output Voltage: The output voltage limits of the ignition exciter should be specified, as well as measurement conditions.

6.3.5 Spark Igniter Firing Requirements: The minimum voltage required to fire the spark igniter under specified conditions should be specified. In addition, the specified conditions of operation should include all temperature and pressure extremes under which the spark igniter is to operate.

6.3.6 Duty Cycle: The duty cycle must be specified. For intermittent duty systems, considerable savings in size, weight, and cost may be realized by limiting electrical operational time to the minimum necessary for successful engine operation.

6.3.7 Endurance Life: The expected endurance life of the system should be specified in actual electrical "ON" time. This may be estimated on the basis of time between overhaul and the duty cycle requirements.

6.3.8 Service Limits: Certain of the foregoing requirements such as stored energy, spark igniter firing voltage, etc., change with accumulated operational time. It is necessary that the permissible quantitative changes be specified in order to provide component designs acceptable under all stages of engine operation.

6.4 Mechanical Requirements:

6.4.1 Physical Size & Weight: The physical size and weight limitations include preferential mounting and terminal locations.

6.4.2 Lead Length: The length of leads, at least approximate, should be specified to assist in determining energy requirements. Lead design is affected by the distance over which the energy must be carried. Ø Terminal configurations for both ends of the lead and the temperature gradient along the lead should be specified.

6.5 Environmental Requirements: These conditions may be specified as the requirements of existing specifications being sure to specify the necessary limits or schedules of following items for the exciter, leads, and spark igniter:

6.5.1 Maximum and minimum ambient temperatures, both operating and soak.

6.5.2 Altitude Requirements.

6.5.3 Vibration.

6.5.4 Shock Impact.

6.5.5 Sustained Acceleration.

6.5.6 Humidity.

6.5.7 Salt Spray.

6.5.8 Fungus.

6.5.9 Sand and Dust.

6.5.10 Solvents

7. IGNITION VARIABLES AFFECTING ENGINE STARTING PERFORMANCE:

The following brief summaries of the more important ignition variables are given as a guide for the engine designer and his negotiations with ignition equipment manufacturers.

Each combustion system presents a unique set of requirements for the ignition system. The interrelation of such variables as: input power, stored energy, spark rate, spark energy, size, weight, ambient temperature, and component capability must be so matched as to result in an ignition system that is economical, lightweight, and reliable.

7.1 Ignition System Energy: The energy requirement for a particular ignition application will be a value determined by the engine burner characteristics. While initiation of combustion in a burner at ambient conditions may be relatively simple, the energy requirement must be considered carefully to provide reliable ignition characteristics at the extreme burner operating conditions. The characteristics that determine the ignition system energy requirement of a particular burner are functions of the following variables: fuel to be used, fuel-air mixture limits, pressure, temperature, altitude, gas flow, burner configuration, and spark igniter location. When applying ignition to a new engine design, it may be possible to determine very closely the ignition system energy by similarity with previous designs. If a new burner configuration is to be used, tests should be made at the extreme ambient conditions with a spectrum of spark energies. A variable energy test set-up is a valuable tool for determining energy requirements. When determining the ignition system spark energy, system spark rate must be considered so that the electrical power to be supplied the ignition system is realistic and within the component capability of the ignition system power supply.

7.1.1 Stored Versus Spark Energy: The spark energy appearing at the tip of the spark igniter will always be some value less than the stored energy of the ignition system, usually 10% to 30% of the stored values. The balance of the energy released in each discharge is lost in the effective resistance of the discharge circuit. The loss elements of the discharge circuit are: internal wiring, discharge gap arc, terminal connections, ignition lead conductor, spark igniter construction, ground return path, and stray electrical leakage. The energy that will be available for ignition of a combustible mixture is that expended in the spark igniter arc. To make this value as large as possible compared to stored energy, the energy dissipated in the loss elements must be kept to a minimum.

7.1.1 (Continued)

While the total energy of a spark generated by two ignition systems may be nearly the same, the time of discharge and peak energy may be considerably different.

Figure 8 illustrates how a relatively minor change in inductance present in the discharge portion of the ignition circuit can significantly influence the spark discharge characteristics. As shown in figure notes, the same ignition system (exciter, lead, spark igniter) was used, except in Test 2 the discharge circuit inductance was double that of Test 1.

The time of discharge and peak energy become more important as the ignition to mixture characteristics become critical. At the present time, maximum or minimum values are used to express the requirements of spark discharge time and peak energy.

7.1.1.1 Effect of Lead Length: An ignition lead represents a resistance loss in the discharge curcuit that is roughly proportional to the length of the lead. It is therefore desirable to keep the lead length as short as possible. A second undesirable condition of lead length is attenuation of ignition system voltage. This condition is most prounced with a high tension output.

Improvement in lead efficiency may be made by use of low resistivity conductor, insulation of high dielectric quality, and good design of the ground return path.



Figure 9 illustrates the value of using short discharge leads wherever possible. For these tests, the same ignition exciter and spark igniter were used, and the same lead construction and materials were used but varied in length as given in the figure notes.

7.1.1.2 Effect of Spark Igniter Tip Design: The design of the spark igniter tip has as much or greater effect on the energy delivered by the spark, relative to the stored energy, as any other feature in the discharge path. To deliver the greatest portion of the stored energy at the tip, the arc resistance must be large relative to the loss elements in the discharge path. The effective resistance of the discharge arc, once initial breakdown has occurred, is primarily a function of electrode spacing and configuration. Therefore to increase the arc resistance by larger electrode spacing will increase the initial breakdown voltage. Various tip geometries used by spark igniter manufacturers affect the arc voltage drop with a resultant effect on arc energy.

As a spark igniter is used, the spark discharge and engine operation erodes the electrodes. This results in a greater dissipation of energy at the tip but increases the initial breakdown voltage. Fuel wetting of the spark igniter tip will increase the energy expended but also raises the breakdown voltage. When the breakdown voltage of spark igniter reaches a predetermined value, it must be considered unfit for further use. Therefore, the design of a spark igniter tip will be a compromise between initial breakdown voltage, voltage variation with use, and arc resistance. Electrode geometry, electrode area, and electrode spacing will be determined accordingly.

Figure 10 illustrates the effect that spark igniter electrode erosion has on the spark characteristics. The values and changes in values indicated are actual readings taken on one ignition exciter, one discharge lead, and a new and used spark igniter. Other varieties of ignition system components will produce different values and changes but the trend is common to all. Figure 11, for instance, deomonstrates similar tendencies on tests made with a higher energy system than employed for Figure 10.

Ø The foregoing discussion is based on the general assumption that electrodes erode faster than ceramic. If ceramic erosion is more rapid than electrodes, such as may occur with certain soft ceramics and solid semiconductor materials, a cavity effect may confine the spark resulting in lower delivered energy.

7.1.1.3 Effect of Ground Return Paths: The ground return path of a discharge circuit is as important as the resistance of the lead conductor and must be kept short and of low impedance. The ignition lead shielding is usually used as the main ground return path with the engine frame acting as supplementary ground. To provide a low loss return path, more stringent requirements may be placed on the shielding construction than for radio shielding. In the event engine specifications do not require radio shielding and an unshielded lead construction is deemed adequate, care must be taken to assure good, low loss ground returns between the spark igniter and the exciter housing via the engine frame.

7.2 Required Spark Rate: The number of ignition discharges per second - spark rate - depends on the velocity of the fuel-air mixture, oscillation and/or rate of change of the fuel-air mixture, propagation speed of the burner, and permissible ignition delay. If the velocity of the combustible mixture is high and the spark rate low, propagation of ignited mixture may not be fast enough to establish a stable flame front. To improve this condition, flame holders may be used or spark rate increased to provide successive fire balls to establish a flame front. It should be recognized, however that increasing the ignition spark rate requires more input power, places more strain on and reduces the life of the ignition system components, with special emphasis given to the life of the spark igniter.

7.3 Spark Discharge Characteristics: The characteristics of the spark discharge become increasingly important with use of low volatility fuels, low ambient temperatures, and high altitude. The characteristics which are used to define the spark discharge are: spark duration, peak power, and spark energy.

The spark duration to be used for a particular system is determined from engine tests or from similarity to previous systems. The value may vary from 10-500 microseconds. Values for high tension systems are higher than those for low tension systems because of the inductance of the high frequency coil.

The peak power is important to provide reliable ignition and is determined as a minimum value. This value may vary from 10,000-500,000 watts for various types of ignition systems.

Figure 12 illustrates the effect on spark characteristics when a high voltage ignition system is modified to a low voltage system, accomplished by removing the high frequency transformer component from the discharge circuit. The same lead and spark igniter were used for both tests. Keeping this major change in mind, an examination of Figure 13 will illustrate again how changing lead length affects spark characteristics. By using a discharge lead three times as long as that used in Figure 12, we see that the 418,000 wattage peak is decreased to 278,000 with an accompanying drop in total energy from 2.23 Joules to 1.65 Joules.

8. ENGINE DESIGN DATA DETERMINING IGNITION CHARACTERISTICS

8.1 General:

8.1.1 Successful ignition of a turbine engine may be considered to occur in two stages: first, initiation of a flame in a very small volume surrounding the spark igniter tip and, second, propagation of the flame throughout the combustion zone. The limit of successful ignition may be determined by conditions affecting either one or both of these stages.

8.1.2 Obviously, local conditions at the spark igniter tip may be more or less favorable to the initiation of combustion than is indicated by overall conditions. Therefore, while they may be adequate for comparing propagation characteristics, such overall conditions may not be the basis for a valid comparison of starting characteristics.

8.2 Design Considerations:

8.2.1 The design of a gas turbine combustion system must of necessity include those characteristics conducive to the most efficient combustion for specific engine requirements. Mechanical considerations thus involved frequently necessitate compromise as, for example, the location of the spark igniter in relation to the fuel nozzle and spray pattern.

8.2.2 The engine designer may be expected to proceed in providing an optimum environment for initiation of combustion only as far as is necessary to meet engine performance requirements. For engines with atomizing fuel nozzles, the resulting design usually locates the spark igniter relatively close to a nozzle with its firing tip on the outer fringe of the spray and far enough forward in the combustion chamber to be out of the high temperature area during engine operation. The ignition system specified is usually of relatively high stored energy (2 to 20 Joules).

Figure 14 shows a typical spark igniter orientation in a spray nozzle combustor.

8.2.3 Should the arrangement initially selected prove inadequate, a number of adjustments and modifications may be investigated. The penetration of the spark igniter may be varied or its location altered with provision for cooling air, if necessary. Baffles or other means may be used to alter the air flow pattern in the vicinity of the spark igniter. Dual orifice nozzles may be used. Increased spark energy may be tried. And, more elaborately, separate starting fuel nozzles and torch ignition may be investigated.

8.2.4 For engines with vaporizing type nozzles or low pressure slinger type fuel injection, auxiliary atomizing type starting fuel nozzles are common practice. The nozzle and spark igniter are located in optimum position relative to each other and the combination may be located up-stream of the combustion chamber. The ignition system specified may be of relatively low energy (less than 2 Joules). Such a system has the extra advantage of providing added heat release to aid flame propagation or engine acceleration during starting.

Figure 15 shows a typical ignition nozzle and spark igniter relationship in an engine using slinger distribution of main fuel.

8.2.5 Other factors which are pertinent to the problem of turbine engine ignition involve fuel characteristics, temperature, pressure, velocity, nozzle characteristics, and spark characteristics including energy, repetition rate, and discharge wave form.

8.2.5.1 Fuel Characteristics: From the viewpoint of engine starting capability, two important fuel characteristics are volatility and viscosity. The viscosity is important in its effect on atomization by the fuel nozzle; relatively low viscosity is desirable. Volatility is a term used to describe the ease with which the fuel vaporizes. The more easily vaporized fuel, of course, is easier to light; therefore, high volatility is desirable. Also, for consistent starting results, it is desirable that the fuel be consistent in these characteristics; variations from batch to batch may produce inconsistent starting results.

8.2.5.2 Temperature: The important temperature is that of the fuel. So long as it is below that which will cause cracking or coking, the higher the fuel temperature the better from a starting viewpoint as volatility increases and viscosity decreases with temperature. Air temperature is important primarily as it assists in warming the fuel.

8.2.5.3 Pressure: The more rarified the mixture the more difficult it is to light. Therefore, engine restart capability is a direct function of combustion chamber pressure; the lower the pressure or, conversely, the higher the altitude the poorer the relight capability. Fuel pressure under starting conditions is also important to the extent that it affects atomization of the fuel by the nozzle; the higher the fuel pressure the better.

8.2.5.4 Velocity: Low air velocity may contribute to sea level starting limitations by allowing an excessively rich mixture to develop in the vicinity of the spark igniter. High air velocity is the principal contributor to altitude starting limitations as it affects both initiation and propagation of the flame. By suitable design, velocity may be restricted locally in the vicinicy of the spark igniter thereby making the limiting factor the velocity at which the flame will propagate.

8.2.5.5 Nozzle Characteristics: When the same nozzles are used for starting and running, the nozzles are designed primarily for the running conditions. The higher visocsity, lower fuel flow, and lower fuel pressure characteristics of starting conditions adversely affect atomization of the fuel. Improved atomization may be obtained by the use of dual orifice nozzles or separate starting fuel nozzles.

8.2.5.6 Spark Characteristics: Spark energy, spark rate, and spark discharge characteristics as they affect engine starting performance are discussed in paragraph 7.

8.3 Combustor Ignition Envelope: At low altitudes no undue problem with ignition might be expected except at extremely low temperatures. However, where high altitude ignition is required, development may be necessary. The following approach should prove helpful in this case:

1. Establish combustor windmilling air flow and inlet pressure and temperature over the range of altitude, required at the aircraft gliding speed, or, in multi-engined aircraft, at forward speeds to be expected with one or more engines off. These variables may be measured in an altitude test chamber, or in flight, or may usually be computed with sufficient accuracy particularly if one or two points are known.

2. Select several pressures in the area of interest and, in an altitude combustor test facility, set up in turn these pressures selected with their corresponding air flows and air and fuel inlet temperature established from item 1. Measure lean and rich blowout limits and lean and rich ignition limits by varying fuel flow at the set conditions.

3. Curves of the form of Figure 16 may now be plotted.

A study of this curve with flight ignition limit points on it will frequently serve to indicate the factor that is causing failure to start and so act as a guide to what to do about it.

For example, an optimum fuel flow for ignition might be expected to follow a line between rich and lean ignition limits. If the point where the engine fails to light falls near the lean combustor limit a simple increase of fuel flow may aid ignition. It should be pointed out here that fuel volatility or temperature variations may shift the curves toward richer or leaner mixtures as the controlling air fuel ratio is a local value in the primary combustor zone. The overall value plotted here does not vary exactly with this local value and is used only because it can be determined comparatively easily.

If ignition is required outside or to the left of the combustor stable buring range, some means of improving combustor stability until the engine accelerates to a higher combustor pressure may be needed. If basic combustor primary zone air flow adjustments to accommodate ignition are not possible for any reason, auxiliary ignition and piloting devices may be resorted to.

The shaded area at the bottom is intended to point up a deficiency in this method of ignition development. The effective air fuel for ignition will be different to that for combustion due to the absence of the vaporization from the combustion heating of the fuel. When a light is obtained, it will be followed by a rich blow out unless enough energy is released in the transient to accelerate the engine out of this area.

## 9. SUMMARY

The data and comments presented herein are necessarily condensed to the extent of illustrating the main issues requiring consideration in an engine/ignition system coordination program. It is intended to serve as a guide for those who may become involved in such efforts and to establish the major check points that should be considered early enough in any program to help expedite the most satisfactory and earliest final results. Negotiation and discussion between the engine manufacturer and ignition manufacturer will enlarge the issues and supplement the effort with necessary details peculiar to the particular situation involved.

While many of the phenomena of successful application of spark ignition to gas turbines are known and understood, much work remains yet to be done. Relatively minor adjustments in the engine burner design produce significant effects on the size, weight, and cost of the ignition system. Attention to those factors affecting energy delivered at the spark igniter tip can help reduce size, weight, and cost by raising ignition efficiency. The ultimate limit of these variables has not been reached and can only be sought for by continued efforts of all concerned. Such efforts, to be successful, must be based upon knowledge and acceptance of all contributors to the program.

## 10. NOTES

10.1 Marginal Indicia: The phi (ø) symbol is used to indicate technical changes from the previous issue of this report.



PREPARED BY

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TEST 1 STANDARD H. V. 14 J. SYSTEM
TOTAL SPARK ENERGY = 3.19 JOULES
PEAK WATTS = 170,000
SPARK DURATION = 69 μ SEC.

TEST 2 STANDARD H. V. 14 J. SYSTEM
WITH INDUCTANCE OF OUTPUT
CIRCUIT 2 TIMES THAT OF TEST 1.
TOTAL SPARK ENERGY = 2.74 JOULES
PEAK WATTS = 108,000
SPARK DURATION = 90 μ SEC.

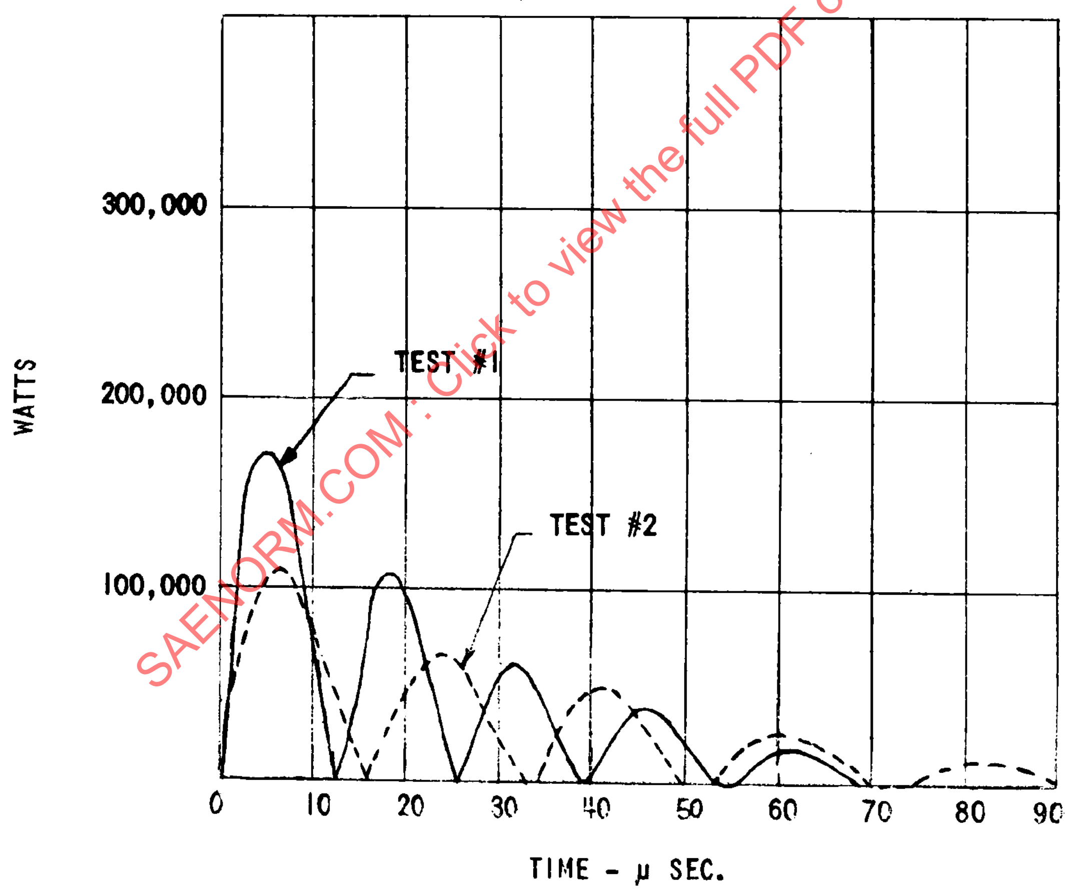


FIGURE 8

TEST 3 STANDARD H. V. 14 J. SYSTEM
TOTAL SPARK ENERGY = 3.19 JOULES
PEAK WATTS = 170,000
SPARK DURATION = 69 μ SEC.

TEST 4 STANDARD H. V. 14 J. SYSTEM
WITH OUTPUT LEAD LENGTH
3 TIMES THAT USED IN TEST 3.
TOTAL SPARK ENERGY = 2.35 JOULES
PEAK WATTS = 144,000
SPARK DURATION = 67 μ SEC.

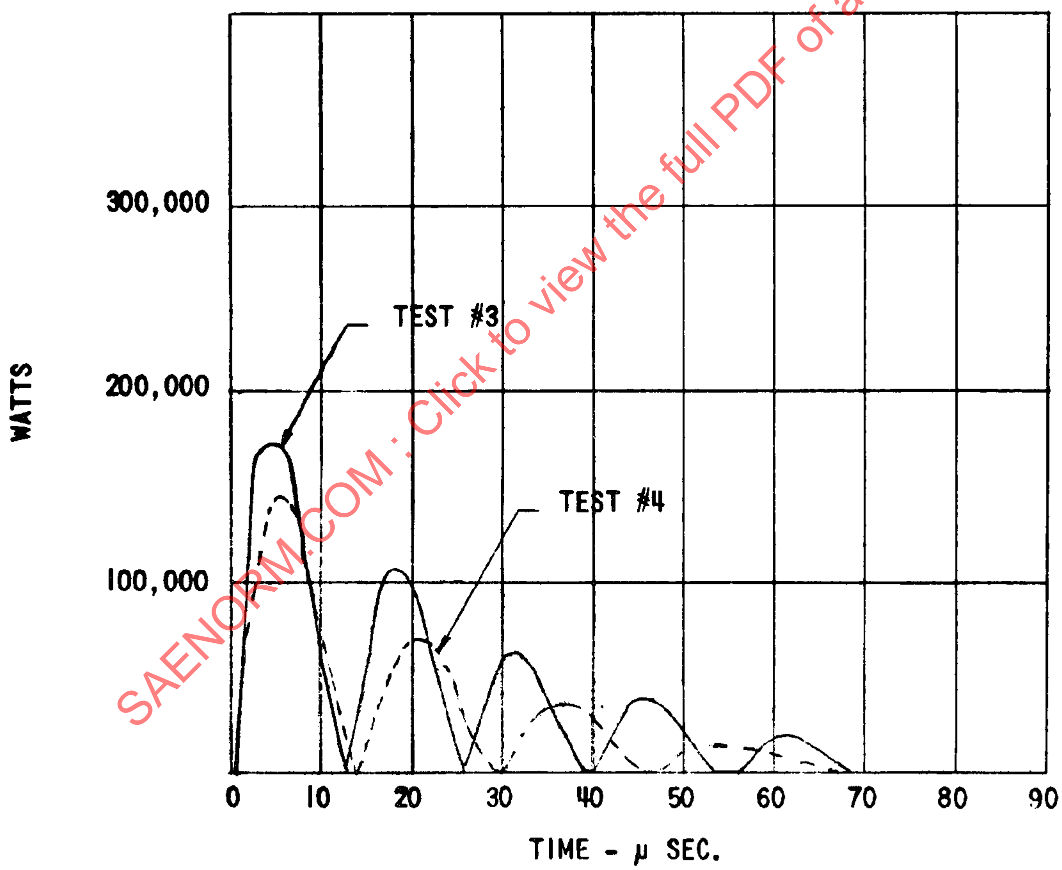


FIGURE 9

TEST #5 STANDARD H. V. 14 J. SYSTEM
TOTAL SPARK ENERGY = 3.19 JOULES
PEAK WATTS = 170,000
SPARK DURATION = 69 μ SEC.

TEST #6 STANDARD H. V. 14 J. SYSTEM
WITH BADLY WORN IGNITER PLUG
TOTAL SPARK ENERGY = 3.25 JOULES
PEAK WATTS = 198,000
SPARK DURATION = 67 μ SEC.

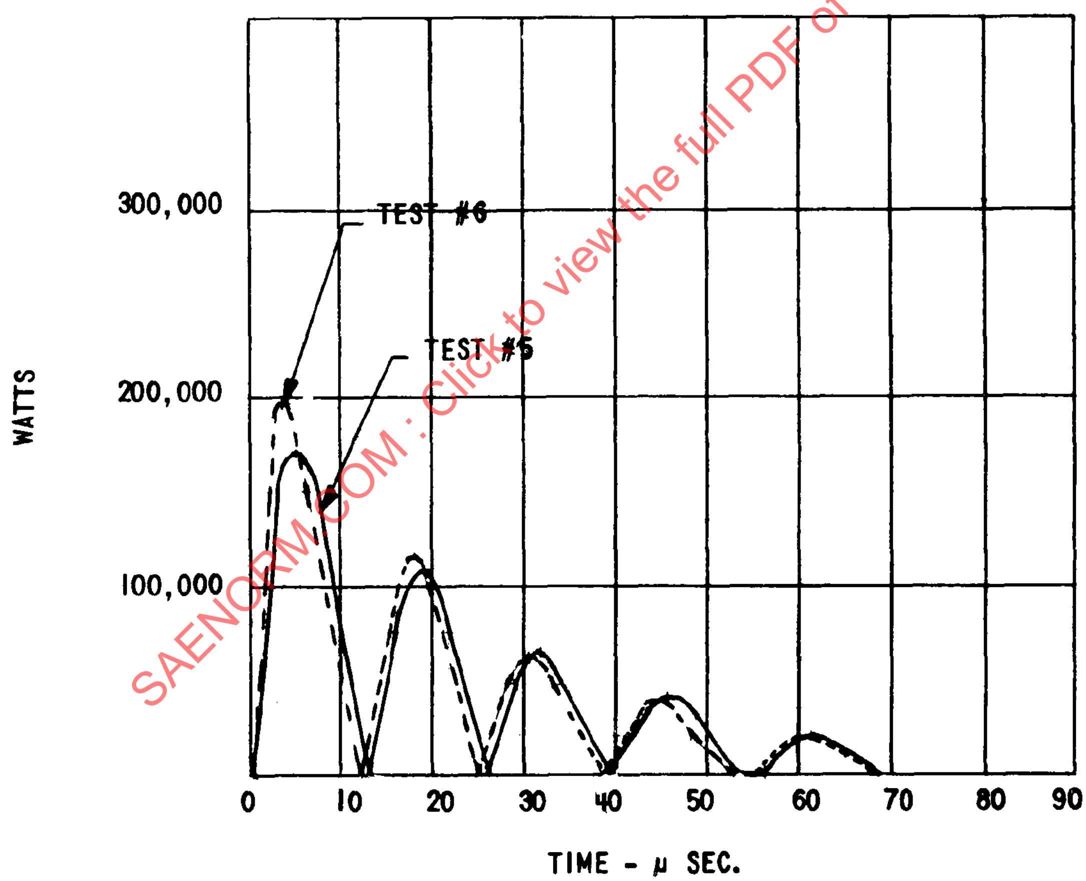




FIGURE 10

TEST #9 STANDARD H. V. 20 J. SYSTEM
TOTAL SPARK ENERGY = 6.03 JOULES
PEAK WATTS = 93,000
SPARK DURATION = 310 μ SEC.

TEST #10 STANDARD H. V. 20 J. SYSTEM
WITH OLD IGNITER PLUG JUST
PRIOR TO BEING WORN OUT.
TOTAL SPARK ENERGY = 8.6 JOULES
PEAK WATTS = 114,000
TIME DURATION = 340 μ SEC.

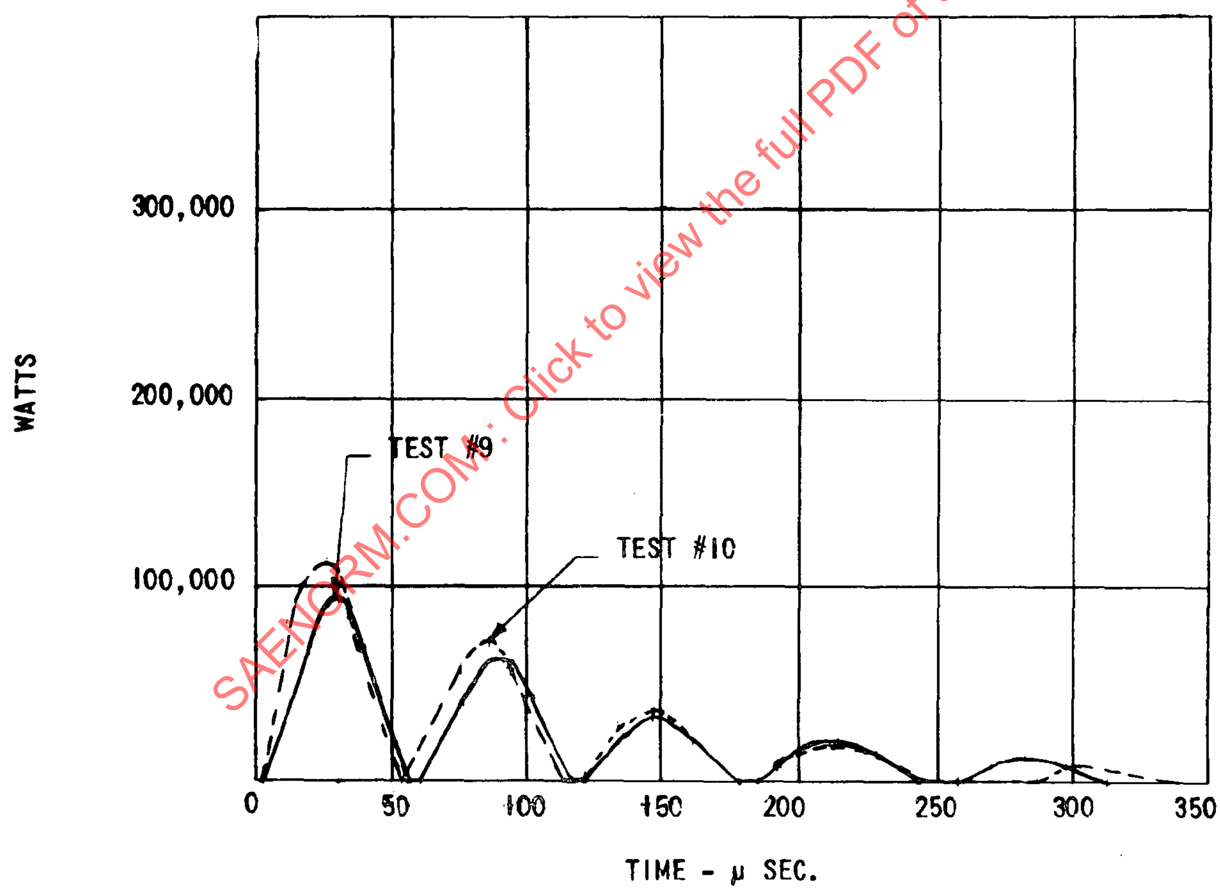


FIGURE 11