



400 Commonwealth Drive, Warrendale, PA 15096-0001

AEROSPACE INFORMATION REPORT



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

1. SCOPE:

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

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.

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.

1.1 Purpose:

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.

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.

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

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SAE AIR784 Revision C**2. REFERENCES:****2.1 Applicable Documents:**

The following publications form a part of this specification 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.

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

ARP484 Spark Igniter Gap Types
 ARP846 Low Tension Spark Igniter Sparking Voltage Test

2.2 Related Publications:

The following publications are provided for information purposes only and are not a required part of this document.

AIR77 Spark Energy Measuring Using Oscilloscopic Methods
 AIR84 Ignition Peak Voltage Measurements
 ARP294 Terminal, Lead, Low Voltage Igniter Plug
 ARP295 Terminal Well, Low Voltage Igniter Plug
 AS422 Spark Igniter Outline - Right Angle Flange Mounting
 AS423 Spark Igniter Outline - Flange Mounting
 ARP424 Spark Igniter Outline, Threaded Mounting Abbreviations
 AS453 Gasket
 ARP494 Terminals - Input - Ignition Exciters
 ARP504 Ignition System Testing - Metering and Power Supplies
 ARP670 Terminal, Aircraft Ignition
 AS692 Igniter, Spark, Aeronautical Engine (High Tension)
 AIR801 Oscillographic Method for Measuring Spark Energy of Capacitor Discharge Ignition Systems
 AS803 Igniter, Spark, Aeronautical Engine (Low Tension)
 AS814 Spark Igniter Outline - .750-20 Threaded Mounting
 ARP841 Leads Flexible, Shielded, High Energy Ignition
 AIR885 The Spark Calorimeter
 AIR1090 Ignition Exciter Output Voltage Pulse Measurement Using a Pressurized Ball Gap
 AIR1091 High Voltage Pulse Generator
 AIR1092 High Tension Exciter Output Voltage Measurement Using Cathode-Ray Oscilloscope
 AIR1423 Electromagnetic Compatibility on Gas Turbine Engines for Aircraft Propulsion

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2.2 (Continued):

RTCA/DO-160	Environmental Conditions and Test Procedures for Airborne Equipment
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-STD-1818	Electromagnetic Effects Requirements for Systems
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-8595	Engines, Aircraft, Turboprop, Qualification Test for
MIL-E-8597	Engines, Aircraft, Experimental Turboprop Preliminary Flight Rating 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

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 and categorized by "high voltage air gap, high voltage surface gap, and high voltage air surface gap" by ARP484. This type requires more than 5 kV potential to create a spark between the electrodes.
- 3.1.2 Low Tension: Defined same as 3.1.1 and categorized by "shunted surface gap" in ARP484. 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 V is applied, per ARP846.

SAE AIR784 Revision C**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." 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 3.2.1, 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.

3.4 Capacitor Discharge System:

An ignition system in which the spark energy is primarily the result of a capacitor discharge. (See 4.1, 4.2, and 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 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.) "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 microseconds, 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 ($1/2 LI^2$).

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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, 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 DC Capacitor Discharge System, High Tension (See 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 to 500 V). 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 in Figure 1 are available in many publications and in manufacturer's literature.

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4.1 (Continued):

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

- a. 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.

- b. 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 DC Capacitor Discharge System, Low Tension (See 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 in Figure 2 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:

- a. 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 are feasible in the air gap or surface gap types of high tension spark igniters.

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4.2 (Continued):

- b. 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.
- c. Lower discharge voltages permit smaller cable insulation, lighter leads, and are more easily controllable under extremes of ambient temperature and altitude.
- d. 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 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 (See 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:

- a. 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).
- b. It has three main disadvantages:
 - (1) Low spark peak power capable of igniting only the more easily ignitable fuels, and within narrow fuel-air ratio limits.
 - (2) Inductive sparks may be more readily quenched by fuel or moisture wetting, and shorted by carbon fouling or other products of combustion.
 - (3) High voltage output 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.

SAE AIR784 Revision C**4.4 Comments on DC Powered Circuits:**

The circuits illustrated in Figures 1 to 3 are shown as deriving their electrical power from a DC source. Also, the power portion of the circuits illustrates a vibrator-transformer used to interrupt and transform the DC 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 electromechanical 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 AC Powered Circuits (See Figure 4):

Figure 4 illustrates a typical AC powered capacitor discharge, high tension system. Comparing it with the DC powered circuit of 4.1 (see Figure 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 AC powered system, and the AC transformer can be substituted for the vibrator transformer in circuit 4.3.

Generally speaking, AC circuits may have one or all of the following advantages over DC powered circuits:

- a. Increased reliability
- b. Less cost
- c. Lighter weight
- d. Smaller size
- e. Longer operation life before overhaul
- f. Most adaptable to extreme ambient temperatures

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

4.6 Dual Ignition and General Comments:

In each of the previous 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.

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 circuit shown in Figure 6 is being used extensively in the gas turbine engine industry.

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 preceding 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 requires 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 troubleshoot 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 sensing elements and appropriate connectors. It should be noted that the only absolute guarantee of a spark occurring in the proper location is through some optical detection means.

SAE AIR784 Revision C**4.7 Unidirectional Discharge Circuit (See Figure 7):**

A unidirectional capacitance discharge circuit can produce discharge efficiencies of 20 to 60% rather than the 10 to 30% mentioned in 6.1.1. The unidirectional discharge circuit provides a nonoscillatory 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 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 bypasses 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 (see Figure 17), rather than an oscillatory wave form shown in Figures 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

Limitations of this type of circuitry are:

- a. High surge current and high temperature diodes. Availability may be a limiting factor in some applications.
- b. Igniter electrode erosion may differ from that of an oscillatory system of comparable delivered energy.
- c. Igniter electrode erosion patterns are more affected by discharge polarity than in oscillatory systems.