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AN IGNITION SPARK DETECTOR
FOR THE NES STEAM GENERATOR

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AN IGNITION SPARK DETECTOR
FOR THE NES STEAM GENERATOR

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ROCKET ENGINE OPERATIONS - NUCLEAR

April 1965

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ABSTRACT

In the NES Steam Generator spark ignitor circuit one of three conditions will exist: (1) proper sparking, (2) no spark due to lack of proper voltage at the electrodes, and (3) no spark due to a shorted or fouled plug. As a result, the display should be "go" for (1), and "no go" for (2) and (3).

Two basic approaches to spark detection were considered - the first utilizing 60-cycle components of current, and the other utilizing higher frequency components.

Basic data were gathered on the 60-cycle approach and analyzed. It was soon found that this approach was impractical since the differentiation between "go" and "no-go" conditions was much too subtle.

The method utilizing high-frequency components of arc current was investigated and found to be very practical. Furthermore, this method has been used for some time as an oscilloscope presentation for internal combustion engine operation diagnosis.

A practical circuit utilizing these high-frequency components for detection was designed, tested, and delivered as an operational unit.

for
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1.1 INTRODUCTION - The NES Steam Generator two-stage ignitor incorporates a first-stage to second-stage differential pressure switch to sense combustion in the first stage chamber. If pressure is not detected within 1 to 2 sec, a time delay will trip the control circuit, close all valves, and send back a signal, "No First-Stage Ignition."

However, assuming that the propellants did not ignite, the operator cannot know whether the ignition spark was at fault. It was desired, therefore, to determine proper spark operation - both during the pre-start "cold checkout" phase and during the hot run - and display this information as a "go, no-go" light on a console about 1400 ft away.

2.1 CRITERIA OF OPERATION - The criteria of operation of the spark detector for remote display are that the indicator light should come on if, and only if, an ignition spark exists in the gap. Neglecting the possibility of an arc occurring external to the gap (a very low probability), the following Truth Table delineates the conditions found to exist:

TRUTH TABLE

No.	Description	Electrical Conditions at Gap			Indicator Light
		at 60 Cycles		at High Freq	
		Voltage	Current	Voltage	
1	Open Circuit	10 kv rms	Zero	Low	Off
2	Normal Spark	Approx 300 v	Approx 30 ma	High	On
3	Shorted Plug	Zero	Approx 30 ma	None	Off

Consideration of the Truth Table suggests a plan of approach utilizing 60-cycle components of current or voltage. If the voltage across the gap is not zero and the current through the gap is not zero, the spark is normal.

2.2 CHARACTERISTICS OF THE ARC - Before discussing spark detection methods, it would be well to look briefly into typical characteristics of the arc. This is best done oscillographically.

Curve A of Figure 1 shows the unloaded (or open) circuit voltage waveform at the secondary of the transformer. At the pressure utilized (i.e., 109 psig), no arc occurs at the gap since no ionization can be initiated. (See Figure 2 for curve of these relations.) The voltage available for driving the arc is seen here to be 21.2 kv peak.

Curve B waveform shows the voltage occurring at the spark gap under arcing conditions. This voltage is measured at a pressure of 20 psig which permits ionization and, thus, the arc. The first positive burst shows 4850 v. This represents the ionizing potential under these conditions and correlates with Figure 2. Immediately following this first burst is seen the transient oscillations whose peak-to-peak voltage is approximately 3200 v. These transient oscillations seem to have an abrupt, unexplained, discontinuity at the trailing edge.

The remainder of the half-cycle wave flattens out at approximately 350 v and represents the sustaining, steady-state voltage across the spark gap.

However, at the half-wave period there occurs another positive pulse. No explanation for this has been determined. In fact, it is not known whether this occurs before or after the generated voltage wave crosses the zero axis.

Curve C is, for all practical purposes, the same as Curve B except that the arc was at atmospheric pressure.

2.3 CONSIDERATIONS OF LOW-FREQUENCY ARC COMPONENTS - Two arc detection schemes are discussed in the paragraphs below.

2.3.1 The first arc detection scheme to come to mind is that of measuring the current through the arc and determining whether that current is within limits. Figure 3 shows a test setup and table of observed data for

T1 - Hi Voltage Transformer
 E1 - 40 mil Spark Gap
 Z1 - Dummy load 5.6 M ohm Resistor
 OSC - Oscilloscope

Horz. Sweep = 2 ms/cm

A

884v/cm

B

4420v/cm

C

2110v/cm

Figure 1
 Spark Gap Voltages

(See Figure 1 for Schematic)

Figure 2

Extinguishing Gap at 15 kv rms

T1 - High Voltage Transformer, Webster Manufacturing Co., Type 721-A18
Prim 115V 4.5a Sec 15 kv 30 ma 60 cps

M1 - Milliammeter, 0-30 ma, Weston MDL 370 $\pm \frac{1}{4}\%$, Internal Res 915 ohm

R1 - Precision Shunt, 1830 ohm $\pm 0.1\%$

E1 - Variable Spark Gap - 32 pitch screw

GAP WIDTH Inches x $\frac{1}{1000}$	METER READING ma	ARC CURRENT ma	VARIATION From Midpoint, %
0	21.40	32.10	+0.16
16	21.50	32.10	+0.16
31	21.40	32.10	+0.16
47	21.37	32.05	0
63	21.35	32.02	-0.09
78	21.35	32.02	-0.09
94	21.34	32.01	-0.13
109	21.35	32.02	-0.09
125	21.35	32.02	-0.09
141	21.38	32.06	+0.03
156	21.35	32.02	-0.09
172	21.35	32.02	-0.09
188	21.35	32.02	-0.09
203	21.33	32.00	-0.16
219	21.33	32.00	-0.16

Figure 3

Arc Current

checking current variation with a change in arc impedance (as controlled by gap width). Note that a maximum variation of 0.32% in current exists throughout the range of gap widths.

Although current detection differentiates between normal spark and open circuit, it cannot be used for detection of a shortened plug and was therefore considered impractical for the intended purpose.

2.3.2 Another scheme for 60-cycle detection is suggested by the "Truth Table: that of detecting both current and voltage through an "And-gate." Such a scheme, shown in Figure 4, uses "Raysistors" as detecting elements. This proved unsuccessful due to the extreme range of voltages occurring across the gap and hence across the neon lamp in Q2, during each cycle. The characteristics of photoconductive switches and neon lamps follow in Sections 3.1 and 3.2.

At this stage of the investigation, final design considerations were inherent in the recorded data. This will be discussed in Section 4.1.

3.1 PHOTOCONDUCTIVE SWITCHES - The ratio of lighted conductivity to dark conductivity of cadmium sulfide and cadmium selenide cells range from approximately 2500 to 750,000. A typical device has a lighted resistance of 1000 ohm and a dark resistance 100 of megohms. This is a conductance ratio of 100,000.

If a relay were connected in series with this cell, and the cell irradiated from a light source, an inexpensive and extremely reliable light-actuated switching circuit would result. If, further, this light source were an incandescent or neon lamp, then the combination would constitute a relay with good electrical isolation between input and output. In this investigation, for purposes of high-voltage and low-current input characteristics, a unit was chosen using a neon lamp as the light source.

The particular unit chosen was one of a line of "Raysistors" as manufactured by the Industrial Components Division of the Raytheon Co., Newton, Massachusetts. Figure 5 shows the characteristics of this device.

Schematic

- T1 - High Voltage Transformer
- M1 - Milliammeter
- E1 - 40 mil Spark Gap
- Q1 - Incandescent "Raysistor"
- Q2 - Neon "Raysistor"
- R1 - Current Adjusting Resistance
- R2 - Voltage Adjusting Resistance

Figure 4

Spark Detector, E & I "And-Gate"

Figure 5

Rayistor Output Resistance vs Control Current for Raytheon No. CK 1105

3.2 NEON LAMP CHARACTERISTICS - In the deionized condition, a neon lamp displays an extremely high impedance - in the order of 10 k-ohms. As a result of this, the burden imposed by the lamp on a voltage source is effectively zero before ionization. Furthermore, this zero current produces no voltage drop across any element connected in series with the lamp; hence, the full source voltage is present at the terminals of the lamp. At any source voltage over about 100 v, this ensures at least ionization of the neon.

In the ionized condition, the lamp operates in a completely different condition wherein it becomes a constant voltage device. This, then, converts the series network comprising Z1 and VI (Figure 6a) in such a manner that the resultant impedance is equal to Z1; Z1 then becomes the sole current regulator.

Another phenomenon was observed in the neon light: an apparent reduction of ionizing potential required as the frequency applied increased. It is assumed that this is related to the capacitive effect in the neon bulb itself.

4.1 HIGH-FREQUENCY VOLTAGE - Considerations in the Truth Table in Section 1 point up another method of detection. As seen in the table, the only condition producing high values of high-frequency voltage is that of normal arc (i.e., this is the one parameter that exists only during spark discharge).

The oscillograms in Figure 7 show the effect of a tuned filter on the waveform. These patterns should be compared with similar curves in Figure 1.

The filter, tuned to 22.5 kc is composed of the L-C-R network (L1, C1, and R1). The parallel tank (L1 and C1) presents a low impedance to all frequencies except 22.5 kc which happens to be the natural resonant frequency of the ignition transformer and connected wiring. This, then, permits the high frequency (22.5 kc) to flow through into the detector while rejecting, substantially, the 60-cycle frequency components.

Figure 6

Detector Coupling to High-Voltage/High-Frequency Source

T1 - H V Transformer

E1 - Spark gap

C1 - 0.007 F

L1 - 7 mh

R1 - 5.6 M

Z1 - Dummy load
7 M

Figure 7

Basic Tuned Filter Spark Detector

Curve A shows the waveform under conditions of 109-psi chamber pressure and no arc across the spark gap. The slight amount of 22 kc present is judged to result from the presence of corona discharge in the wiring associated with the test setup. This can be reduced considerably by careful design. As seen on the oscillogram, the amplitude is approximately 100 v peak.

Comparing Curve B, where the 22 kc waveform reaches approximately 1000 v peak, to Curve A shows that this method furnished a 10-to-1 differentiation between arcing and not-arcing conditions. This is ample for reliable "go, no-go" indication.

Curve C shows the same waveform when the chamber pressure is reduced to atmospheric. Here, the voltage is reduced to approximately 600 v peak, but is still entirely adequate for indication.

4.2 OUTPUT CIRCUIT

The waveforms in Figure 8 are the result of further waveshaping in the transistor circuits. This shaping is largely a matter of pulse stretching in order to keep the indicator, DSL, energized sufficiently long during each pulse to show a positive light when necessary. The diagram shows one successful solution to the problem of arc detection. That portion to the left of Test Point "2" would retain its configuration under all variations of this basic detection scheme. That portion to the right, however, could have numerous variations - all successful to varying degrees.

5.1 OPERATIONAL CIRCUIT - Figure 9 shows a circuit utilizing the high-frequency characteristics of an ignition spark circuit along with a Raysistor, a transistor, and a relay. Rapid changes of current in the r-f choke (L1), connected in series with the ignition transformer secondary and spark gap, occur at the instant of spark initiation with ionization. The extremely fast rise time of the current pulses through the choke results in large voltages $\left(L \frac{di}{dt} \right)$ across this element which far exceed the firing potential of the neon lamp.

Figure 8

Tuned Filter With Amplifier and Pulse Network

Relay shown in energized condition

- T1 - H.V. Transformer
- E1 - Spark Gap
- L1 - 200 μ h
- R1 - 470 ohm, $\frac{1}{2}$ w
- R2 - 10 k ohm, $\frac{1}{2}$ w
- Q1 - 2N1026
- Q2 - Raysistor, CK1105
- K1 - Relay, 2.5k ohm
- DS1 - Remote Indicator Lamp
- CR1 - 1N645

Figure 9

Schematic of Ignition Spark Detector, P/N 096734

With the neon lamp firing, the impedance of the photosensitive resistor (CdS) is low (about 8000 to 14,000 ohms), whereas the dark resistance is about 1 megohm. In the low impedance state, sufficient current flows into the base of the transistor (Q1) to operate the relay (K1) in the emitter circuit.

The back biased diode (D1) across the relay coil protects the driver transistor from destructive relay coil transients which might otherwise be imposed on the emitter-base junction, and the emitter-base resistor (R2) tends to keep the emitter-base voltage below the nominal 0.7 v normal for a silicon transistor. The result is that the driver transistor will remain essentially cut off (with respect to the relay) until the neon lamp is excited by the input firing pulses.

The series resistor (R1) connected to the neon lamp limits the average current through the lamp to a safe value for reliable operation. The resistance value is calculated to limit the lamp current to 3 ma with the spark operating at nominal chamber pressure.

The original breadboarded circuit used a resistor instead of the choke, but although this circuit provided an output indication, it did not provide frequency discrimination between 60 cycle and 22 kc (see Section 6.1). Additionally, the original circuit did not use a driver transistor. The driver was added to assure reliable operation with a "standard" relay.

No definite conclusions can be made on the effects of gamma radiation on the driver transistor since no testing was conducted in this environment. However, the literature indicates that 10 hours of operation in a 6×10^6 erg/g(C) flux is very likely with the 2N1026 transistor used. If this should prove marginal, a special radiation-resistant type can be substituted. The circuit should operate satisfactorily with any silicon PNP transistor having a beta greater than 3.7 and a leakage current of less than 26 μ a. These figures are derived from a worst-case analysis assuming 28 ± 4.2 v and the manufacturer's specification on the upper limit of beta of 44. This analysis also neglected the further stabilizing effects of the 10 k-ohm resistor (R2) at the base. Under these conditions, beta would have to be degraded to 20% of the minimum specified in the manufacturer's data sheet, and leakage current could go up by three orders of magnitude before equipment failure resulted.

6.1 ADDITIONAL CONSIDERATIONS - Figure 10 shows the completed package, P/N 096734A. The circuit diagram of this device (Figure 9) is not considered optimum. It was designed for a specific application but is considered applicable for any service with similar parameters.

Some improvements could be investigated in the laboratory. One that comes to mind would be to replace the CdS cell with a light-activated diode (otherwise known as a 4-layer switch) and possibly eliminate the transistor. This would decrease the circuit time constant and would require a-c operation to commutate the switch, or some other means to turn it off.

Another possibility is indicated in Figure 6. In sketch (a) of this figure, Z1 is shown as a typical series impedance element, resistive only. This is typical of neon lamp applications for 120 v, ac, 240 v, ac, etc. As a high voltage detector, it is excellent. However, if a series capacitor of appropriate value is added (as in Z2), a frequency sensitive element is introduced such that, within limits, the current through the neon lamp is proportional to the frequency of the source voltage. This then will differentiate between the 60-cycle and the 22-kc voltages.

This concept can be taken even farther by eliminating the resistor entirely and depending upon the capacitor for the series current regulating impedance as in Z3. This series capacitor can be further modified as shown in Figure 6b by building one plate of the capacitor in the form of a semi-shield external to the glass bulb of the lamp. The other plate of the capacitor is constituted by the combination of the normal electrodes in the bulb and the neon.

Under deionized conditions, the electrodes constitute one plate of the capacitor whose dielectric is the neon and the glass envelope. On the other hand, during ionized conditions, the neon constitutes the plate of a capacitor whose dielectric is the glass envelope. Here again, the current (hence, light intensity) is proportional to frequency. If the voltage and frequency are high enough, this furnishes an excellent and inexpensive spark detector for remote indication. A possible package configuration is shown in Figure 11.

Figure 10
Ignition Spark Detector

NOT TO SCALE

Figure 11

Possible Package for Improved Spark Detector