NASA TECHNICAL MEMORANDUM

NASA TM-73833

NASA TM-73833

(NASA-TM-73833) A SUSTAINED-ARC IGNITION SYSTEM FOR INTERNAL COMBUSTION ENGINES (NASA) 15 p HC A02/MF A01 CSCL 09C

N78-13331

Unclas

G3/33 55242

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November 1977

1. Report No. NASA TM-73833	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A SUSTAINED-ARC IGNITION SYSTEM FOR INTERNAL COMBUSTION ENGINES		5. Report Date
		6. Performing Organization Code
7. Author(s) Arthur G. Birchenough		8. Performing Organization Report No. E-9420
		10. Work Unit No.
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

A sustained-arc ignition system has been developed for internal combustion engines. It produces a very-long-duration ignition pulse with an energy in the order of 100 millijoules. The ignition pulse waveform can be controlled to predetermined actual ignition requirements. The design of the sutained-arc ignition system is presented in the report.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Spark ignition; High voltage converter; Automotive ignition systems; High energy ignition	Unclassified - unlimited STAR Category 33

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified		

* For sale by the National Technical Information Service, Springfield, Virginia 22161

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SUMMARY

Current ignition systems operate by discharging energy stored in an inductor or capacitor into a gap, and are thereby limited in the amount of energy which can be delivered. Additionally, the duration of the ignition pulse is limited. Lean operation of internal combustion engines requires a very-high-energy and long-duration ignition pulse. The sustained-arc ignition system does not rely on discharging stored energy, and therefore can develop very-long-duration pulses and high energy levels. Pulse duration is limited only by the engine physical requirements and not the ignition system itself.

This ignition system was developed for use in an internal combustion engine research program. The ignition parameters can be varied to control the ignition pulse and determine actual ignition requirements for lean operation. The ignition system developed ignition pulses of high energy and long duration as designed on an automotive engine. No component failures were encountered with either the ignition system or existing engine components during the operation of the engine.

INTRODUCTION

Automotive ignition systems have been relatively unchanged over the last fifty years since the Kettering system was developed. Early electronic ignitions reduced point current and, therefore, deterioration, but retained the Kettering ignition system principles. Later developments have replaced the points with magnetic and photoelectric pickups, but still retained the Kettering system.

The first real change in ignition systems was the introduction of capacitive discharge ignition, relying on capacitive instead of inductive energy storage to provide the ignition energy.

Recently more effective ignition systems have been sought to decrease engine misfiring and allow leaner operation to reduce pollution and increase efficiency. Typical approaches have been improvements in the Kettering system, and multiple-firing capacitor discharge systems. A longer arc duration is desired, but these systems deliver energy only for short durations or in a series of discrete bursts. Many theories of lean engine operation indicate that a long-duration continuous discharge is necessary to initiate combustion in a lean mixture (refs. 1 and 2).

The Sustained-Arc Ignition System described in this report was developed to provide a continuous ignition source for long arc durations, not limited by energy storage capacity as with the Kettering or capacitive discharge systems. The ignition source can be controlled to accurately determine the ignition energy level and duration requirements of an engine. Although developed primarily as a research tool, this ignition system could be practical for mass production automotive use if the potential advantages of high-performance ignition systems can be realized.

OPERATING PRINCIPLE

In the Kettering ignition system, primary current builds up as the points, or electronic switches, are closed. As the points open, the magnetic energy stored in the primary is transferred through a high-turn ratio transformer to the secondary. The inductive voltage spike generated, in the order of 5 to 50 kV, breaks down the spark plug gap, initiating current flow in the spark plug. Once fired, the arc voltage is 1 to 2 kV, and the arc current decreases to zero in 0.5 to 1 msec as the stored energy is dissipated.

Assuming a lossless system, except for the arc dissipation, the initial arc current will be the primary current divided by the turns ratio. The current decreases then by the relation:

$$E = L\frac{di}{dt} \text{ or } \frac{di}{dt} = \frac{E}{L} \qquad (1)$$

E = Secondary Voltage
L = Secondary Inductance
i = Secondary Current

Additionally, the available stored energy is given by

$$\mathcal{E} = 1/2\ Li^2 \qquad (2)$$

$\mathcal{E}$ = Stored Energy
L = Primary Inductance
i = Primary Current

Reducing the arc voltage, a function of spark plug gap, or increasing the coil inductance or primary current will increase the arc duration. But the duration and energy are still limited to the energy storage capabilities of the coil.

Reducing the voltage to zero in equation (2) would indefinitely sustain the arc current. In the sustained-arc ignition system arc duration is extended by connecting a high voltage dc source approximately equal to the arc voltage in series with the ignition coil. The coil acts as a stabilizing impedance maintaining arc current during transients. Because of the high voltage source the voltage across the coil is nearly zero, and the arc can be sustained until the high voltage source is turned off. The arc may also be terminated by turbulence in the cylinder, essentially blowing out the arc, or by the high voltage distributor moving away from the proper spark plug, which would also require a large arc voltage inside the distributor. The arc can be easily sustained for 30°, far exceeding conventional systems.

On the sustained-arc ignition system developed, a Kettering system is used to initiate the arc. The sustaining system has no effect on the striking portion, and provides a low impedance return path for the secondary current. A dc-dc converter generates the 1 to 2 kV required to sustain the arc. The arc voltage varies considerably with cylinder pressure, air-fuel ratio, turbulence, and spark plug gap. The converter should, therefore, produce a high impedance current source output. Output voltage ripple is noncritical because the ignition coil secondary inductance is an effective output current filter. The converter must be turned on when the points open and off when the arc should be terminated.

IGNITION SYSTEM DESIGN

The sustained-arc ignition system currently developed is designed for use on multicylinder conventional automotive engines, using the breaker points for timing and a conventional distributor for high voltage distribution. It can be adapted for single-cylinder engines, and timed by magnetic or photoelectric sensors. Conventional mechanical timing advance mechanisms are used, although electronically-controlled timing advance could be used as with any electronic ignition.

Although the points could switch the ignition coil primary current directly, a transistorized switch is used to obtain faster rise times, higher current capability, and to reduce deterioration of the points.

The dc-dc converter, powered directly from the 12 V battery, is a flyback converter (refs. 3 and 4), which inherently has a high output impedance, approximating a current source. The converter is turned on and off by the points. When the points open, the transistor switch is opened to initiate the arc, and the converter is turned on. Closing the points turns off the converter and closes the transistor switch, reestablishing the ignition coil primary current. The ignition coil is essentially a conventional 100:1 turn ratio coil; but instead of a conventional autotransformer connection, the secondary winding is returned to the converter output. A block diagram is shown in figure 1. The transistor switch represents the conventional ignition portion of the circuit. A complete schematic of the ignition system is shown in figure 2 with a parts list in table I. The Kettering ignition section is a two-transistor switch, using a Darlington output stage clamped by zener diodes and a capacitor, which control peak voltage and risetime respectively. A ballast resistor is used to limit primary current to approximately 5 amps, which gives a 50 mA initial secondary current.

The dc-dc converter is a flyback design which is very similar to the Kettering ignition principal. A transistor is turned on, causing a current to increase in the output transformer primary. When this transistor is turned off, the energy stored in the primary inductance is discharged through the secondary, where it is rectified and filtered. This type design is advantageous for this application because the power switch is well isolated from the load, and therefore operation into a widely varying load, including a short circuit is easily accommodated. The converter is basically operated with constant off time, and transistor on time is controlled by sensing transistor current. Transistors Q_2 and Q_3 (fig. 2), are a quasi-Darlington connected pair switching primary current. Primary current is sensed by R8, and compared to a voltage developed across zener diode D3, using one section of a quad-integrated circuit comparator Z1b. When the primary current exceeds 10 amperes, the output of comparator Z1b goes low, turning off the output transistors Q2 and Q3 through comparator Z1a and diodes D1 and D2 to the converter output. There are two series connected output windings to reduce the stress on the diodes and reduce interwinding capacitance effects. As soon as transistors Q_2 and Q_3 turn off, comparator Z1b goes high, but Z1a inhibits turn on until the C1 - R_5 network recharges, $\approx 50\ \mu$sec, generating the constant off time. Comparator Z1c senses when the points are closed, and inhibits the converter during this time. Comparator Z1d senses overvoltage to protect the output transistors, diodes and capacitors. During overvoltage the converter changes to variable off time operation. The converter has a high output impedance, which maintains reasonably constant output current during load variations. The ideal converter for this application would be a true current source. This could be approximated by using current feedback in this design, but is not necessary for reasonable operation. The output voltage as a function of converter supply voltage and output current (load) is shown in figure 3.

PERFORMANCE

Spark plug voltage and current waveforms are shown in figure 4(a). The initial high voltage spike is not visible in the photographs. The current trace shows a slight decline from the initial current level determined by the Kettering system discharge to the sustaining portion, which is then nearly constant until turnoff. The voltage during arcing is nearly constant except for the transients due to arc instability. Ignition voltage does not decrease to zero immediately due to cable capacitance. A typical trace of instantaneous power and a running integral of power (energy), are shown in figure 4(b). Standard ignition system traces are shown in figure 5 for equal conditions. These waveforms were obtained from an ignition energy instrument developed during this program.

The system described is nonadjustable, but can be easily modified to provide for parameter changes. Changes in duration, energy level, initial current level, peak voltage, maximum sustaining voltage, and risetime, for example, can be accomplished by changing point gap, converter supply voltage, ballast resistor, zener clamps, overvoltage regulation, and capacitor C7, respectively. Optimum values for these parameters would be determined during engine testing.

Input power is in the order of 60 watts, and results in ignition energies around 100 millijoules. A normal Kettering system consumes half the input power, but only produces a 10 millijoules pulse during lean engine operation.

This design requires careful component layout to isolate the high voltage components, but operated reliably during testing, with standard ignition system components-distributor, ignition wires, spark plugs - on the engine. There were no failures in the system during engine operation.

CONCLUDING REMARKS

Lean-burn internal combustion engine operation requires improved ignition. The long-duration ignition pulse produced by the sustained-arc system may be the optimum waveform for lean operation. The sustained-arc system permits parameter variation to determine the actual ignition requirements.

The ignition system described produces 100 millijoules ignition energies in normal engine operation. Pulse duration is typically 30° on an eight-cylinder engine. Tests performed showed reliable performance and produced the long-duration pulses as designed.

REFERENCES

1. Johnston, Richard W.; Neuman, John G.; and Agarwal, Paul D.: Programmable Energy Ignition System for Engine Optimization. SAE Paper 750348, February 1975.

2. Burgett, Richard R.; Leptich, Joseph M.; and Sangwan, Karma, V. S.: Measuring the Effect of Spark Plug and Ignition System Design on Engine Performance. SAE Paper 72007, January 1972.

3. Mc Lyman, William T.; and Willner, K.: Boost Regulator Design and Development. (TR-1001, Wilorco, Inc.; NASA Contract NAS7-100.) NASA CR-100448, 1969.

4. Babaa, Ihsan M. H.; Wilson, Thomas G.; and Yu, Yuan: DC to DC Converter Regulated by a Constant-Frequency Duty-Cycle Generator. Proceedings of the National Electronics Conference, Vol. XXIV. National Electronics Conference, Inc., 1968.

TABLE I. - PARTS LIST

$C_{1, 2, 3}$	0.001/1000
$C_{4, 5, 6}$	0.002/6000 V
C_7	0.1/6000
$D_{1, 2}$	50 mA, 6000 V, Fast recovery
D_3	IN4735
$D_{4, 5}$	IN5385
$Q_{1, 4}$	2N2222
Q_2	2N2405
Q_3	2N5038
Q_5	SVT6002
$R_{1, 4}$	4.7 K
R_2	180 Ω 1 W
R_3	220 Ω
$R_{5, 12}$	47 K
R_6	22 Ω 1/2 W
$R_{7, 11, 13}$	10 K
R_8	0.1 Ω 10 W
$R_{9, 10}$	27 K
R_{14}	30 meg 2 W
R_{15}	2 Ω 50 W
R_{16}	220 Ω 1 W
R_{17}	470 Ω
R_{18}	100 Ω 5 W
T_1	23 tns tapped at 2 tns 10 amp sat.
T_2	1150 tns × 2
Z_1	Modified standard ignition coil
	MC3302

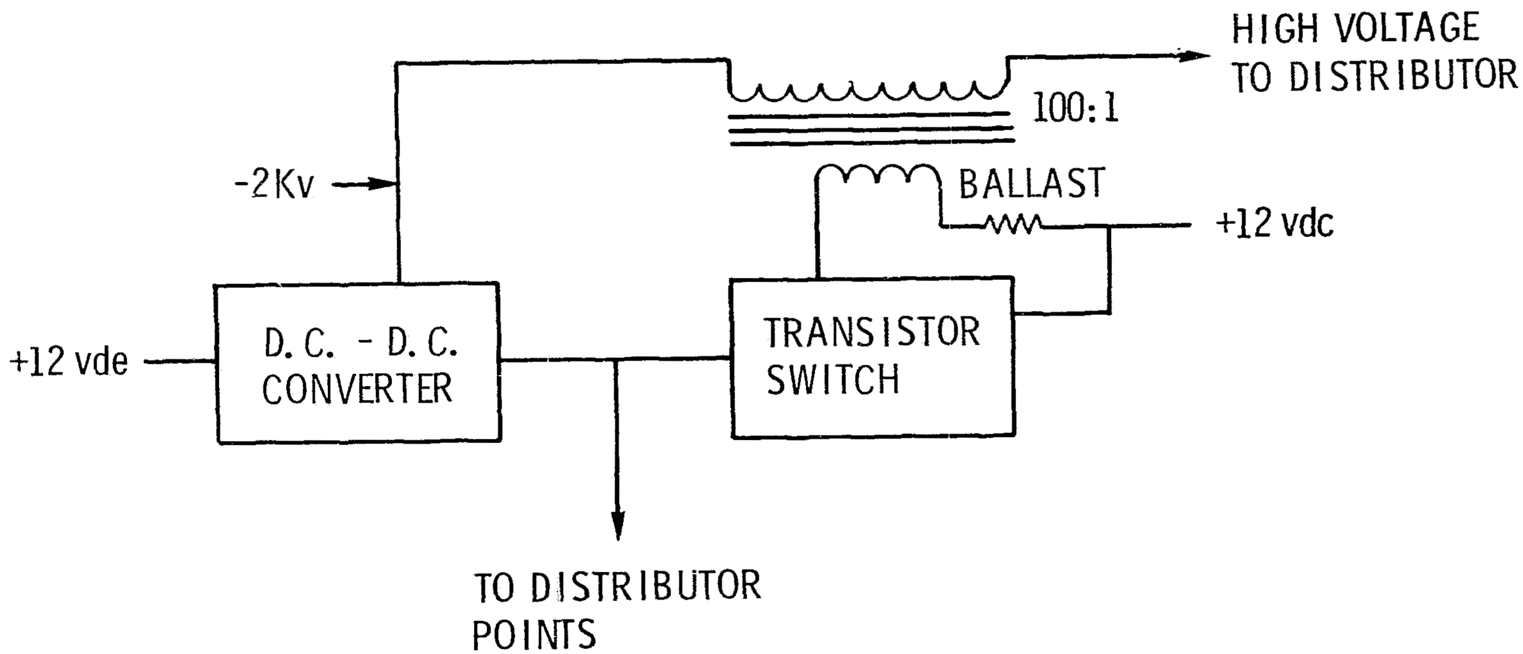

Fig. 1. - Block diagram sustained arc ignition.

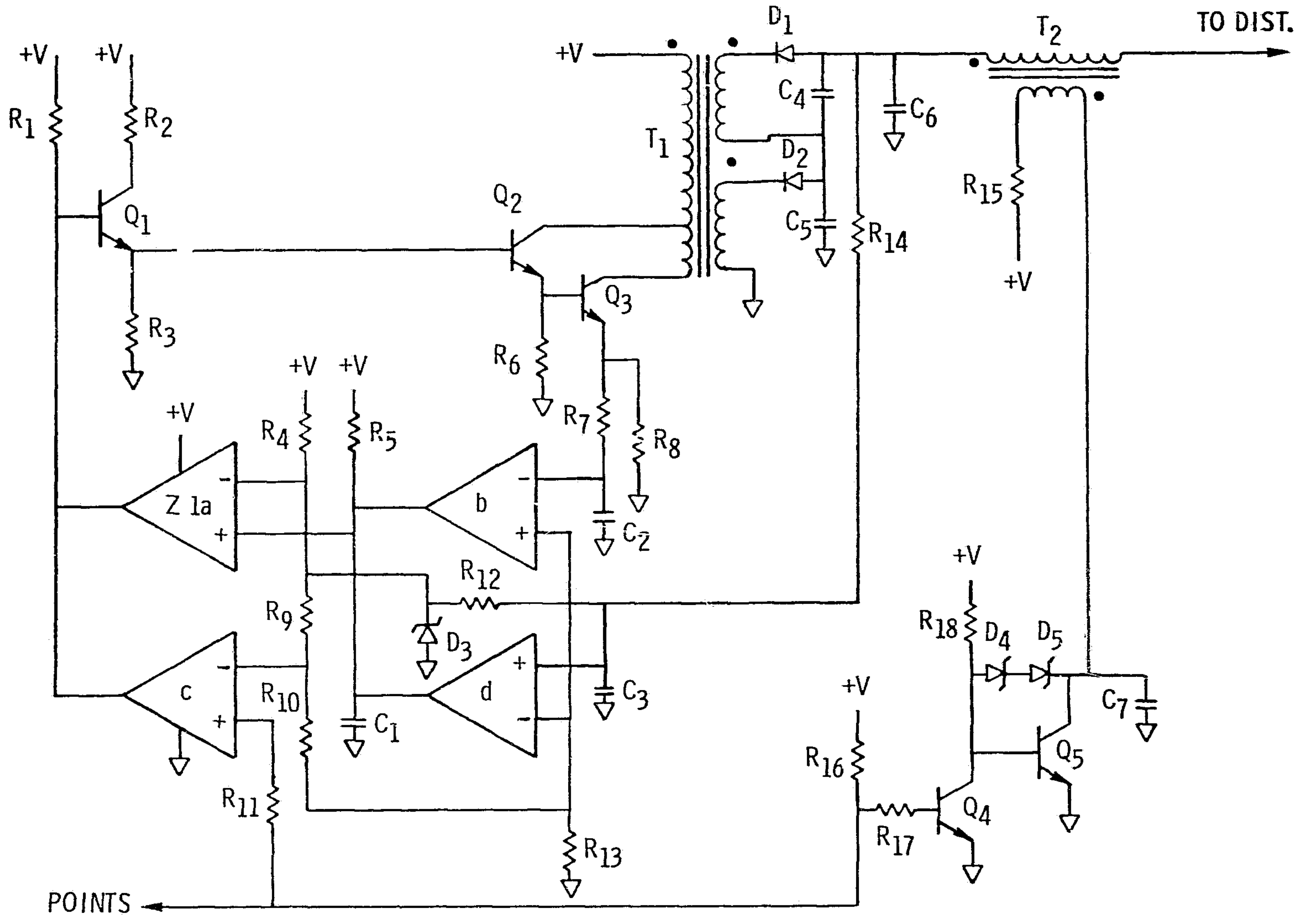

Figure 2. - Sustained arc ignition system schematic.

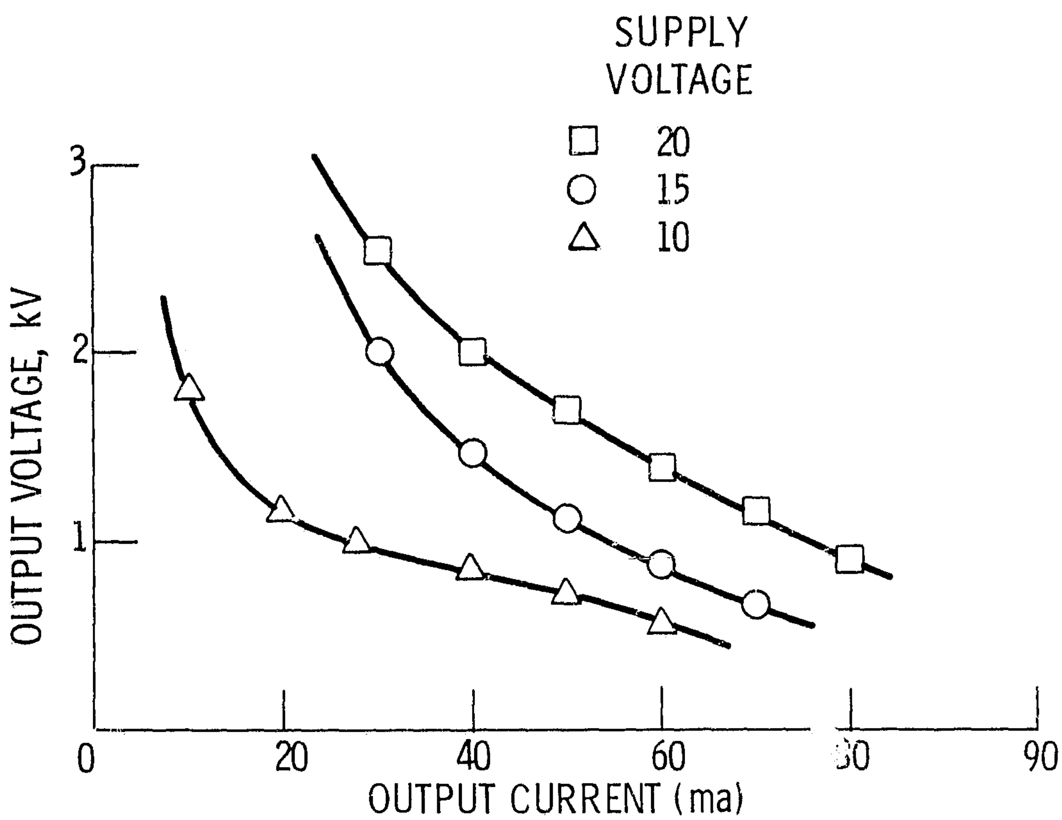

Figure 3. - DC-DC converter output characteristics.

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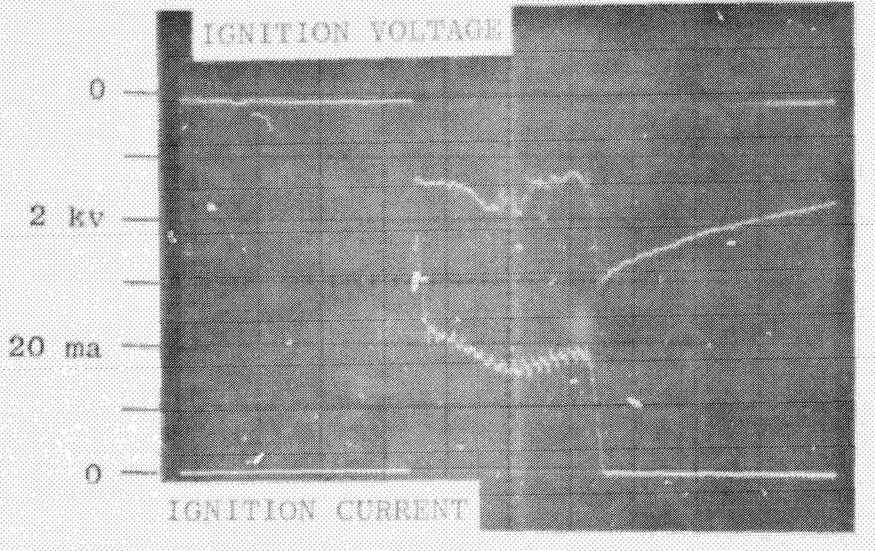
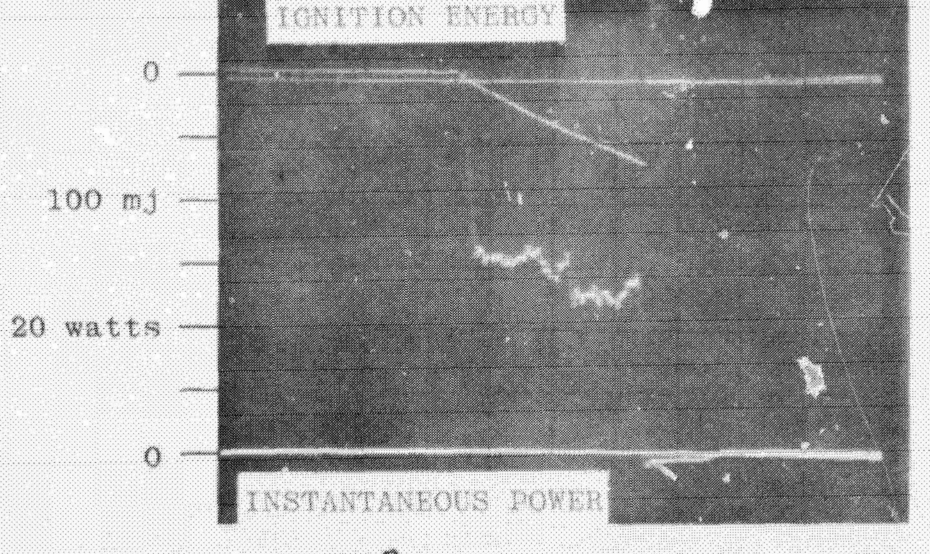
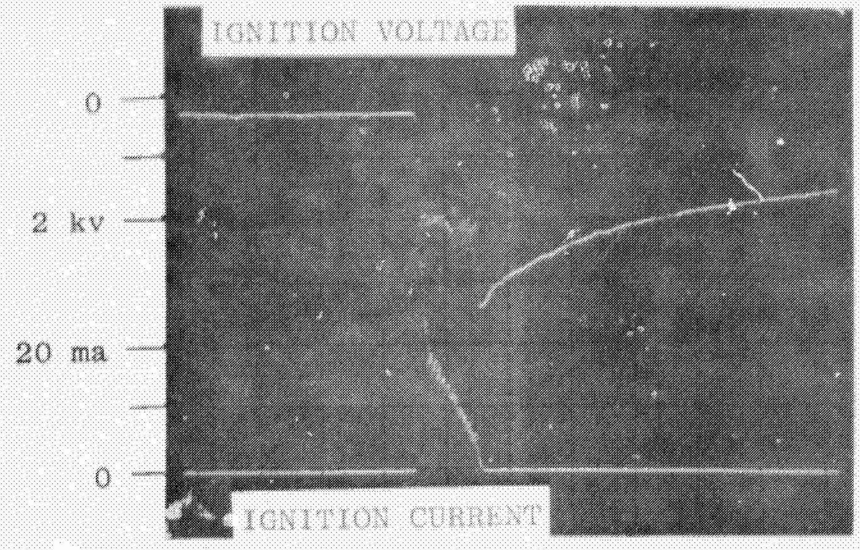


10°/div 2140rpm
(a) IGNITION VOLTAGE AND CURRENT

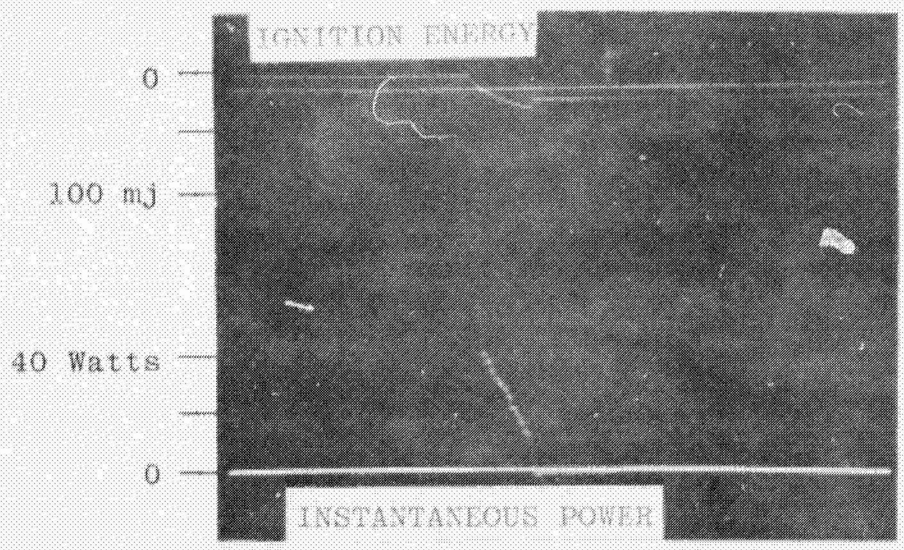


10°/div 2140rpm
(b) INSTANTANEOUS POWER AND ENERGY

FIGURE 4. - SUSTAINED ARC IGNITION WAVEFORMS



10°/div 2145rpm
(a) IGNITION VOLTAGE AND CURRENT



10°/div 2145rpm
(b) INSTANTANEOUS POWER AND ENERGY

FIGURE 5. - CONVENTIONAL IGNITION WAVEFORMS