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Fundamental Study of a Plasma Generating for Gasoline Ignition Applying AC Power

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Abstract

In this study, as a fundamental study for the realization of lean combustion in gasoline engines, compared the ignition performance of traditional ignition methods and an ignition method applying AC power. The experiment simulated the ignition system for the 1.6L gasoline engine from company H, and converted the pulse signal on the supply circuitry inside the inverter into revolutions per minute. With the sparks produced from ignition plugs, energy volume was observed to increase with decreasing air density. As for the AC power ignition system, it was concluded that with the absence of damped oscillation after discharge, it could be used to improve ignition performance.

Keywords: Downsizing, Flame Spread, Ignition Coil, Line-burn, Secondary Wave

1. Introduction

Today's automotive industry is transitioning towards downsizing, which can give equal or better performance[1–3]. As for gasoline engines among existing internal combustion engines, through the development of lean air/fuel ratio combustion technologies such as Direct Injection (GDI), Exhaust Gas Recirculation (EGR), and lean burn, efforts are being made to improve mileage by reducing pumping losses and lowering the temperature of combustion gases under partial load[4–6].

With engine performance being improved and optimized by the day, ignition technologies, which are at the core of engine control, have been developed and are in use in various forms, including types of breaker, full transistor, electronic advance, and DLI[7]. However, engines are faced with the limitation that the risk for misfire exists when sufficient ignition energy is not supplied during combustion under lead air/fuel ratio conditions. Therefore, in order to guarantee sure initial ignition, the development of new ignition technologies is crucial[8].

An examination of previous literature shows that studies on current amplification devices, visualization of combustion flames, flow techniques for laminar flows, and plasma jets for ultra-lean combustion have been performed. As for studies to convert the ignition systems inside engine combustion chambers into pulse output using Alternating Current (AC), no such studies have been published domestically.

Therefore, in this study, as a fundamental study for the realization of lean burn technology, aims to verify through experimentation whether conversion of AC power into pulse energy is able to overcome the limitations of existing ignition methods.

2. Test Device and Method

In order to test, as shown in Figure 1, an ignition system identical to that for the 1.6[L] gasoline engine from company H was designed and fabricated. An oscillation device to apply AC power was also designed and fabricated.

As for the inverter, a device able to convert from 150[W] DC 12[V] to AC 220[V] was used, with a LIS–100T 330[W] 8[Ω] inverter. As for the diode, using a BY255P–1344C element was used with a reverse element to form a circuit. As for the cable, a 5CHFBT high voltage

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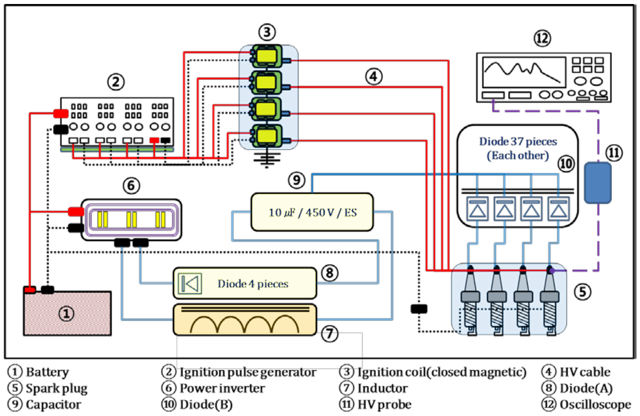


Figure 1. Schematic diagram of experimental device.

coaxial cable able to transfer the high voltage from the AC power to the ignition plugs was used. Using the 27301–2B110 pencil-type coil from company Y as the ignition coil, high voltage was generated. A nickel-plated spark plug product from company Y was used.

As for the DC ignition oscillator circuit for applying AC power, NE555-N type element and capacitor variable resistance were matched to form a transistor clock pulse circuit. A 104[K] 450[V] capacitor was used to store AC power for stabilization.

As for the testing method, the DC ignition oscillator circuit for AC power was used to implement traditional point ignition and AC inverter plasma ignition methods. The order of operation is as follows.

Battery power is supplied to the DC ignition oscillator device, and the input side of the power inverter. The DC ignition device generates pulses from the power input from the battery according to capacitor capacity, and transmits the clock to the input side of the ignition coil. According to the clock, the ignition coil boosts voltage at the primary coil then re-boosts voltage at the secondary coil. Through the high voltage cable, power is transferred to the spark plug. Here, the power inverter is started, and the alternating current (L) occurring within the inverter is applied to the inductor, while simultaneously, the alternating current (C) passes through the diode to store AC voltage in the 104[K] 450[V] capacitor. The alternating current stored in the capacitor passes through the BY255P–1344C diode when the spark plug discharges. At the spark plug, sparks are generated between the electrodes from the clock pulse generated from the direct current. At the time when the spark is generated, the alternating current stored in the capacitor is discharged, generating plasma. The oscilloscope was used to trigger high voltage when the spark and AC plasma are generated. The test was conducted with a scale of 500[ms] on the X axis, and 100[V] on the Y axis. Also, an amplification ratio of 500:1 was set for the high voltage probe, so that high voltage could be triggered. All circuits were earthed at the same point to minimize the generation of noise.

The revolutions of the engine were set at 800[rpm], 1,000[rpm], 2,000[rpm], and 3,000[rpm], while the variable resistance of the ignition oscillator simulation device was set to 13.3[Hz], 16.7[Hz], 33.3[Hz], and 50.0[Hz] so that sparks could be generated within the range of engine revolutions. The test was conducted with the gap between ignitions plugs set to 1.0[mm] in order to compare results under conditions identical to traditional point ignition methods. Details as to the test device and conditions are presented in Table 1 and Table 2.

Using the above testing method, the ignition system was tested for the four aforementioned conditions, repeating an average of five times.

3. Test Results and Discussion

This study, sections of the secondary ignition waveforms for the traditional ignition system and AC power ignition system were analyzed. The X axis denotes time [ms], while the Y axis represents voltage [kV].

Table 1. Specifications of part components for experiment

Item	Specification
Battery	Voltage and Current : DC 12V 200Ah Temperature: (–)40°C to 70°C
DC Ignition pulse generator	Temperature: (–)25°C to 85°C Measured at 1 (±) 0.1kHz
Ignition coil of pencil	Primary : 1.0 to 1.3, Secondary: 6,000 to 30,000
Spark plug	Heat range : 5 to 11.5 Performance : 70%
Oscilloscope	Sampling speed : 1GSaps Bandwidth : 70[MHz]

Table 2. Specifications of experimental condition

Engine speed(rpm)	Plug gap(mm)	Ignition (type)	Manufactures (each)
800 1,000 2,000 3,000	1.0	Point – Base AC Plasma	Y

Figure 2 shows the respective surge voltages in the traditional ignition system and AC power ignition system by time according to engine revolutions. It can be observed that surge voltage is generated near 0.0[ms], at the point where discharge first occurs.

A reduction of approximately 26.8[kV] was observed at 800[rpm] with the traditional ignition system, whereas the reduction was approximately 4.8[kV] for the AC power ignition system at the time of transistor off at 22.0[kV]. A reduction of approximately 26.4[kV] was observed at 1,000[rpm] with the traditional ignition system, whereas the reduction was approximately 3.2[kV] for the AC power ignition system at the time of transistor off at 23.2[kV]. A reduction of approximately 27.6[kV] was observed at 3,000[rpm] with the traditional ignition system, whereas the reduction was approximately 3.2[kV] for the AC power ignition system at the time of transistor off at 24.4[kV]. However, at 2,000[rpm], results similar to the traditional ignition system were received at the time of transistor off. This is judged to owe to better energy transfer efficiency than other revolutions, due to the duty ratio of 5:5 (on: off) of the transistor.

As for surge voltage, it can be observed that surge voltage in the AC power ignition system is generally about 3~18% lower than in the traditional ignition system. Whereas in the traditional ignition system, the voltage requirement of the secondary coil is stabilized at the time of transistor off, resulting in a high surge voltage, in the case of the AC power ignition system, surge voltage is reduced due to the increased current resulting from the process of conversion to plasma with an alternating signal, not DC voltage.

Figure 3 shows the respective discharge voltages for the traditional ignition and the AC power ignition system against time at each revolution.

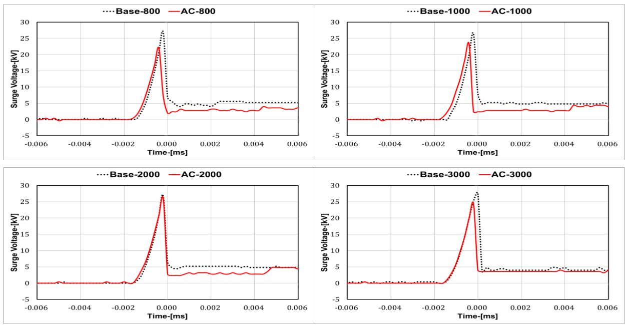


Figure 2. Surge voltage characteristics according to engine speed (rpm).

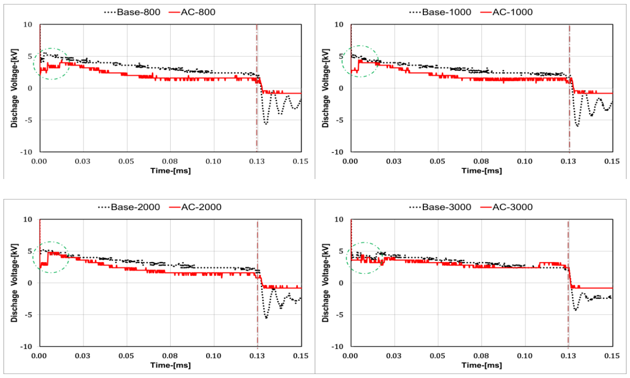


Figure 3. Discharge voltage characteristics according to engine speed (rpm).

Under the 800[rpm] condition, the traditional ignition system showed a voltage reduced by approximately 5.6[kV] at 0.0[ms]. This voltage was reduced through discharge by approximately 3.6[kV] to 2[kV] at 0.13[ms], the time of discharge delay completion. As for the AC power ignition system, the discharge voltage, which began at 2.8[kV] at the same point of discharge delay completion as the traditional ignition system, increased to 4.4[kV] at least of 0.01[ms], then maintained a stable voltage of 1.6[kV] from 0.06[ms] to 0.13[ms].

Under the 1,000[rpm] condition, the traditional ignition system showed a voltage reduced by approximately 5.2[kV] at 0.0[ms]. This voltage was reduced through discharge by approximately 3.2[kV] to 2.0[kV] at 0.13[ms], the time of discharge delay completion. As for the AC power ignition system, the discharge voltage, which began at 2.4[kV] at the same point of discharge delay completion as the traditional ignition system, increased to 4.4[kV]at least of 0.01[ms] then maintained a stable voltage of 1.6[kV] from 0.07[ms] to 0.13[ms].

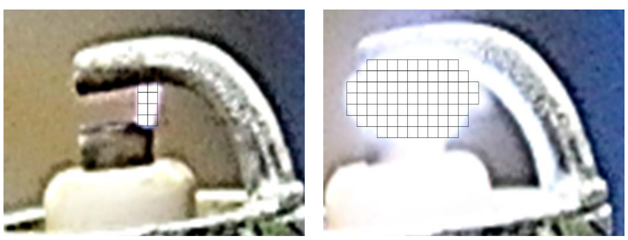
Under the 2,000[rpm] condition, the traditional ignition system showed a voltage reduced by approximately 4.4[kV] at 0.0[ms]. This voltage was reduced through discharge by approximately 2.4[kV] to 2.0[kV] at 0.13[ms], the time of discharge delay completion. As for the AC power ignition system, the discharge voltage, which began at 2.4[kV] at the same point of discharge delay completion as the traditional ignition system, increased to 4.8[kV] at least of 0.01[ms] then maintained a stable voltage of 1.6[kV] from 0.07[ms] to 0.13[ms].

Under the 3,000[rpm] condition, the traditional ignition system showed a voltage reduced by approximately 5.6[kV] at 0.0[ms]. This voltage was reduced through discharge by approximately 2.0[kV] to 3.2[kV] at 0.13[ms], the time of discharge delay completion. As for the AC power ignition system, the discharge voltage, which began at 3.6[kV] at the same point of discharge delay completion as the traditional ignition system, increased to 4.4[kV] at around 0.01[ms] then maintained a stable voltage of 2.4[kV] from 0.07[ms] to 0.13[ms].

However, results of discharge time showed that under all conditions, both the traditional ignition system and the AC power ignition system had delayed sparks between 0.0ms and 1.3[ms]. With the ignition pulsed duty rate set to 5:5 (on: off), the time for spark generation was increased. It was observed that the volume of the spark was maximized in the AC power ignition method compared to the traditional ignition method, due to the fast movement of countless electrons in the spark energy.

Figure 4 is a comparison of the cross sections of the ignition sources of the traditional ignition and AC power ignition system at 800[rpm], with the clock pulse of the ignition oscillator. It was observed that the cross section had increased to approximately 9 times that of the traditional ignition system.

Figure 5 shows the respective discharge voltages according to time for the traditional ignition system and the AC power ignition systems at different engine revolutions. The X axis represents time [ms], and the Y axis represents voltage [kV].



(a) (b)

Figure 4. Comparison of ignition cross sections at 800rpm **(a)** Point ignition and **(b)** AC power ignition.

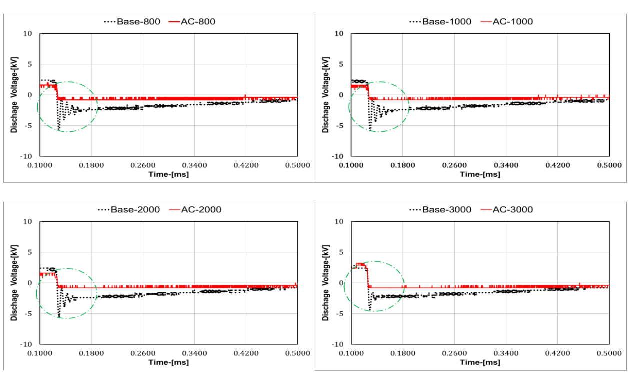


Figure 5. Discharge delay characteristics according to engine speed (rpm).

Whereas in the case of the traditional ignition system, damping vibrations occurred at the time of voltage discharge completion, no damping vibrations occurred in the AC power ignition system. This can be analyzed to mean that with the secondary coil in the DC system of the traditional ignition system, a phenomenon that hinders the next routine results from the damping vibrations of the internal voltage, while in the case of the AC power ignition system, the region where damping vibrations did not occur could be used for a new routine. Also, it can be observed that the difference in discharge voltages is smaller in the AC power ignition system than in the traditional ignition system. As this generally allows for the current to be applied for a shorter time, it is judged that this will allow for better generation of discharge energy.

4. Conclusion

This study was a fundamental study for realization of lean burn, and reached the following conclusions from performance testing of an ignition simulation device applying DC/AC inverters to overcome the limitations of traditional ignition methods by converting AC power to pulses.

- It was observed that the time of the impulse when the spark occurs in the secondary side high voltage from the ignition coil was stabilized according to the frequency cycle of the DC/AC inverter.
- It could be seen that unlike in the traditional ignition system, in the AC power ignition system, the discharge energy acts as the heat source to generate the flame, resulting in a pronounced difference in spark volume.
- As for the energy of the spark generated at the ignition plus, the promotion of ionization of free electrons resulted in maximization of the plasma sheath according to changes in the potential barrier.
- Whereas in the traditional ignition system, damping vibrations over 3 to 6 times after discharge hinder the next routine, in the AC power ignition system, an absence of damping vibrations allows for use in a new routine.
- Whereas discharge time tended to be similar to the traditional ignition system, a tendency for discharge voltage to decrease was observed. Through additional testing

to supplement performance and stabilize circuitry, it is thought that smooth combustion will be possible under the combustion conditions of gasoline engines.

5. Acknowledgement

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