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Low-Cost Automotive Capacitive Discharge Ignition (CDI) Coil for Low Frequency Ozone Generator

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Abstract — This paper presents an alternative solution for generating ozone using a low-cost automotive Capacitive Discharge Ignition (CDI) coil. High voltage ozone generating theory is implemented using a capacitive discharge circuit that uses ignition coil as its high voltage step-up transformer. A computer simulation has been performed to confirm the validity of the circuit function. By calculation and measurement, the coil has 196.71 voltage amplification factor. Furthermore, it has been implemented at a low frequency of about 10 - 40 Hz. Meanwhile, ozone output is measured using colorimetric method. From a series of test, that coil implementation has successfully generating high voltage on ozone reactor tube at 31.47 kV voltages that essential for ozone production. Change of frequency will change ozone concentration output linearly. The test was conducted using three different frequency: 10 Hz, 20 Hz, and 40 Hz. The result has shown that the highest ozone yield was 80 mg/hour.

Keywords – Capacitive discharge ignition, ozone, ozonizer, ignition coil, frequency, high voltage

I. INTRODUCTION

Ozone plays an essential role in several industrial hygiene processes and home sanitation. Ozone has a unique property that can be utilized for the antiseptic agent. Since ozone degrades to oxygen, it does not produce harmful residue or waste. The need for ozone was highlighted in various researches. In the previous research, ozone is used as a sterilization agent for pathogen bacteria, swimming pool’s water treatment, residential water treatment, food industries, and animal cage [1]–[3].

Although ozone can be produced naturally, it can be generated artificially through various ozonizer methods for the industrial purpose such as corona discharge/dielectric barrier discharge, UV-based ionization, and electrolysis[2]–[6]. Corona discharge or dielectric barrier discharge method is more cost-effective than other methods[2]–[4]. The air ionization process is started when oxygen molecules give and get electrons. The electric field in the ozonizer reactor tube will give ionization energy to free-electron to change oxygen to ozone. The ozone output is equal to the amount of electron that reacts with oxygen.

Most ozone generating methods require high voltage power supply since it is mandatory to generate corona for the ozonizer process [4][7][8]. However, a high voltage power supply, especially its transformers, are quite complex and costly. The dimension of the conventional power supply is in a large volume due to the present of the transformer. Regard to safety, high voltage may not be suitable for household applications [9]. Few studies have investigated the design and construction of a transformer-less power supply for an ozone generation. Even without a specifically designed high voltage transformer, the circuit can generate sufficient voltage to produce the ozone [10][11]. However, the papers mentioned above address only high-frequency high voltage device for generating ozone.

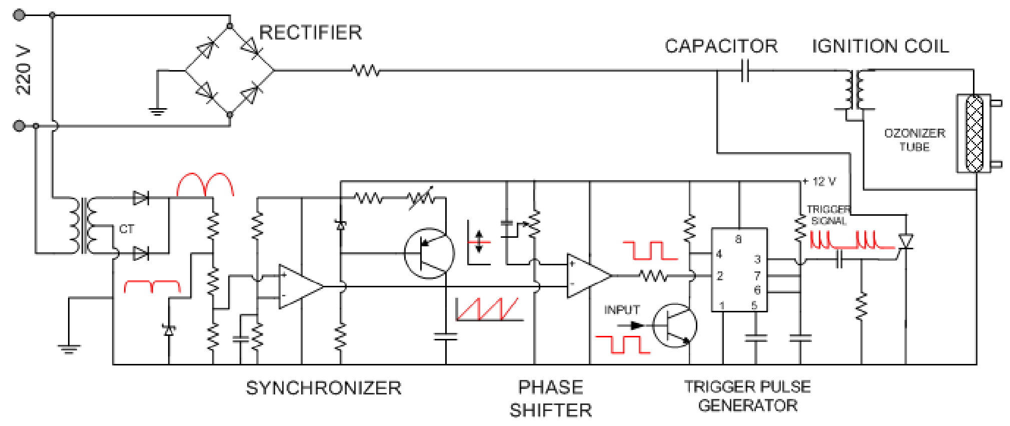


Fig.1 Capacitive Discharge Circuit For Ozone Generator

Another method for generating high voltage can be found in the automotive. Capacity Discharge Ignition (CDI) systems are widely used in automotive. It should be noted that the average energy of the discharge in the spark gap is about 30 mJ [12]. The major advantage of CDI is that the capacitor can be fully charged in a very short time. Motorcycle ignition coil was suggested as an alternative to conventional high voltage step-up transformer due to its cost-effective, easy to obtain, and has been proven as a high voltage converter [13]. Determining ozonizer output is a challenging task due to the unstable nature of ozone. Several more complex and costly methods can be utilized, such as PWM (Pulse Width Modulation), fuzzy logic, and PID (Proportional-Integral-Derivative)[14]–[16].

This paper puts forth an alternative idea of ozonizer, which utilizes a low-cost automotive Capacitive Discharge Ignition (CDI) coil as a high voltage generator. This study aims to investigate how to combine between capacitor and motorcycle ignition coil to produce ozone. Furthermore, since most of the home in Indonesia uses 220 V/ 50 Hz grid voltage, the ozonizer must conform to its frequency using the synchronizer device. Last but not least, the effect of low frequency on the ozone generating process is proposed and further analyzed in this study.

II. RESEARCH METHOD

The ozonizer system is divided into several parts (Fig.1). They are,

- Capacitive discharge circuit,
- Zero cross and synchronizer circuit,
- Ignition Coil and Ozone Reactor Tube.

A. Capacitive Discharge Circuit

The capacitive discharge circuit stores the charge in a capacitor. This circuit has two cycles, namely the charging cycle and the discharge cycle. Charging is carried out at half the signal cycle from the source of the grid that has been rectified. The charging process time depends on the frequency of the AC electrical signals used. Because it is used by the home electrical grid so that the time needed is around 1/100 second. Illustration of the process is shown in Fig.2a. When the Silicon-Controlled Rectifier (SCR) gate receives a signal from the trigger pulse generator circuit, the switch closes, and the capacitor is discharged into the primary winding of ignition coil (Fig.2b). Ignition coil then increases the voltage to reach the high voltage needed to produce ozone. The amount of energy that can be stored by a capacitor depends on the capacitance and voltage rating of the capacitor.

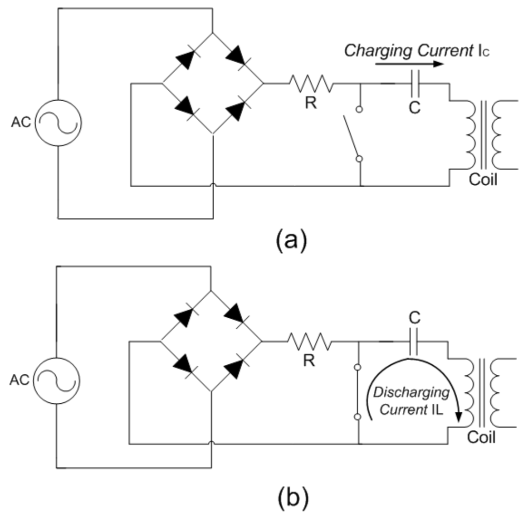


Fig.2. (a) Charging Cycle and (b) Discharging Cycle

B. Zero Cross and Synchronizer Circuit

This circuit is needed to trigger the SCR when zero crosses. The circuit will detect the transition changes in voltage value when it approaches zero value. With this circuit, the capacitor charging process in a capacitive discharge circuit occurs when zero crosses, which means that the amount of charge is more filled in the capacitor. Meanwhile, the trigger pulse generator circuit is designed to produce pulses with certain frequencies, which are then connected to the SCR. This circuit is a monostable multivibrator that functions to produce pulses that regulate the closed and open switch. This trigger circuit uses a 555 timer IC as its main component.

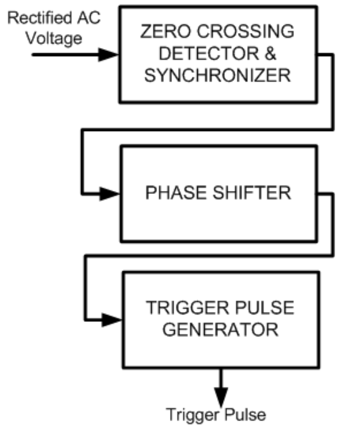


Fig.3. Zero Crossing Detector Block Diagram

The circuit synchronizes between grid voltage signals by generating a ramp signal. When the phase shift output signal changes to 0, the trigger pulse generator circuit will generate series of pulses. The schematic diagram and signal output of each part can be seen in Fig.3, and Fig.4.

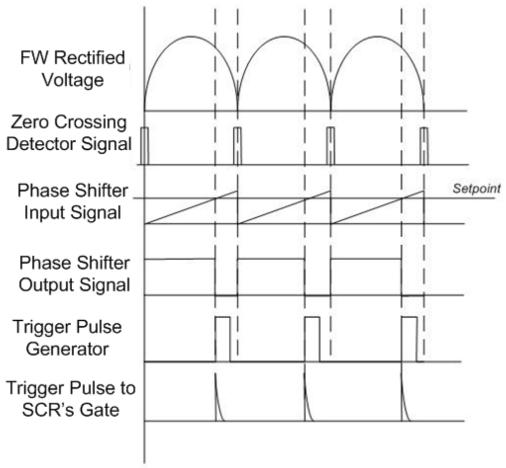


Fig.4. Circuit Signal Output

The SCR will be switched ON when the rectified voltage is close to zero. The switching process when the zero cross condition causes the energy stored in the capacitor to be discharged to the reactor tube to be more optimum. Since the grid frequency is 50 Hz, that means that the maximum frequency of the trigger pulse circuit is 100 Hz. The capacitor will be charged every half cycle of sinusoidal signals. All of the circuits are then implemented in a PCB, as shown in Fig.5.

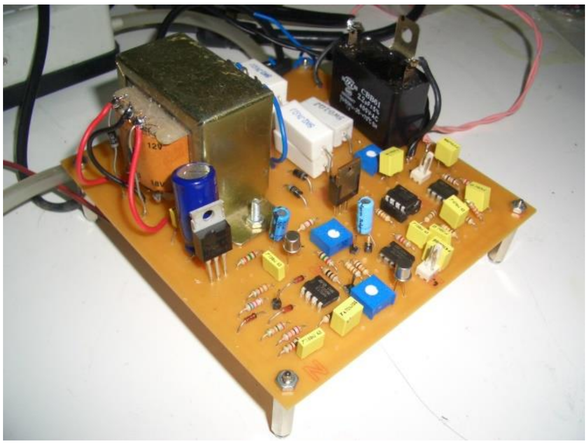


Fig.5. Capacitive Discharge Circuit Implementation.

C. *Ignition Coil and Ozone Reactor Tube*

The working principle of the ignition coil is the same as the step-up transformer. Ignition coil will increase input voltage until it reaches the value needed to produce ozone. The ignition coil is chosen as a step-up transformer because it is economically lower than the cost of making a transformer specifically. In addition, the coil can be easily found on the market. The Ignition Coil can be seen in Fig.6.

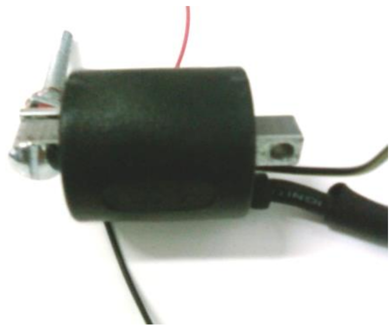


Fig.6. Yasuho Type 30500 KEV-950 Ignition Coil

The coil's output is then connected to the reactor tube. The tube is made by Paiho Electronics type PA-021. The tube can be seen in Fig.7.

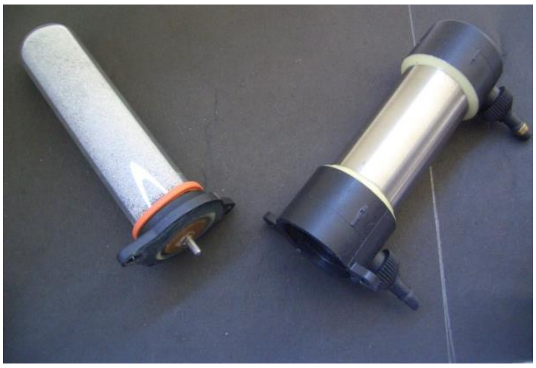


Fig.7. Ozonizer Reactor Tube Type PA-021.

III. RESULTS

This section presents the results obtained from circuit simulation and several tests on hardware, i.e., capacitive discharge ignition circuit. This section also presents an ozonizer's yield measured by the colorimetric method.

A. Capacitive Discharge Ignition Circuit

In the CDI circuit, the ignition coil acts as a replacement for the high-voltage transformer to convert the low voltage into high voltage. There is some information needed from the coil, i.e., optimal working frequency range. This information is generally provided by producers, but because there is no datasheet from coil producers, this experiment was conducted to obtain this data. However, this data cannot be used to obtain a transformer gain. Therefore, another method is conducted to get the reinforcement factor from the ignition coil.

Inductance factor is defined as the self-inductance per unit turn of a coil of a given shape and dimension wound on a magnetic core, and is determined by the following formula [17][18]:

$$L = A_L \cdot N^2$$

While L is a coil inductance, A_L is a specific inductance factor whose value is different for each type of wire, and N is the number of turns. Using RLC meter, both primary and secondary windings inductance are measured with the following results:

1. Primary windings inductance (L_P) = 0,23 mH.
2. Secondary windings inductance (L_S) = 8,9 H

Then, this data is used on the following formula:

$$0,23\times10^{-3} = A_L \cdot {N_P}^2 \quad (1)$$

$$8,9 = A_L \cdot {N_S}^2 \quad (2)$$

$$\frac{N^2{}_S}{N^2{}_P} = \frac{8,9}{0,23\times10^{-3}} \quad (3)$$

$$\frac{N_S}{N_P} = \sqrt{\frac{8,9}{0,23\times10^{-3}}} = 196,71 \quad (4)$$

To verify the CDI circuit, a series of simulations using *Electronic Workbench* software was conducted. The circuit is arranged in a configuration, as shown in Fig.8.

Fig. 9a shows that a series of the pulse is generated every half cycle of the full-wave rectified grid signal. This pulse is then triggered the capacitive discharge circuit. Fig. 9b shows an impulse-shaped output signal. This impulse indicates the discharging process of the capacitor.

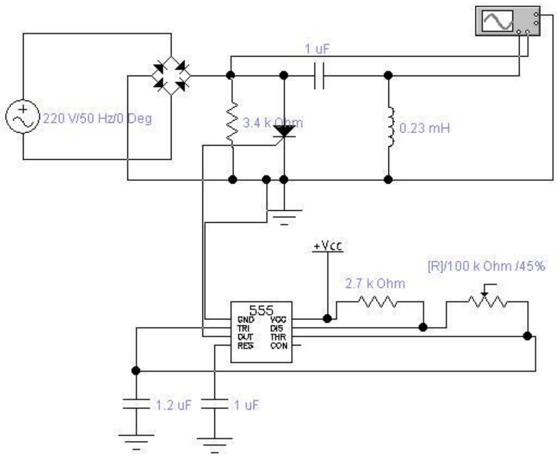
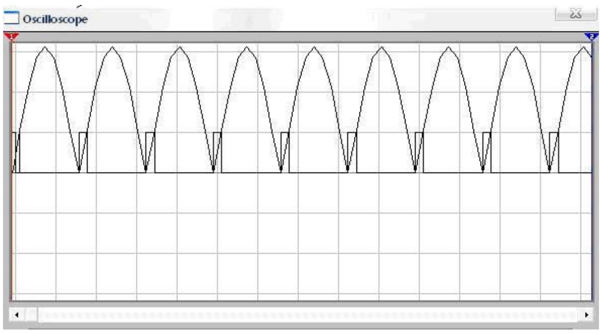
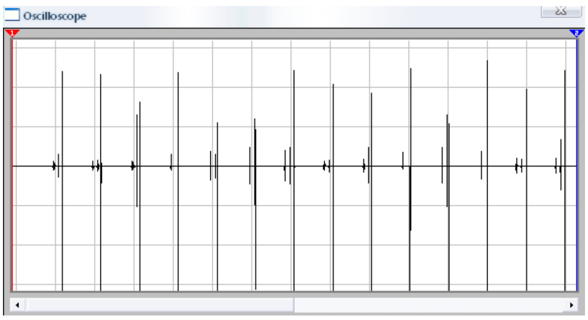


Fig.8. Circuit Simulation



(a)

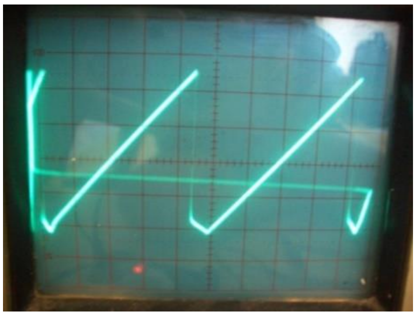


(b)

Fig. 9. (a) Zero Crossing Detector Circuit Output Signal, (b) Discharging Process of The Capacitor

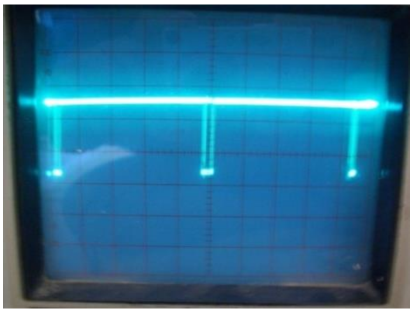
B. Circuit Implementation Evaluation Test

After the simulation, the actual circuit is implemented and tested to verify its functionality. Fig.10 displays the ramp signal for phase-shifting (Fig.10a). This figure also displays the phase shift signal in maximum(Fig.10b) and minimum conditions (Fig.10c), the trigger pulses to trigger the ON (Fig.10d) and OFF process of the SCR (Fig.10e).



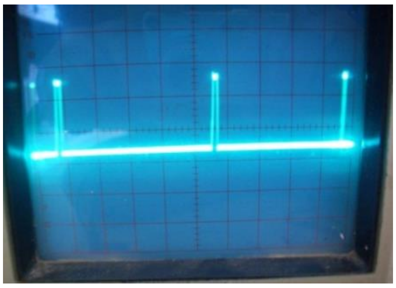
Ramp signal for phase shifting

(a)



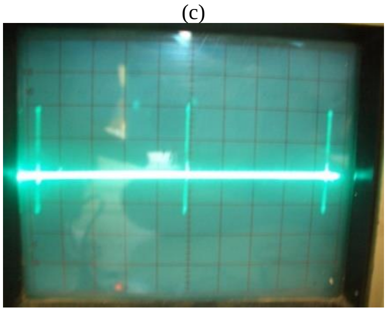
Display the phase shift signal at maximum / close to π

(b)



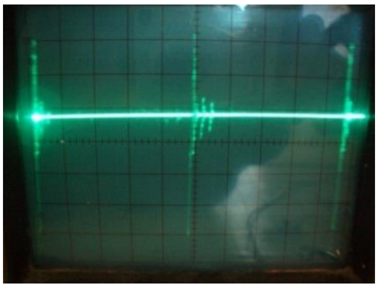
Display the phase shift signal at minimum / close to 0

(c)



Trigger pulse

(d)



Discharge pulse

(e)

Fig.10. The Output Signal from Several Points on The Circuit.

The experiment was conducted to observe the capacitive discharge circuit output. This result has demonstrated that the output signal is relatable with the simulation results. From the oscilloscope, it is measured that the signal frequency is 100 Hz, and the amplitude of the signal is 160 V. By using the transformer amplification factor data from the experiment, ignition coil output voltage can be determined using (5).

$$V_{out} = \frac{N_S}{N_P} \times V_{in} \quad (5)$$

$$V_{out} = 196.71x\ 160 = 31.47\ kV \quad (6)$$

C. *Ozone Output Experiment*

Ozone output was measured using the conventional absorption spectroscopy[19][20]. This tool measures gas concentration using the colorimetric method. This method is done by taking 50 ml or 100 ml air samples, and the chemical compounds in the detection tube will react with the gas to be concentrated. Then, the ozone concentration data is obtained by comparing the color changes that occur due to the chemical reaction with the scale in the detection tube (Fig.11).

Using this method, the output of the ozonizer is tested in three frequency conditions: 10, 20, and 40 Hz. The test results are presented in **Error! Reference source not found.**. From **Error! Reference source not found.**, linear trends in correlations were present for ozone concentration output. Then, the characteristic curve is observed to determine the optimum working frequency of the ozonizer.

Fig.11. Ozone Output Measured by the Colorimetric Method.

Another experiment was conducted to determine the effect of capacitor charging time = R.C on the ozone produced. The experiment was conducted using 3 capacitors with different capacitances and resistors with a fixed resistance of 2.7 kΩ. The result experiment is shown in Table 1.

Table 1. Effect of capacitor charging time constants on ozone production

No.	Capacitance (μF)	Ozone Concentration (ppm)	Time Constant (seconds)
1	3,5	600	9,45 x 10^{-3}
2	2,2	1000	5,94 x 10^{-3}
3	1,5	1300	4,05 x 10^{-3}

IV. DISCUSSION

A. *Capacitive Discharge Ignition Circuit*

From the calculation on equation (1) – (4), it can be determined that the ignition coil amplifying factor is 196.71. This result is then used to determine output voltage on the coil's secondary windings. If the input voltage is 160 V, the output can be obtained by multiplying input value with the amplifying factor. That means the coil output is around 31.47 kV. This voltage is sufficient to establish the corona discharge effect in the ozone reactor [3].

The automotive ignition coil has been proven to be highly valid as a high voltage converter. The current results also underscore the importance of corona discharge generating ability for producing ozone. Our finding is thus an important contribution to the corona discharge generating method using relatively low frequency and low cost.

B. *Ozonizer Output Measurement*

Ozonizer output capacity is typically presented in the g/hour unit. To convert ozone concentration unit C from ppm to g/m^3, equation (7) can be used.

$$C = \frac{ppm}{467} \tag{7}$$

$$1\ g\ O_3 / m^3 = 467\ ppm\ O_3 \tag{8}$$

$$1\ ppm\ O_3 = 2.14\ mg\ O_3/m^3 \tag{9}$$

Then, to calculate ozone output in mg/hour unit:

Ozone output (g/hour) = Concentration (g/m^3) x air flow (L/minutes) x 0.001(m^3/L) x 60 minutes

From experiment results, it can be determined that the maximum output of ozonizer is 250 ppm on 2.5 L/minute airflow condition.

$$Concentration = \frac{250}{467} = 1{,}07\ g/m^3 \tag{10}$$

$$Ozone\ output\ (g/hour) = 1.07\ g/m^3 \times 2.5\ L/minutes \times 0.001(m^3/L) \times 60\ minutes = 0.08\ g/hour = 80\ mg/hour. \tag{11}$$

From **Error! Reference source not found.**, it can be seen that the curve is linear, and the higher the frequency, the greater the concentration of ozone produced in the same time span. Using the data, it is easier to analyze the amount of ozone that can be produced by the ozonizer.

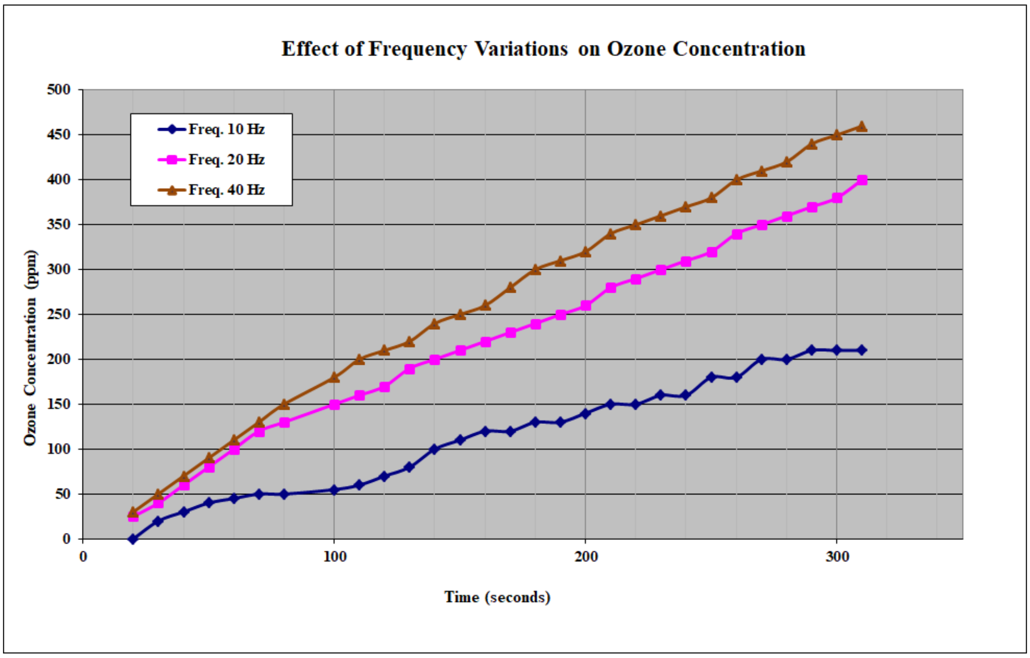


Fig. 12. Effect of Frequency Variation on Ozone Output

However, there is a major concern in the colorimetric method for ozone measurement. The problem lies in practical implementation since the ozone measurement test pack can be used once. It would be impractical to change the test pack for routine measurement. For more practical implementation and real-time monitoring, the advance ozone sensor is required.

C. Effect of capacitor charging time constants on ozone production.

From the results of the experiment, **Error! Reference source not found.** shows that changes in capacitors with smaller capacitances will produce higher concentrations of ozone. This is caused by a time constant whose value gets smaller when the capacitor capacitance increases. The ozonizer circuit operates at a frequency of 100 Hz (T = 10 ms) so that the capacitor voltage will be maximum at a time of ½ T. This is what causes the ozone concentration to increase because of q = CV.

A further interesting issue worth exploring is the effect of duty cycle variation on Pulse Width Modulation (PWM) to the ozone generator output. Since the variation of the duty cycle would affect the frequency of the corona spark, it could be utilized for controlling the ozone output. Nevertheless, the computer-based controller, e.g., microcontroller, must be used as the main controller.

V. CONCLUSION

This paper successfully presented an alternative solution for generating high voltage using an automotive ignition coil, specifically motorcycle coil. The capacitive discharge ignition circuit can be used to generate ozone. The findings of our study suggest that a combination of resistance values and capacitance (capacitor charging time constant) in the capacitor discharge circuit affects the ozone level produced. The relationship between changes in frequency and ozone production is linear. The results support the use of the automotive ignition coil as a high voltage converter for ozone production. This research could be expanded to include an ozone sensor to obtain accurate ozone concentration data. It should be further observed the effect of frequency and voltage on ozone production.

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