Implementation of a Capacitive Discharge Ignition for Dual-cylinder Motorcycles

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(Received July 24, 2019; accepted November 5, 2019)

Keywords: CDI, dual-cylinder, contact-type, HC, CO

In this paper, the implementation of a capacitive discharge ignition (CDI) for dual-cylinder motorcycles is presented. The structure of the proposed CDI mainly includes one microcontroller, one flyback converter, two capacitive-discharge circuits, and two over-voltage protection circuits. The proposed CDI mainly uses Hall sensors to sense the optimal signal of the ignition time. Therefore, the optimal ignition angle of the spark plugs can be obtained. In comparison with a traditional contact magnetic ignition, the proposed CDI can obtain more exact ignition timing of the spark plugs and reduce hydrocarbons (HC) and carbon monoxide (CO) in the exhausts of motorcycles. Therefore, air pollution is reduced and the environmental quality can be significantly improved. Finally, to verify the performance of the proposed CDI for dual-cylinder motorcycles, a prototype hardware circuit was built and implemented. From the experimental results, the feasibility of the proposed CDI has been verified.

1. Introduction

In recent years, the rapid development of economies and vehicles has resulted in the greenhouse effect. The hydrocarbons (HC) and carbon monoxide (CO) emitted from vehicles already account for a quarter of the world’s emissions.1,2 In this society of convenient transportation, motorcycles are indispensable for daily life. Therefore, how to reduce the amounts of HC and CO in the exhausted gas emitted from motorcycles has become an important issue. Usually, the ignitions of motorcycles can be divided into two categories: magnetic ignitions and capacitive discharge ignitions (CDIs).3–6 A magnetic ignition via a speed-signal generator produces two ignition signals of the spark plugs. However, a magnetic ignition has the following disadvantages: 1) its speed signal generator cannot accurately calculate the optimal ignition time, resulting in the deviation of the ignition angle of the spark plugs. 2) When the engine is operated at a high speed, the output voltage of the ignition becomes smaller, which results in the difficulty in ignition by the spark plugs. These phenomena cause the fuel to burn incompletely, which will increase air pollution. According to a technical manual of...
motorcycles, the optimal ignition angle of the spark plugs occurs when the crankshaft angle is 10° after the top dead point, as shown in Fig. 1.\textsuperscript{(7–10)}

To overcome the above disadvantages, a CDI with a microcontroller and Hall sensors to obtain optimal ignition angles of dual-cylinder motorcycles is presented, as shown in Fig. 2. The Hall sensors sense the ignition signal via a microprocessor to calculate the optimal ignition timings of the spark plugs, and thus obtain optimal ignition timings at different speeds of the dual-cylinder engines.\textsuperscript{(11–13)} The structure of the proposed CDI is described in Sect. 2. The operational principles of the proposed CDI are described in Sect. 3. The experimental results obtained from the proposed CDI are presented in Sect. 4. Finally, a conclusion is given in Sect. 5.

## 2. Structure of CDI

The proposed CDI for dual-cylinder motorcycles is shown in Fig. 2 and its block diagram is shown in Fig. 3. In Fig. 2, the voltage of the discharging capacitors $C_{D1}$ and $C_{D2}$ is boosted to 150 V\textsubscript{DC} via a flyback converter. After the microcontroller receives a trigger signal from the ignitor, it generates a corresponding trigger signal to turn on the discharging switches $S_{w1}$ and $S_{w2}$. Thus, the energy stored in $C_{D1}$ and $C_{D2}$ is discharged to the spark plugs via the ignition coils $T_{r1}$ and $T_{r2}$. The ignition coils are high-voltage transformers, which boost the voltage of the discharging capacitors (about 25 kV) to ignite spark plugs 1 and 2.

![Fig. 1. (Color online) Relationship between cylinder pressure and crankshaft position.](image1)

![Fig. 2. (Color online) Structure of the proposed CDI for dual-cylinder motorcycles.](image2)

![Fig. 3. (Color online) Block diagram illustrating the structure of the proposed CDI.](image3)
According to Fig. 1, the optimal ignition angle of the engine occurs when the crankshaft angle is 10° after the top dead point. A delay or missing this ignition angle results in a lower cylinder pressure, which leads to more fuel consumption and exhausted gas emission. To obtain an optimal signal at an ignition angle of 10°, a microcontroller combined with software is incorporated into the proposed CDI to detect the engine speed. The control flowchart for the optimal ignition angle is shown in Fig. 4.

3. Operational Principles

Figure 5 shows the detailed circuit of the proposed CDI for dual-cylinder motorcycles. The operational principles of the proposed CDI over one switching cycle can be divided into six major operating modes. Figure 6 shows the current and voltage waveform of the key components and the driving signals of the switches Sw1 and Sw2. Figure 7 shows the equivalent circuit modes of the proposed CDI. To simplify the description of the operational modes, the following assumptions are made.

The discharging capacitors CD1, CD2, CD3, and CD4 are sufficiently large for the voltages across them to be constant over a switching cycle.

All the magnetic components, power switches, and power diodes are ideal.

**Mode 1 [Fig. 7(a), t0 < t < t1]:**

At time t0, the main switch M1 is turned on, and the discharging switches Sw1 and Sw2 and the diodes D1 and D2 are turned off. The magnetic current \( i_{Lm} \) of the transformer \( T_r \) flowing through the path \( V_s \rightarrow L_m \rightarrow M_1 \) is linearly increased. The magnetic current \( i_{Lm} \) of the transformer \( T_r \) can be expressed as
Fig. 5. Detailed circuit of the proposed CDI for dual-cylinder motorcycles.

Fig. 6. (Color online) Voltage waveforms of the key components for proposed CDI.

Fig. 7. (Color online) Equivalent circuits of the proposed CDI for dual-cylinder motorcycles. (a) Mode 1, (b) Mode 2, (c) Mode 3, and (d) Mode 4.
The equivalent circuit is shown in Fig. 7(a).

Mode 2 [Fig. 7(b), $t_1 < t < t_2$]:

At time $t_1$, the main switch $M_1$ is turned off, and the discharging switches $S_{w1}$ and $S_{w2}$ and diodes $D_1$ and $D_2$ are turned on. The magnetic current $i_{Lm}$ of the transformer $T_r$ is transferred to the discharging capacitors $C_{D1}$ and $C_{D2}$. The currents $i_{CD1}$ and $i_{CD2}$ of the discharging capacitors $C_{D1}$ and $C_{D2}$ are increased and can be expressed as

$$i_{CD1}(t) = \frac{1}{C_{D1}} \int_{t_1}^{t_2} V_{CD1} dt,$$

$$i_{CD2}(t) = \frac{1}{C_{D2}} \int_{t_1}^{t_2} V_{CD2} dt,$$

where $V_{CD1}$ and $V_{CD2}$ are the voltages across the capacitors $C_{D1}$ and $C_{D2}$, respectively.

The equivalent circuit is shown in Fig. 7(a).
and

\[ i_{CD2}(t) = \frac{1}{C_{D2}} \int_{t_1}^{t_2} V_{CD2} dt. \]  

(3)

The equivalent circuit is shown in Fig. 7(b).

**Mode 3** [Fig. 7(c), \( t_2 < t < t_3 \):]

At time \( t_2 \), the main switch \( M_1 \) is kept turned off. The voltages of the discharging capacitors \( C_{D1} \) and \( C_{D2} \) are charged to \( V_{Lm}(N_1 / N_2) \), and then the diodes \( D_1, D_2, D_3 \) and \( D_4 \) are turned off. The equivalent circuit is shown in Fig. 7(c).

**Mode 4** [Fig. 7(d), \( t_3 < t < t_4 \):]

At time \( t_3 \), the driving signal of the switch \( S_{w1} \) is generated, and the discharging capacitor \( C_{D1} \) begins discharging via \( S_{w1} \) and \( T_{r1} \). During this interval, spark plug 1 is rapidly ignited. The equivalent circuit is shown in Fig. 7(d).

**Mode 5** [Fig. 7(e), \( t_4 < t < t_5 \):]

At time \( t_4 \), the voltage of the discharged capacitor \( C_{D1} \) is dropped to zero, and the driving signal of the switch \( S_{w1} \) is turned off. At this time, the main switch \( M_1 \) is turned on once again. The magnetic current \( i_{Lm} \) of the transformer \( T_r \) can be expressed as

\[ i_{Lm}(t) = \frac{V_r}{L_m}(t_4 - t_3). \]  

(4)

The equivalent circuit is shown in Fig. 7(e).

**Mode 6** [Fig. 7(f), \( t_5 < t < t_6 \):]

At time \( t_5 \), the main switch \( M_1 \) is turned off, and the discharging switch \( S_{w1} \) and the diodes \( D_1 \) and \( D_2 \) are turned on. The magnetic current \( i_{Lm} \) of the transformer \( T_r \) is transferred to the discharging capacitor \( C_{D1} \). The current \( i_{CD1} \) of the discharging capacitor \( C_{D1} \) is increased, which can be expressed as

\[ i_{CD1}(t) = \frac{1}{C_{D1}} \int_{t_5}^{t_6} V_{CD1} dt, \]  

(5)

The equivalent circuit is shown in Fig. 7(f).

**Mode 7** [Fig. 7(g), \( t_6 < t < t_7 \):]

At time \( t_6 \), the main switch \( M_1 \) is kept turned off. The voltage of the discharging capacitor \( C_{D1} \) is charged to \( V_{Lm}(N_1 / N_2) \), and then the diodes \( D_1 \) and \( D_2 \) are turned off. The equivalent circuit is shown in Fig. 7(g).

**Mode 8** [Fig. 7(h), \( t_7 < t < t_8 \):]

At time \( t_7 \), the driving signal of the switch \( S_{w2} \) is generated, and the discharging capacitor \( C_{D2} \) begins discharging via \( S_{w2} \) and \( T_{r2} \). During this interval, spark plug 2 is rapidly ignited. The equivalent circuit is shown in Fig. 7(g). At time \( t_8 \), the voltage of the discharging capacitor
CD₂ drops to zero, and the driving signal of the switch Sₚ₂ is turned off. At this time, the main switch M₁ is turned on once again. The magnetic current $i_{Lm}$ of the transformer $T_r$ flowing through the path $V_s \rightarrow L_m \rightarrow M_1$ is linearly increased. The magnetic current $i_{Lm}$ of the transformer $T_r$ can be expressed as

$$i_{Lm}(t) = \frac{V_s}{L_m}(t-t_f).$$

(6)

The equivalent circuit is shown in Fig. 7(h). At this stage, the operational mode of the proposed CDI over one switching cycle is completed.

4. Experimental Results

To verify the feasibility of the proposed CDI for dual-cylinder motorcycles, a prototype was built. The specifications and key components are shown in Tables 1 and 2, respectively.

Figure 8 shows an experimental igniting signal, the voltage of the discharging capacitor, and the switching frequency of the main switch waveforms, from which it can be seen that an igniting signal is generated, and the voltage of the discharging capacitor is rapidly reduced to zero. Figure 9 shows experimental voltage waveforms of the discharging capacitors Cₓ₁ and Cₓ₂ operated in the engine speed range of 1000 to 10000 rpm, from which it can be seen that the voltages of Cₓ₁ and Cₓ₂ can easily become 150 V. Figure 10 shows the experimental igniting voltage waveforms of spark plugs 1 and 2, from which it can be seen that the igniting voltage is

| Table 1 | Specifications of CDI. |
|---------|------------------------|
| Input voltage | 12 VDC |
| Igniting voltage of spark plug | 25 kV |
| Test speed of engine | 1000–10000 rpm |
| Switching frequency of main switch | 50 kHz |

| Table 2 | Key components of CDI. |
|---------|------------------------|
| Main switch M₁ | IRF640 |
| Igniting switches Sₓ₁ and Sₓ₂ | R5013ANX |
| Power diodes D₁, D₂, D₃, and D₄ | US1J |
| Core of transformer $T_r$ | RM-8 |
| Discharging capacitors Cₓ₁ and Cₓ₂ | 2.2 μF / 450 V |
| Microcontroller | PIC16F684 |

Fig. 8. (Color online) Key waveforms of the proposed CDI: (a) igniting signal of spark plug 1, (b) charging and discharging of capacitor Cₓ₁, and (c) switching frequency of main switch M₁.
Fig. 9. (Color online) Experimental voltage waveforms of discharging capacitors $C_{D1}$ and $C_{D2}$: (a) 1000, (b) 5000, (c) 7500, and (d) 10000 rpm.

Fig. 10. (Color online) Experimental igniting voltage waveforms of spark plugs 1 and 2.
25 kV. Figure 11 shows extended igniting voltage waveforms of spark plugs 1 and 2. Figure 12 shows the exact igniting conditions of spark plugs 1 and 2. To verify that the proposed CDI for dual-cylinder motorcycles can reduce exhausted emission, the exhausted emissions for magnetic ignition and the proposed CDI are compared in Table 3.

Table 3

| Exhausted HC and CO at engine speed of 5000 rpm | Magnetic ignition | Proposed CDI | Decreases |
|-----------------------------------------------|------------------|--------------|-----------|
| Measurement of exhausted gas                 | Measurement of exhausted gas |                      |
| HC (ppm)                                      | 223              | 182          | HC = 41 ppm |
| CO (%)                                        | 1.85             | 1.62         | CO = 0.23%  |
5. Conclusions

In this study, a proposed CDI for dual-cylinder motorcycles has been built and implemented. The proposed CDI mainly uses Hall sensors to sense the optimal signals of ignition times, from which the optimal ignition angles of the spark plugs can be obtained. In a comparison of exhausted emission between magnetic ignition and the proposed CDI, it was found that HC emission was reduced by 41 ppm and CO emission was reduced by 0.23%. Therefore, air pollution can be reduced and environmental quality can be improved significantly by adopting the proposed CDI. Experimental results have verified that the proposed CDI is suitable for dual-cylinder motorcycles.

Acknowledgments

This work was supported by the Ministry of Science and Technology, Taiwan, under Grant No. MOST 107-2221-E-167-018.

Author Contributions

All of the authors contributed to publishing this paper. Jye-Chau Su wrote the paper, and Cheng-Tao Tsai and Ji-Xin Chen contributed to the design of the circuit and experimental results.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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