1. Introduction

Exhaust gas from internal combustion engines contains CO, HC, NOx and CO₂ and has been one cause of recent serious environment problems such as global warming, air pollution and so on. On the other hand, the market for internal combustion engine automobiles and motorcycles keeps growing because of their convenience. Therefore, it is necessary to take measures for environmental issues. Many countries and regions have adopted regulations on the amount of emissions. These regulations have become stricter in recent years. Many emissions reduction technologies such as fuel injection systems with oxygen feed-back control and a 3-way catalytic converter have been developed also for motorcycles.

Regulations for environment protection do not involve only restrictions on emissions but also the introduction of OBD systems which automatically diagnose malfunctions in the vehicle and inform the driver of the fact. The detection targets of the OBD II system include an emission control system malfunction that causes deterioration in tailpipe emissions. With this system, it is possible to detect cases where emissions continuously exceed the regulation limits. The OBD II system has already been implemented in automobiles. For motorcycles, implementation will become mandatory when Euro-5 emission regulations are introduced in Europe and Bharat Stage VI (BS-VI) emission regulations, in India.

One item for which detection is mandatory in OBD II regulations is misfire. Misfire occurs when the engine does not fire correctly due to ignition failure or poor combustion of the air fuel mixture, resulting in serious deterioration of tailpipe emissions due to discharge of unburned gas. It may also cause deterioration of the catalytic converter. For these reasons, the OBD II regulations require detection and warning for misfiring occurrences which cause worse tailpipe emissions than the specified levels and/or pose a risk of catalytic converter erosion by overheating.

Misfire detection technology for automobiles has been well developed and there are many strategies that are currently employed, using variation in characteristics, such as crank angular velocity, cylinder pressure or ionic current. These technologies have proven to be effective in the detection of misfiring in automobile engines.

However, in the case of motorcycle engines, have the following characteristics compared with automobile engines:
- there are unique engine variations such as engines with uneven firing intervals; and
- there is a lower combustion stability on no-load or low-load driving points because the engines are designed for high-power and high-speed performance.

As an example, Figure 1 shows the difference in the Indicated Mean Effective Pressure (IMEP) between a motorcycle engine and an automobile engine when running at a steady speed of 50km/h. In this case, the Coefficient of Variation (COV) calculated from the IMEP of the motorcycle engine is 13.77 and that of the automobile engine is 1.27. This reveals that the combustion stability of the motorcycle engine is considerably lower than that of the automobile engine.

Moreover, as a complete vehicle, a less expensive system is required and there is only limited space for the installation of hardware.

Furthermore, the system needs to detect misfiring at a higher engine speed than that for automobiles. Therefore, it is considerably difficult to adapt misfire detection methods for automobiles to motorcycles.

This paper presents the results of our study into misfire detection algorithms focusing on the uneven firing of a motorcycle V-twin engine. Some of the proposed algorithms use variation characteristics in crank angular velocity for detection. Utilization of these algorithms would not lead to any increase in cost, but only limited installation space is necessary since there are no requirements for any additional sensors or other devices. Firstly, performance of these algorithms was evaluated efficiently and quantitatively, by control simulation using various measurement data as input. The algorithm which showed good potential in simulation was subsequently integrated in the ECU in order to confirm its effectiveness through vehicle testing. Finally, this paper summarizes the prospect of practical utilization suggests directions for future research.

2. Testing Environment

2.1. Test Engine

In this research, a motorcycle with a water-cooled uneven firing twin-spark V-twin engine was used as a test vehicle. The engine was installed with a twin-spark firing system in which two spark plugs were equipped for each cylinder. Table 1 shows the specifications of the engine. The engine was developed for a high performance sports motorcycle.

2.2. Trigger Wheel / Pick-Up Sensor / Timing Teeth

The test vehicle had a trigger wheel and a pick-up sensor used for fuel injection and ignition control. The trigger wheel with 22 teeth (placed at each 15 degrees of rotation with 2 continuous missing teeth) on its periphery was mounted on an extension of the crankshaft. A pick-up sensor was installed on the outside of the trigger wheel. It detected the edge of the teeth and generated a sinusoidal wave.

The positions of these devices are shown in Figure 2 and Figure 3. The crank angular velocity can be calculated using these devices.

In addition, the missing tooth sections correspond to the following 2 stroke timing points;
- Cyl. #1: Suction stroke, Cyl. #2: Expansion stroke

![Fig. 1 Difference in IMEP between motorcycle engine and automobile engine](image-url)
Table 1 Specification of Test Engine

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displaced Volume</td>
<td>1,301 cc</td>
</tr>
<tr>
<td>Number of Cylinders</td>
<td>2 cylinders</td>
</tr>
<tr>
<td>Engine Architecture</td>
<td>V-type (Angle of the V : 75 deg)</td>
</tr>
<tr>
<td>Phase Difference</td>
<td>Cyl. #1 to Cyl. #2 : 435 deg</td>
</tr>
<tr>
<td>Stroke</td>
<td>71 mm</td>
</tr>
<tr>
<td>Bore</td>
<td>108 mm</td>
</tr>
<tr>
<td>Compression Ratio</td>
<td>13 : 1</td>
</tr>
<tr>
<td>Valve Train Layout</td>
<td>DOHC 4 valves</td>
</tr>
<tr>
<td>Cooling Type</td>
<td>Water cooled</td>
</tr>
<tr>
<td>Maximum Output</td>
<td>118 kw / 8,750 rpm</td>
</tr>
<tr>
<td>Maximum Torque</td>
<td>140 Nm / 6,750 rpm</td>
</tr>
</tbody>
</table>

- Cyl. #1 : Expansion stroke, Cyl. #2 : Suction stroke

Figure 4 shows the relationship between the missing tooth sections and the stroke timing of each cylinder.

2.3. Misfiring Method

Missfire generation software was designed and integrated in the ECU in order to generate intentional misfire. This software generates an ignition cut-off at equal intervals by presetting the target cylinder, the total number of ignition events and the number of times for misfire generation. For example, when cylinder #1 is set to generate one misfire for each ten combustion cycles, nine ignitions and one ignition cut-off are repeated alternately.

The test engine adopted a twin-spark firing system. Therefore, when misfire was generated, ignition cut-off was executed for both plugs on the cylinder.

3. Pre-testing Results

In this research, misfire detection algorithms using crank angular velocity focused on the fact that when misfire occurs, no combustion energy is generated, and thus the crank angular velocity decelerates. Incidentally, the teeth intervals and missing teeth of the trigger wheel influenced the linearity of the crank angular velocity calculation and affected misfire detection accuracy. The aim of this research was to create an algorithm misfire detection with a trigger wheel missing 2 teeth at 15 degree intervals as installed in the test vehicle.

In addition, in conventional misfire detection algorithms using crank angular velocity, digital filtering calculations have been often used to extract characteristic frequency components at misfiring or to remove components unnecessary for detection. In order to design such filtering calculations, it is
necessary to check the frequency components of angular velocity by normal combustion or misfiring.

Prior to the construction and evaluation of misfire detection algorithms, the following two items were pretested.
1. Confirmation of lack of combustion and crank angular velocity variation
2. Frequency analysis of crank angular velocity

3.1. Confirmation of Lack of Combustion and Crank Angular Velocity Variation

Purpose:
The purpose of this first stage of testing is to confirm lack of combustion by misfire generation and to also confirm that decrease of crank angular velocity due to lack of combustion can be observed at 15-degree intervals using the trigger wheel equipped with missing teeth and the pick-up sensor.

Method:
With the test vehicle secured to a chassis dynamometer, misfire was generated by software. The lack of combustion was confirmed from analysis of the IMEP and angular velocity variation was calculated from the output of the pick-up sensor. The same test process was carried out for each cylinder.

Result:
Due to misfiring, IMEP decreased greatly. From this result, it was evident that lack of combustion was occurring by misfiring. Additionally, at the same time with IMEP decrease, a decrease in crank angular velocity was also observed. Figure 5 shows the difference of IMEP value and crank angular velocity variation at NE=1,400rpm and 9,500rpm.

Conclusion/Decision:
A lack of combustion occurred due to misfiring. At that time, decrease of crank angular velocity was confirmed by calculations using the trigger wheel with two missing teeth at 15-degree intervals. Although this tendency was found to be weaker when the NE was higher, as a result of these tests, misfire detection using the trigger wheel and pick-up sensor was judged possible for this test engine.

3.2. Frequency Analysis of Crank Angular Velocity

Purpose:
The purpose of this analysis was to check frequency components of angular velocity in test engine for reference in the design of misfire detection algorithms and also to confirm the characteristics of an uneven firing engine by comparing with frequency analysis results from an even firing engine.

Method:
With the test vehicle secured to a chassis dynamo, angular velocity calculated by the output of the pick-up sensor was analyzed using a Fast Fourier Transform (FFT) algorithm in post-processing. Also, the analysis results were compared with results from a comparison engine (even firing) which had been preliminarily tested. Table 2 shows the specifications of the comparison engine.

Results:
As a result of the FFT analysis of angular velocity of the test engine, it was found that...
the 0.5\textsuperscript{th} order of crankshaft rotation is the basic frequency component. Additionally, even if either of the cylinders was misfiring, there was no distinct frequency component. The result of FFT analysis is shown in Figure 6.

On the other hand, the results from the comparison single cylinder engine show that the 0.5\textsuperscript{th} order of crankshaft rotation is the basic frequency component. Additionally, a distinct frequency component at the 0.25\textsuperscript{th} order of crankshaft rotation occurred when misfiring. Results of the FFT analysis is shown in Figure 7.

**Conclusion/Decision;**

In the test engine, the 0.5\textsuperscript{th} order of crankshaft rotation was the basic frequency component in both normal combustion and misfiring. In addition, a distinct frequency component occurred when there was misfiring in the comparison engine (even firing), but this did not occur in the test engine (uneven firing). The reason is assumed to be that the crank angular velocity variation patterns from combustion for each cylinder are different.

### Table 2  Specification of comparison engine

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displaced Volume</td>
<td>109.1 cc</td>
</tr>
<tr>
<td>Number of Cylinders</td>
<td>1 cylinder</td>
</tr>
<tr>
<td>Stroke</td>
<td>55.6 mm</td>
</tr>
<tr>
<td>Bore</td>
<td>50.0 mm</td>
</tr>
<tr>
<td>Compression Ratio</td>
<td>9 : 1</td>
</tr>
<tr>
<td>Valve Train Layout</td>
<td>OHC 4 valves</td>
</tr>
<tr>
<td>Cooling Type</td>
<td>Air cooled</td>
</tr>
<tr>
<td>Maximum Output</td>
<td>6.4 kw / 7,500 rpm</td>
</tr>
<tr>
<td>Maximum Torque</td>
<td>9.36 Nm / 5,500 rpm</td>
</tr>
</tbody>
</table>

4. Detection Algorithms

In this research, four algorithms were evaluated in parallel and compared for accuracy. These algorithms were composed of four parts, and the input used is the time between the edges of pulses calculated from the output of the pick-up sensor.

Misfire detection was performed by comparing the detection index parameter value calculated from each algorithm with a preset threshold value. Figure 8 shows the construction of each algorithm. The
a decrease in misfire detection accuracy. In order to prevent such a decrease, a moving average calculation, a kind of an LPF calculation, was adopted. Since moving average calculation can be applied to the number of data, crank angle, and not to time, it is possible to remove an intended high frequency component regardless of the speed of the crank angular velocity. Incidentally, each detection index parameter calculation of Part 4 was premised by monitoring the variation pattern of crank angular velocity due to combustion. Therefore, it is not preferable to remove components due to combustion by moving average calculation. As a result of the pre-testing, the component due to combustion was a component at the 0.5\textsuperscript{th} order of crankshaft rotation. Therefore, in this research, by adopting a moving average calculation of six data, which constitutes a 90-degree section, only values below that of the 4\textsuperscript{th} order of the component of rotation were taken into account, and thus high frequency components were removed.

The moving average value of crank angular velocity ($\omega_{MA_n}$) was calculated by equation 3.

$$\omega_{MA_n} = \frac{1}{6} \sum_{i=-5}^{0} \omega_{CRKn}$$

This calculation was applied to all algorithms.

\section*{4.2. Part 2: Low Pass Filter (LPF) Calculation}

Unnecessary high frequency components were included in the crank angular velocity as calculated in Part 1, and these components may have caused

\section*{4.3. Part 3: Identifying Calculation}

In an uneven firing engine, the variation patterns of crank angular velocity show large differences for each cylinder. This calculation aimed at identifying the characterizing portion of combustion corresponding to the crank angular velocity variation

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for each cylinder and formulating it so that the combustion by each cylinder could be regarded as equivalent. With this calculation, we were able to bring the variation pattern closer to that of an even firing engine.

In this calculation, the following six points, P1 to P6, were extracted as combustion characteristics for one cycle (720-degree crank angle). The compression TDC points were extracted as the reference points for the start of combustion, and the points during the expansion stroke and the exhaust stroke were extracted as points where a large difference occurs between normal combustion and misfiring.

- P1: Cyl. #1 Compression TDC
- P2: Cyl. #1 During expansion stroke
- P3: Cyl. #1 During exhaust stroke
- P4: Cyl. #2 Compression TDC
- P5: Cyl. #2 During expansion stroke
- P6: Cyl. #2 During exhaust stroke

The $\omega_{MAn}$ value at these six points was defined as a continuous signal of $\omega_{idn}$.

Figure 10 shows $\omega_{MAn}$ and extraction points with cylinder #1 misfiring at NE=5,000rpm as an example.

This calculation was applied to algorithm 1 and algorithm 2.

### 4.4. Part 4: Detection Index Parameter Calculation

#### Algorithm 1

In Part 3, in order to regard the combustion of each cylinder as equivalent, the $\omega_{idn}$ value was calculated by formulating the crank angular velocity. In this algorithm, the value is compared with the angular velocity at the same stroke with the previous ignition cylinder to calculate detection index parameters. That is, since the previous combustion and the current combustion are compared, the detection index parameter value in the case of misfiring is greatly reduced.

The detection index parameters using this algorithm ($DIP_1$) were calculated by equation 4.

$$DIP_1 = \omega_{idn} - \omega_{idn-3} \quad (4)$$

Furthermore, the $\omega_{idn}$ values calculated at the timing of P1 to P3 were used for cylinder #1 and in the same at the timing of P4 to P6 are used for misfire detection in cylinder #2.

#### Algorithm 2

Firstly, the relative angular velocity was calculated based on the compression TDC of each cylinder for the $\omega_{idn}$ value in Part 3. For cylinder #1, the extracted angular velocity at P1 ($\omega_{RidP1}$) is used as a reference, the relative angular velocity at P2 ($\omega_{RidP2}$) is calculated by equation 5 and the same at P3 ($\omega_{RidP3}$) is calculated by equation 6.
ω_{RidP2} = ω_{idP2} - ω_{idP1} \quad (5)

ω_{RidP3} = ω_{idP3} - ω_{idP1} \quad (6)

In the same manner, for cylinder #2, the extracted angular velocity at P4 (ω_{idP4}) was used as a reference, the relative angular velocity at P5 (ω_{RidP5}) was calculated by equation 7 and the same at P6 (ω_{RidP6}) was calculated by equation 8.

ω_{RidP5} = ω_{idP5} - ω_{idP4} \quad (7)

ω_{RidP6} = ω_{idP6} - ω_{idP4} \quad (8)

Then, relative angular velocities based on the compression TDC timing of each cylinder were integrated so as to be used as misfire detection index parameters. The misfire detection index parameter (DIP_{31}) for cylinder #1 was calculated by equation 9 and the same for cylinder #2 (DIP_{32}) was calculated by equation 10.

DIP_{31} = \sum_{i=1}^{2CT+1} \omega_{RMan} \quad (13)

DIP_{32} = \sum_{i=2CT+1}^{1CT+1} \omega_{RMan} \quad (14)

Algorithm 3

For this algorithm, the ω_{Man} value calculated in Part 2 was used as is. At first, the relative angular velocity was calculated based on the compression TDC of each cylinder for the ω_{Man} value. The extracted angular velocities at the cylinder #1 compression TDC (ω_{MA1CT}) and at the cylinder #2 compression TDC (ω_{MA2CT}) were used as references, and the relative angular velocities (ω_{RMan}) were calculated by equations 11 and 12.

If 1CT + 1 ≤ n < 2CT:

ω_{RMan} = ω_{Man} - ω_{MA1CT} \quad (11)

If 2CT + 1 ≤ n < 1CT:

ω_{RMan} = ω_{Man} - ω_{MA2CT} \quad (12)

The ω_{RMan} value was integrated in the section up to the point before the compression TDC of the cylinder firing next, which was used as the detection index parameter. The misfire detection index parameter for cylinder #1 (DIP_{31}) was calculated by equation 13, and the same for cylinder #2 (DIP_{32}) was calculated by equation 14.

Algorithm 4

The basic logic of this algorithm was the same as algorithm 3. Only the integration section of the ω_{RMan} value was changed so as to be 180 degrees from compression TDC of each cylinder. The reason for that was that the ω_{RMan} value at the section before the compression TDC of the next firing cylinder included many disturbance components such as friction that cannot be attributed to the combustion state, and large deviations in the angular velocities.

The misfire detection index parameter for
cylinder #1 \((DIP_{41})\) was calculated by equation 15 and the same for cylinder #2 \((DIP_{42})\) was calculated by equation 16.

\[
DIP_{41} = \sum_{i=1}^{12} \omega_{RMA} \quad (15)
\]

\[
DIP_{42} = \sum_{i=2}^{12} \omega_{RMA} \quad (16)
\]

The schema of these calculations is shown in Figure 12.

5. Results of Simulations

5.1. Evaluation Method

5.1.1. Evaluation Flow

The signal output from the pick-up sensor was entered into an external measurement instrument and measured. After that, the measured value was entered into a data analysis simulation model on a computer. There were two parts of the simulation model. The first part calculated the crank angular velocity from the pick-up sensor output signal, and the second part applied the four misfire detection algorithms at the same time in parallel. For the next step, detection performance was compared and evaluated based on the behavior of the parameters calculated by each detection algorithm. An outline of the evaluation flow is shown in Figure 13.

One thing that must be mentioned is that sampling rate for the output of pick-up sensor is substantially influenced by the linearity of crank angular velocity calculation as well as the tooth intervals and missing teeth of the trigger wheel.

Subsequently, these factors affect the accuracy of the misfire detection.

In this evaluation, in order to acquire analysis results closer to a real system, the recording rate of the measurement instruments for pick-up sensor output was set to 1 MHz rate which conforms to the read interval of the ECU.

5.1.2. Index for Evaluation

The Signal-to-Noise ratio \((SNR)\) was used as an index for comparing misfire detection performance for each algorithm. \(SNR\) was defined as the power ratio of the signal and background noise. In this evaluation, the detection index parameters calculated by the detection algorithm at misfiring were set as signal, and the parameters calculated at normal combustion were set as noise. In addition, assuming that the detection parameter value exhibits a normal distribution, the \(SNR\) was calculated by equation 17.
\[ SNR = \frac{|AVE_n - AVE_m|}{\sigma_n + \sigma_m} \]  

(17)

\( AVE_n \) : Average of detection parameter with combustion  
\( AVE_m \) : Average of detection parameter with misfiring  
\( \sigma_n \) : Deviation of detection parameter with combustion  
\( \sigma_m \) : Deviation of detection parameter with misfiring

The higher the \( SNR \) value, the easier it is to distinguish between the distribution of normal combustion and that of misfiring. This facilitates the setting of a misfire detection threshold for satisfactory misfire detection performance. For example, when the \( SNR = 3.0 \), the detection accuracy is calculated at approximately 99.8%.

5.2. Evaluation Targets

With the test vehicle secured to a chassis dynamometer, data from running tests were recorded for the following two cases and the data generated by the simulation were evaluated:
- Steady state: By fixed throttle angle; and
- Acceleration state: By wide throttle opening.

During the simulation, misfires were generated at even intervals at the rate of once every ten combustion cycles in one cylinder. The same tests were conducted for both cylinders on the test engine in a warmed-up state (\( TW \geq 80 \) degC). Detection index parameters at a non-intentional misfiring cycles were classified as noise, and those at intentional misfiring cycles were classified as valid signals for analysis.

5.2.1. Measurement Points for Steady State Tests

Data was measured at several load points inside the detection area as defined by the OBD II regulations of the European Union.

Testing points for cylinder #1 are shown in Figure 14 as an example. The mark indicates the gear for each driving cycle.

5.3. Evaluation Results

5.3.1. Steady State Test Results

The misfire detection \( SNR \) values for cylinder #1 at each load point are shown in Table 3 and those for cylinder #2 are shown in Table 4. The algorithms which achieved the highest \( SNR \) at each load point are highlighted in green.

From these results, it was found that algorithm 4
had a high detection performance for both cylinders, and it was judged that this performance was sufficient for practical use.

Figure 15 shows behavior of $\omega_{\text{MAn}}$ and $DIP_{41}$ with intentional misfiring on cylinder #1 at NE = 5,000 rpm with PM = 45.11 kPa. The $DIP_{41}$ value drops sharply according to the misfiring points.

5.3.2. Acceleration State Test Results

In this test, the 3rd gear was used to accelerate with a wide-open throttle. For this acceleration, NE was increased from 3,000rpm to 10,000rpm in 4.0 seconds.

The misfire detection SNR values for the acceleration state are shown in Table 5.

From these results, it was found that the three algorithms excluding algorithm 1 have a high detection performance for both cylinders, and this performance was judged to be sufficient for practical use.

Figure 16 shows the behavior of $\omega_{\text{MAn}}$ and $DIP_{41}$ with intentional misfiring of cylinder #1 for the acceleration state. The $DIP_{41}$ value drops sharply according to the misfiring points in the same way as the results for the steady state tests.
6. Result of Vehicle Tests

6.1. Evaluation Method

Based on the results of the simulations, algorithm 4 was judged to have the highest potential, and thus it was entered into the ECU. During these evaluations, misfire was detected when the detection index parameter value was lower than the detection threshold, a value which, for prototype purposes, is a constant value for the all load points.

With the test vehicle secured to a chassis dynamometer, data from running tests of the vehicle was recorded from the ECU and the detection accuracy of the algorithm was subsequently evaluated.

6.2. Evaluation Targets

The test data for each of the three phases in the World Motorcycle Test Cycle (WMTC) Class 3-2 test cycle (Figure 17) with the engine in a warmed-up state (TW ≥ 80 degC) were measured separately.

In each phase, the detected misfiring rate by our algorithm was compared with the intentional misfiring rate in the detection area. In addition, the value calculated by dividing the sum of the number of undetectable, misdetection or natural misfires by the number of cycles in the detection area was defined as the error rate, which was also evaluated.

The schema of the evaluation targets is shown in Figure 18.

During the vehicle testing, misfire was generated at even intervals at a rate of once every ten combustion cycles in one cylinder in the same manner as the earlier simulations. The same testing was conducted for each cylinder.

6.3. Evaluation Results

The evaluation results for cylinder #1 misfiring at each phase are shown in Table 6, and results for the same for cylinder #2 are shown in Table 7.

In the case of cylinder #1, almost all of intentional misfire could be detected. Although there were a noticeable number of misdetection or natural misfires, the number of undetectable misfires was small, allowing for an error rate of less than 1% in all phases.

In the case of cylinder #2, although the results were inferior to those of cylinder #1, almost all of the intentional misfires could be detected. Although there were a noticeable number of undetectable misfires, the number of misdetection or natural misfires was small, allowing for an error rate of less than 0.5% in all phases.

As mentioned above, the detection thresholds for each cylinder were set at a constant value for all load points for prototype purposes. From these results, it was evident that by optimizing the thresholds based on the number of undetectable and of misdetection misfires, detection accuracy can still be improved further.

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Table 6  Detection accuracy of misfiring in Cyl. #1

<table>
<thead>
<tr>
<th></th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Cycles in Detection Area (times)</td>
<td>7,790</td>
<td>10,969</td>
<td>17,084</td>
</tr>
<tr>
<td>Number of Intentional Misfiring (times)</td>
<td>750</td>
<td>1,083</td>
<td>1,696</td>
</tr>
<tr>
<td>Intentional Misfiring Rate (%)</td>
<td>9.63</td>
<td>9.87</td>
<td>9.93</td>
</tr>
<tr>
<td>Number of Correct Detection (times)</td>
<td>750</td>
<td>1,083</td>
<td>1,694</td>
</tr>
<tr>
<td>Number of Undetectable (times)</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Number of Misdetection or Natural Misfiring (times)</td>
<td>73</td>
<td>93</td>
<td>47</td>
</tr>
<tr>
<td>System Detected Rate (%)</td>
<td>10.56</td>
<td>10.72</td>
<td>10.19</td>
</tr>
<tr>
<td>Error Rate (%)</td>
<td>0.94</td>
<td>0.85</td>
<td>0.29</td>
</tr>
</tbody>
</table>

Table 7  Detection accuracy of misfiring in Cyl. #2

<table>
<thead>
<tr>
<th></th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Cycles in Detection Area (times)</td>
<td>6,124</td>
<td>10,461</td>
<td>17,026</td>
</tr>
<tr>
<td>Number of Intentional Misfiring (times)</td>
<td>561</td>
<td>1,028</td>
<td>1,701</td>
</tr>
<tr>
<td>Intentional Misfiring Rate (%)</td>
<td>9.16</td>
<td>9.83</td>
<td>9.99</td>
</tr>
<tr>
<td>Number of Correct Detection (times)</td>
<td>561</td>
<td>995</td>
<td>1,646</td>
</tr>
<tr>
<td>Number of Undetectable (times)</td>
<td>0</td>
<td>33</td>
<td>55</td>
</tr>
<tr>
<td>Number of Misdetection or Natural Misfiring (times)</td>
<td>12</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>System Detected Rate (%)</td>
<td>9.36</td>
<td>9.63</td>
<td>9.70</td>
</tr>
<tr>
<td>Error Rate (%)</td>
<td>0.20</td>
<td>0.43</td>
<td>0.36</td>
</tr>
</tbody>
</table>

7. Summary

Misfire detection algorithms using crank angular velocity fluctuation which can be applied to uneven firing V-twin engines was proposed. For calculation of the crank angular velocity, output from pick-up sensor with a trigger wheel with two missing teeth at 15-degree intervals was used.

For proposed algorithms, the misfire detection accuracy was evaluated and compared by control simulation using various measurement data as input. Subsequently, the algorithm which showed higher potential in simulation was integrated in an ECU and it was confirmed by vehicle testing that misfire detection was almost possible.

In the future, further studies especially focused on the following issues are needed in order to establish a viable misfire detection system for motorcycles:
- measures to set the optimum detection threshold;
- detection performance for different misfire occurrence patterns;
- measures for abnormalities in one plug in a twin spark engine;
- detection performance when disturbance influences such as rider operation and travel on rough surfaces; and
- application to different engine types.

References

(3) Hiroyasu, H., “Easy understand Internal

Acknowledgments

The author would like to express his gratitude to KTM A.G. R&D EMS team who supported with the provision of a test engine and a vehicle.
All testing data acquisition in this research are from the work package of the misfire detection development project in Keihin Corporation, and the author’s colleague, Yuki Morita contributed greatly in his support of this project.

Remarks

It is a great honor that this paper was chosen for the Best Presentation Award in the 23rd Small Engine Technology Conference (SETC) in November 15-17, 2017, Jakarta.