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Application of Indicated Mean Effective Pressure Calculation Method Forcing on Specific Low-Frequency Components within Pressure Diagram to Double-Peak Pressure Diagram

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Issues that need to be addressed with automotive engines include how to increase fuel consumption rate and reduce exhaust emissions. This requires enhancing thermal efficiency and reduction of unburned gas emissions. Pressure diagram have been used to verify the effectiveness of techniques for making these enhancements. From the pressure diagram, one can calculate such parameters as the indicated mean effective pressure (IMEP), heat release rate, maximum cylinder pressure (P_{max}), and the crank angle at which this occurs (θ_{Pmax}). This is crucial data for engine development. IMEP is often calculated by discretizing its definitional equation, Eq. (1), into Eq. (2). On the other hand, it has been shown that this can be found using a calculation method, as in Eq. (3), which uses the 1st and 2nd order frequency components, taking the crank angle velocity within the analytically derived pressure diagram as the fundamental frequency. This shows that the effective work of the engine is determined by the low-frequency components within the pressure diagram. In a typical automotive gasoline engine, operation occurs at an ignition timing, fuel injection timing, and fuel injection volume that are optimal or near-optimal for torque and fuel consumption. As a result, the pressure diagram can be observed as a single peak. However, ignition timing is sometimes intentionally retarded to protect the engine from knocking or to promote activation of the exhaust catalyst immediately after starting. In this case, a double-peak pressure diagram may occur, with one peak at top dead of center immediately after the compression process, and another from the pressure increase that happens with combustion.

This paper confirms that the IMEP calculation method using Eq. (3) can be applied regardless of the shape of the pressure diagram. For that reason, the researchers conducted their study not only for single-peak pressure diagram but also for double-peak pressure diagram. This study used a four-cylinder, four-cycle engine with a bore of 87 mm, stroke of 99 mm, compression ratio of 10.5, connecting rod length of 152 mm, and piston pin offset of 0.8 mm. A pressure transducer was installed on the fourth cylinder of the test engine and pressure diagram were measured at crank angle intervals of 1 degree using a data recording device.

The study results confirmed that IMEP calculated with Eq. (2) and Eq.(3), as shown in Figure 1, are equivalent not only for single-peak but also double-peak pressure diagram, and that Eq. (3) can be applied to double-peak pressure diagram. This is because the calculation method was analytically derived from the IMEP definitional formula. Furthermore, when IMEP fluctuates under the same operating conditions, including the case of two-peak pressure diagram, cycles with a greater IMEP have a lower proportion of 1st order frequency component on the right-hand side of Eq. (3) compared to cycles with a smaller IMEP. This is because combustion accelerates in cycles with a greater IMEP, resulting in a higher proportion of the 2nd order frequency component, which is of a higher order.

$$IMEP = \frac{1}{V_s}\oint PdV \qquad (1)$$

$$IMEP_0 = \frac{1}{V_s}\sum_{j=1}^{n}\frac{(P_{j+1}+P_j)(V_{j+1}-V_j)}{2} \qquad (2)$$

$$IMEP_f = \frac{\pi}{2h}(C_1\cos\phi_1 + KC_2\cos\phi_2) \qquad (3)$$

$$a_k = \frac{1}{m}\sum_{j=1}^{n}P_j\cos\left(\frac{\pi kj}{mh}\right) \qquad b_k = \frac{1}{m}\sum_{j=1}^{n}P_j\sin\left(\frac{\pi kj}{mh}\right)$$

$$C_k = \sqrt{{a_k}^2 + {b_k}^2} \qquad \phi_k = \tan^{-1}\left(\frac{a_k}{b_k}\right)$$

$IMEP_0$: IMEP calculated by discretizing. Eq.(2)
$IMEP_f$: IMEP calculated using low-frequency components within the pressure diagram. Eq.(3)
a_k, b_k : Amplitude of k^{th} cos, k^{th} sin component
C_k, φ_k : Amplitude and phase shift of k^{th} composite component
V_s : Stroke volume P : Cylinder pressure data
dV : Displacement change
P_{j+1}, P_j : $(j+1)^{\mathrm{th}}$, j^{th} cylinder pressure data
V_{j+1}, V_j : $(j+1)^{\mathrm{th}}$, j^{th} displacement
n : Number of sampling data per cycle m = n/2
k : Order h : Constant (1 for two cycles, 1/2 for four cycles)
$K = (1/2\lambda)(1/(1+4\lambda^2))$ λ : Connecting rod length/crank radius

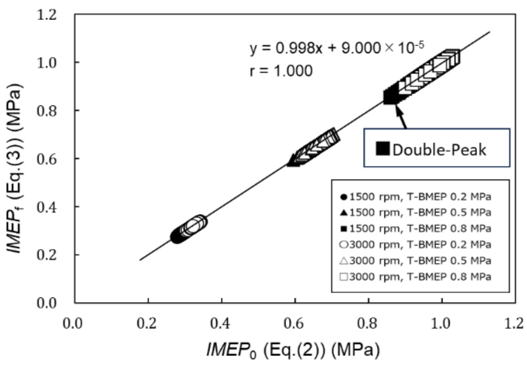

Figure 1 Relationship between $IMEP_0$ and $IMEP_f$