講演番号 235

Evaluation of Piston–Ring Dynamic Behavior Affecting Ring Sealing Performance and Flutter Analysis Techniques

Junjiro Nakanishi [1)] Kouji Shishime [1)] Masaki Fukuma [1)]

1) Mazda Motor Corporation
3-1 Shinchi, Fuchu-cho, Aki-gun, Hiroshima 730-8670, Japan

KEY WORDS: **Heat engine, Engine component or element, Performance/fuel economy/efficiency** Blowby, Piston & Ring dynamics [A1]

Improving engine thermal efficiency requires effective sealing of the combustion chamber, in which piston rings play a critical role. Insufficient sealing leads to blow-by, where combustion gas leaks into the crankcase, resulting in reduced thermal efficiency, deterioration of engine oil lubrication, and degradation of exhaust emission performance. However, piston rings sometimes exhibit unstable motion during engine operation, known as ring flutter, which deteriorates sealing performance. Although several studies have investigated ring flutter, few have examined its relationship with piston secondary motion.

In this study, the mechanism of blow-by increase caused by ring flutter was investigated through engine experiments and numerical analysis using a validated piston–ring dynamic model. Two inline six-cylinder gasoline engines for passenger vehicles were examined. Both engines used identical piston ring packs but had different piston geometries. Experiments simulated the transition from engine braking to combustion operation while continuously measuring blow-by.

Results showed that after fuel injection was resumed, one engine exhibited a significant increase in blow-by, suggesting the occurrence of ring flutter. Numerical simulations revealed that differences in piston secondary motion around −150° crank angle influenced gas flow paths within the ring pack (Fig.1). In the stable engine, piston tilting toward the thrust side allowed atmospheric pressure to enter the lower ring lands, reducing the pressure difference acting on the top ring and stabilizing ring seating. In contrast, the unstable engine showed insufficient piston tilt, preventing pressure equalization and leading to top ring lift and flutter (Fig.2).

Further analysis demonstrated that the piston center-of-gravity position strongly affects piston rotational behavior and consequently ring stability. Modifying the piston mass distribution shifted the center of gravity and changed piston tilt behavior, confirming the relationship between piston dynamics and flutter occurrence.

To quantitatively evaluate ring stability, a stability index based on binarized ring displacement was proposed. The index showed strong correlation with experimentally observed blow-by levels and successfully predicted flutter occurrence in a prototype engine with different displacement. These results indicate that piston secondary motion plays a key role in ring flutter and that the proposed stability index provides an effective design guideline for improving sealing performance.

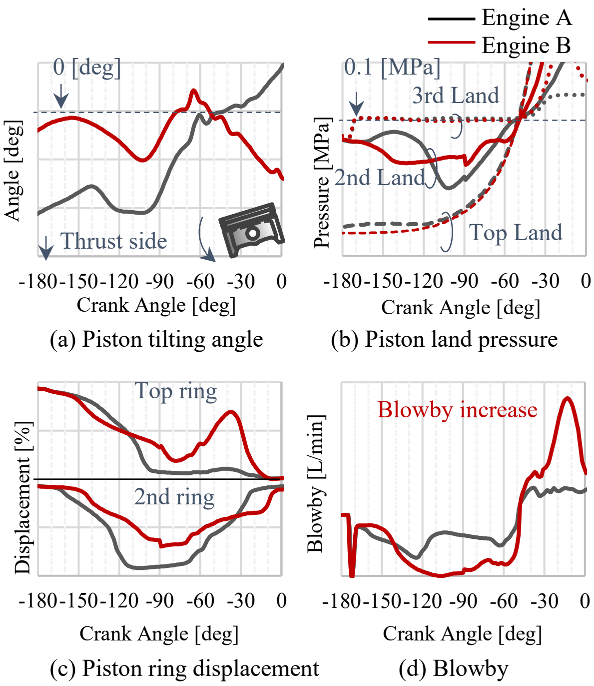

Fig.1 Simulation Results

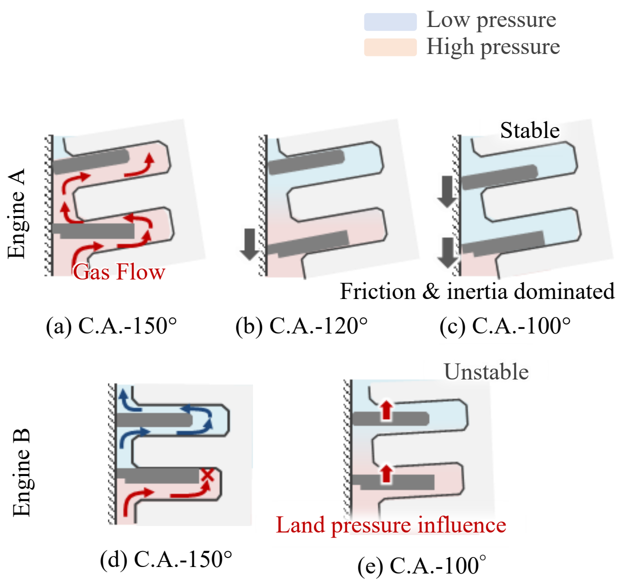

Fig.2 Top Ring & 2nd Ring Behavior in Ring Groove