

Diesel Combustion Noise Reduction by Controlling Piston Vibration

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ABSTRACT

It has been required recently that diesel engines for passenger cars meet various requirements, such as low noise, low fuel consumption, low emissions and high power. The key to improve the noise is to reduce a combustion noise known as “Diesel knock noise”. Conventional approaches to reduce the diesel knock are decreasing combustion excitation force due to pilot/pre fuel injection, adding ribs to engine blocks or improving noise transfer characteristics by using insulation covers. However, these approaches have negative effects, such as deterioration in fuel economy and increase in cost/weight. Therefore, modification of engine structures is required to reduce it.

We analyzed noise transfer paths from a piston, a connecting rod, a crank shaft to an engine block and vibration behavior during engine operation experimentally, and identified that piston resonance was a noise source. In order to absorb resonant energies caused by vertical movement of the piston, we have designed new piston-pin structure integrated with dynamic damper which resonates in the opposite phase to the piston. We verified the diesel knock reduction by using this new technology.

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INTRODUCTION

During diffusive combustion of a direct-injection diesel engine, fuel is injected from the injector when the combustion chamber is ready for ignition and cylinder pressure rapidly rises to trigger self-ignition at the several areas [1]. Since high thermal efficiency can be obtained by fast burn, Premixed charge compression ignition [2] and Homogeneous-Charge Compression Ignition [3] will be employed in the future. However, from Noise and Vibration point of view, due to rapid cylinder pressure applied to engine components by fast burn, engine vibration occurs and “rattling” intermittent diesel knock noise is generated. To achieve both ultimate thermal efficiency and reduction in diesel knock noise, a new engine structure [4][5] needs to be developed to reduce diesel knock noise without depending on combustion control.

It is known that the dominant frequency of diesel knock exists near 3.15 kHz octave band [6]. Therefore, by focusing on 3.15 kHz octave band, the mechanism of diesel knock was identified and a vibration reduction engine structure was developed.

CHARACTERISTICS OF DIESEL KNOCK

Inline 4 cylinder 2.2L direct injection diesel engine was used for the test. To understand the frequency characteristic of diesel knock better, the amount of pre-injection was reduced and combustion excitation force was increased intentionally to generate distinct diesel knock. Figure 1 shows the spectrum of near field radiated engine noise measured at 2000rpm and Pe0.9MPa. Notable noise peak exists at 3.5 kHz.

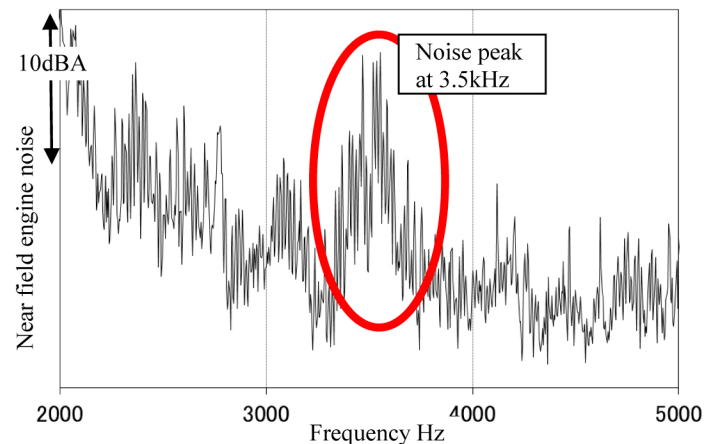


Figure 1. Near field noise spectrum during diesel knock [2.2L DE]

Diesel knock was also replicated from 1.5L engine with increased combustion excitation force intentionally. Figure 2 shows the measured near field radiated engine noise of 1.5L. The peak was also identified at 3.5 kHz. The following are the characteristics of diesel knock:

- ①. The dominant frequency of diesel knock exists between 3kHz and 4 kHz.
- ②. When an engine with different specification was measured, the noise peak also appeared between 3kHz and 4kHz

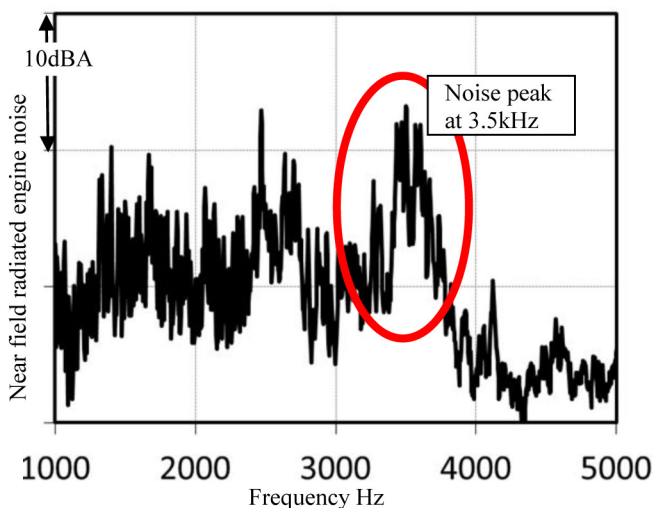


Figure 2. Near field noise spectrum during diesel knock [1.5L DE]

DIESEL KNOCK GENERATION MECHANISM

Measurement of Engine Internal Part Behavior

To understand the mechanism of the noise peak generated between 3 kHz and 4 kHz, several noise transfer paths were experimentally analyzed. Figure 3 shows suspected noise transfer paths that amplify the vibration peak.

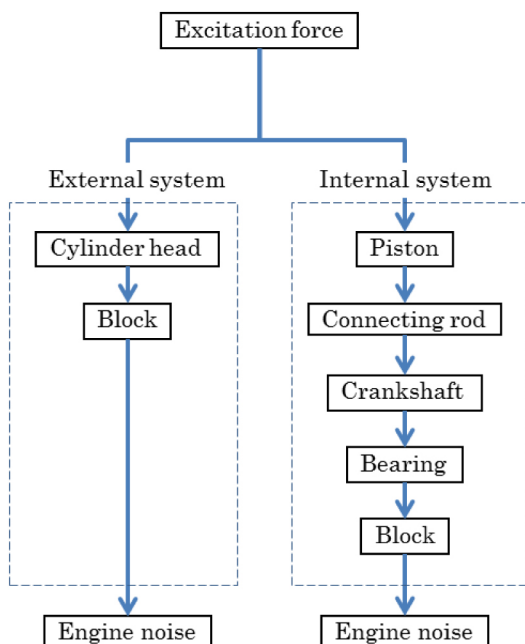


Figure 3. Suspected noise transfer paths

First, the influence of noise transfer path in the external system, which transfers excitation force from the combustion chamber to the cylinder head and engine block, was analyzed. The influence can be verified by hammering test with the engine assembled with the cylinder head and the engine block. As shown in Figure 4, excitation force was applied to the combustion chamber with a hammer and Figure 5 shows frequency response function obtained by measuring

vibration of several locations on the external system. Since distinct vibration peak is not found between 3 kHz and 4 kHz in the FRF, it can be concluded that the vibration peak is not amplified by the transfer path in the external system.

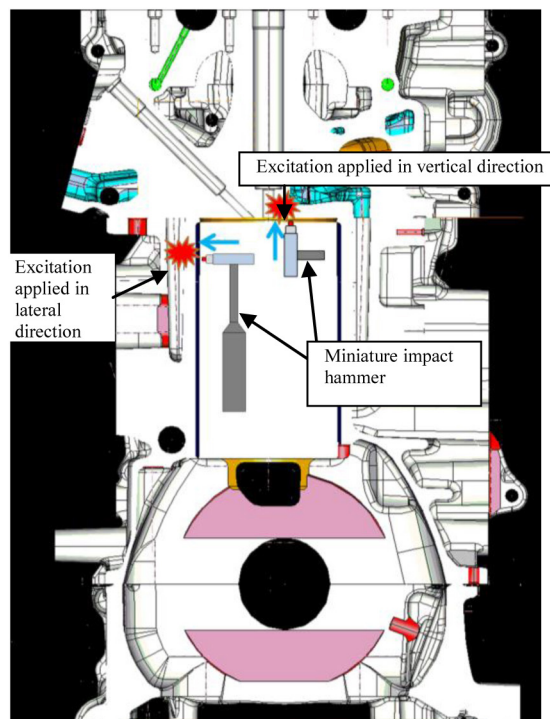


Figure 4. Image of hammering test

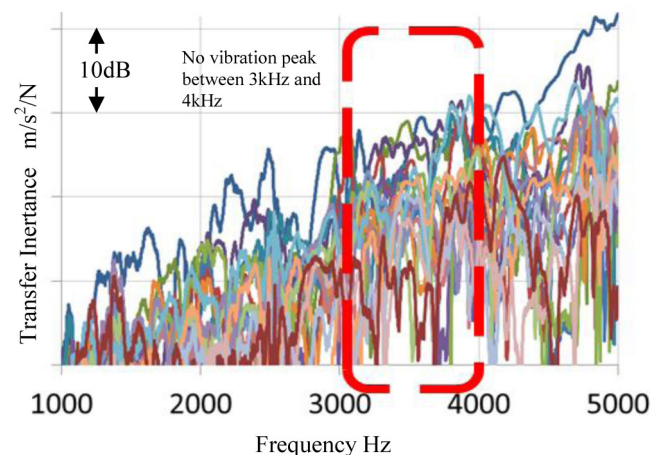


Figure 5. Vibration response of external system with hammering test

Next, the influence of noise transfer path in the internal system, which transfers excitation force from piston, connecting rod, crank shaft, bearing to engine block, was analyzed. During combustion, oil acts as a spring and damper in elastic hydrodynamic lubrication and transfers force to the engine internal parts. Since the conditions of this spring and damper vary with engine operating conditions and crank angle, it is difficult to replicate the boundary conditions of oil under static hammering test. Therefore, internal vibration behavior was directly measured during actual engine operation.

Figure 6 shows the location of an accelerometer on the piston and connecting rod and Figure 7 shows the procedure to retrieve signal from reciprocating parts using a link arm. As shown in Figure 7, the accelerometer cable is bonded to the link arm except for the circled moveable areas so that the cable can be twisted and routed to the outside the engine. Accelerometers with built-in amplifier are used to control the change in electrical resistance variation caused by the cable twist during the operation of the link arm.

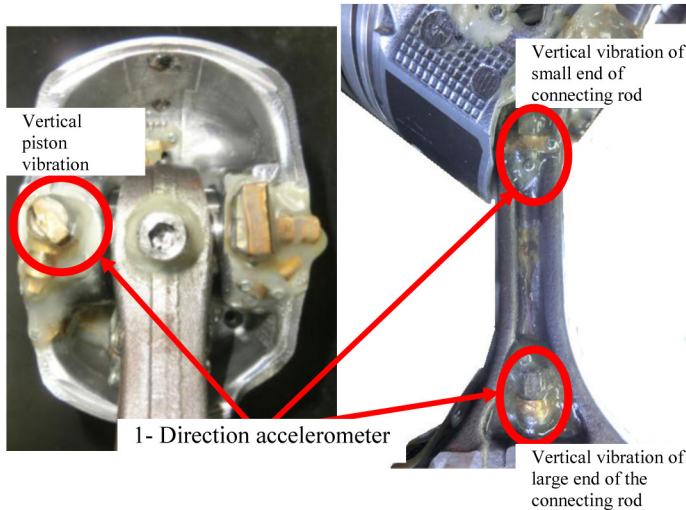


Figure 6. Locations of accelerometers

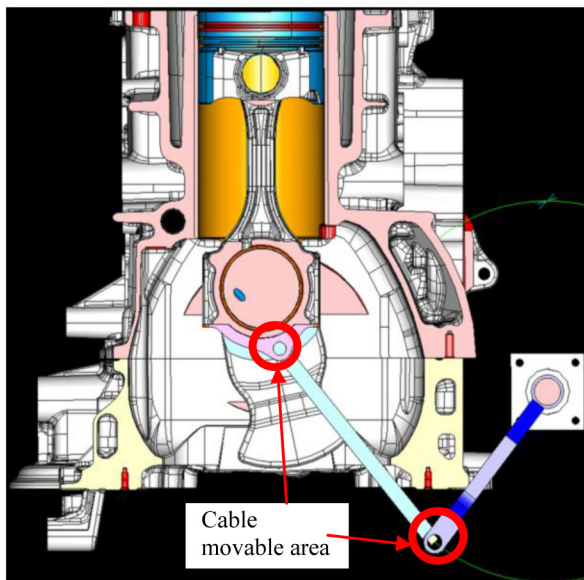


Figure 7. Diagram of link arm

Figure 8 shows time-history graphs measured during combustion in No. 4 cylinder. The moment self-ignition occurs in the cylinder, cylinder pressure level rapidly rises and vibrates the piston first. With delay, vibration is transferred to the connecting rod, crank shaft and finally to the engine block. Therefore, it can be concluded that combustion excitation force is transferred from the internal system to the engine block.

Figure 9 shows spectrum of cylinder pressure and internal component vibration during combustion. The peak of cylinder pressure is not present between 3 kHz and 4 kHz. However, significant vibration

peaks of the piston and other internal components exist between 3 kHz and 4 kHz. The Operating Deflection Shapes at 3.5 kHz is shown in Figure 10.

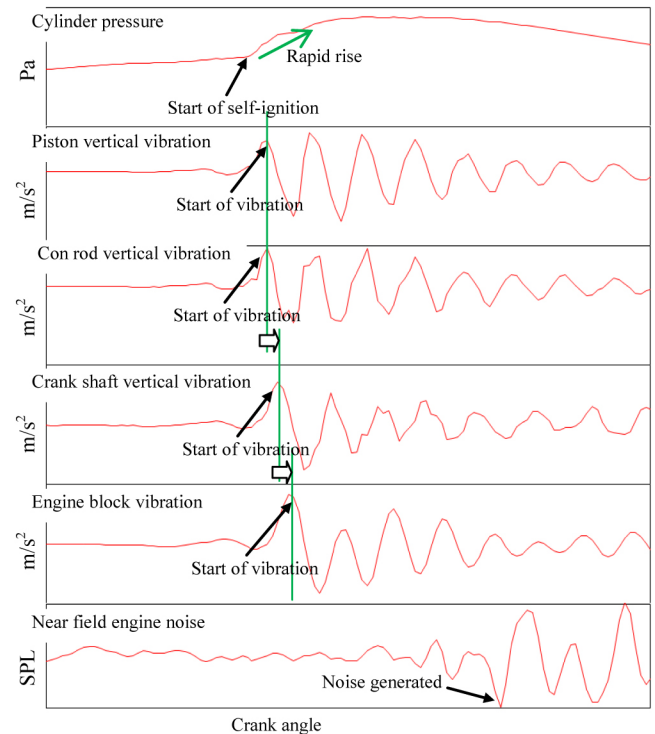


Figure 8. Cylinder pressure and vibration measured during combustion

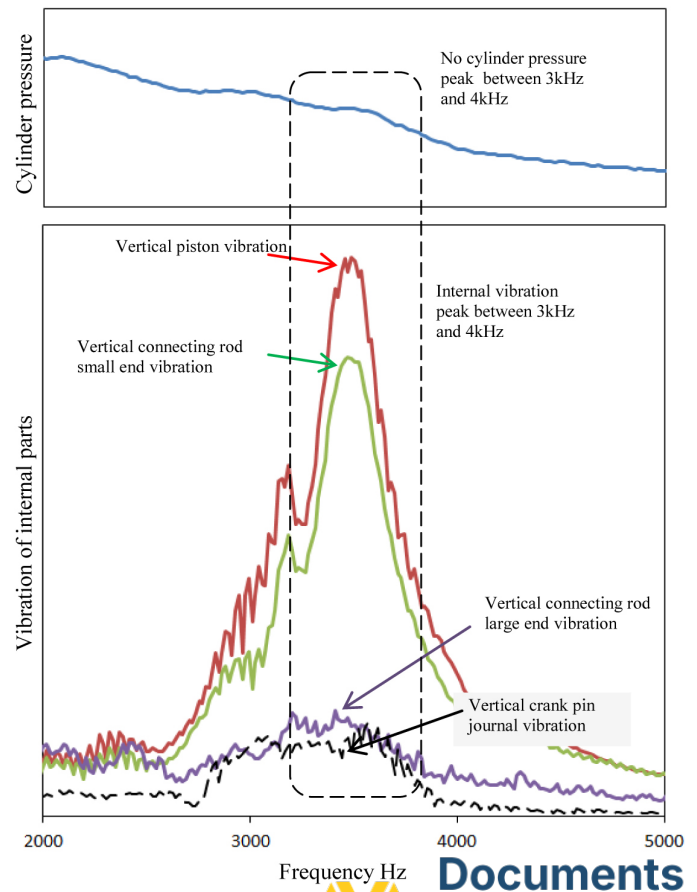


Figure 9. Spectrum of cylinder pressure and vibration during combustion