

Analysis of Ticking Noise from Cam Bearing of a Diesel Engine

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ABSTRACT

Improving idle sound quality as well as reducing idle noise level is increasingly demanded for diesel engines. Therefore, unusual noise occurrence at idle is a serious problem, and the noise must be removed. This paper describes the characteristics and mechanism of ticking noise that is unusual noise radiated from the journal bearing of the camshaft at low idle speeds, based on the mechanism of cavitation in oil film existing between the journal and bearing.

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INTRODUCTION

Ticking noise is known as an unpleasant high-frequency noise caused by cavitation in oil film in a journal bearing [1], [2], [3]. Cavitation is the dynamic process of gas cavity growth and collapse in a liquid [4]. The cavities are due to the presence of dissolved gases or vaporizable liquids, and they are formed when the pressure is lower than the saturation pressure of the gas or the vapor pressure of the liquid [5]. Both vaporous and gaseous cavitations contribute to hydraulic noise and can be characterized acoustically or by vibration measurements [6]. The following steps were taken to prove that ticking noise is caused by cavitation in a camshaft bearing and to clarify the cavitation mechanism for ticking noise.

Firstly, ticking noise was heard from the intake camshaft, so the vibrations on the bearing caps of the intake camshaft, the noise above the cylinder head cover and the crank angle were measured with the engine speed, engine load and oil temperature changed. In the measurement, ticking noise was detected at a crank angle of about 590° from the firing top dead center of No.1 cylinder, and at this angle, only the acceleration measured on No.2 bearing cap was extremely high. Accordingly, it was found that ticking noise radiated from No.2 bearing. Ticking noise was also heard under the motoring conditions. Ticking noise disappeared when the oil temperature was 100°C or lower, or when the engine speed was raised to 1500 rpm or higher.

Secondly, the parameters which are considered to be closely related to cavitation, such as (1) the oil film thickness

in the cam bearing, (2) the oil film pressure in the cam bearing and (3) the velocity of the cam journal center were calculated. From the calculation and measurement results, it was found that (a) the oil film thickness in No.2 bearing was the smallest, (b) the oil film pressure in No.2 bearing was the highest and (c) ticking noise occurred at the timing when the velocity of No.2 journal center reached the maximum. So it was concluded that cavitation in No.2 bearing of the intake camshaft caused the ticking noise. These are the same phenomena that the authors experienced on the main bearing of the crankshaft in a diesel engine.

Thirdly, it was clarified that cavitation in No.2 bearing caused the ticking noise radiating from No.2 bearing, so the orbit of No.2 journal center was calculated to investigate the motion of the journal in the bearing. The reason why cavitation occurs only in No.2 bearing was also discussed, based on the calculation results of the load acting on each journal.

Finally, the reason why the ticking noise disappeared when the oil temperature was 100°C or lower, or when the engine speed was raised to 1500 rpm or higher was discussed, based on the calculation results of the velocities of No.2 journal center, the oil film thicknesses and pressures in No.2 bearing.

CHARACTERISTICS OF TICKING NOISE

ENGINE SPECIFICATIONS

Table 1 shows the engine specifications used for this study. The camshaft layout and the valve train layout are shown in Figures 1 and 2, respectively. Two intake valves and two exhaust valves are provided for each cylinder, and the intake and exhaust camshafts are provided with five journals each, which are held by bearings.

Table 1. Engine specifications

Engine type	4-stroke, turbo-charged diesel
Cylinder layout	4 cylinders in line
Valve train	DOHC 4 valves
Bore x Stroke	$\phi 95.4 \times 104.9$ mm
Displacement	2.999 l
Firing order	1-3-4-2
Maximum power	110 kW at 2800 rpm

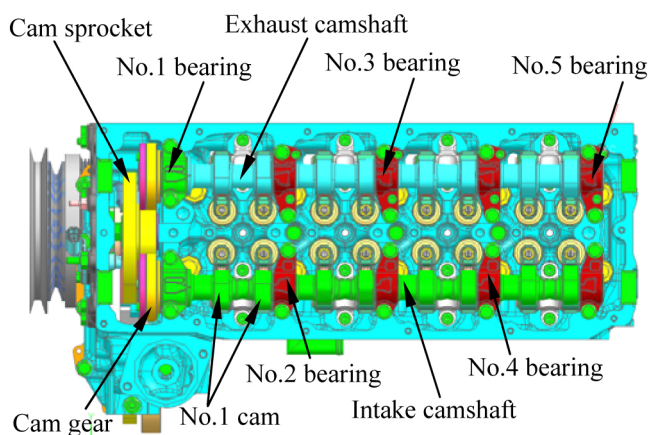


Figure 1. Top view of camshaft layout

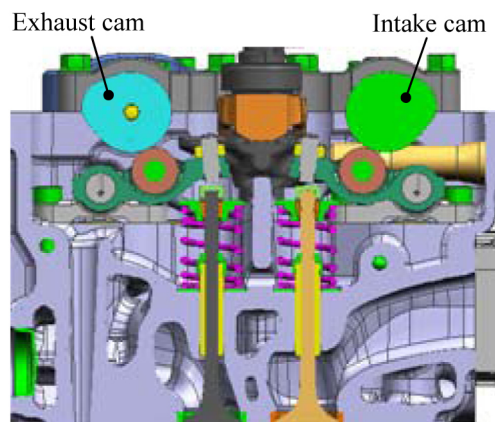


Figure 2. Front view of valve train layout

ACOUSTIC CHARACTERISTICS OF TICKING NOISE

As ticking noise was heard from the intake camshaft, the following were measured; the vibrations on the bearing caps of the intake camshaft, the noise above the cylinder head cover and the crank angle with the engine speed, engine load and cylinder head oil temperature changed. Figure 3 shows the measured sound pressure which was processed with a high-pass filter with a cut-off frequency of 2.5 kHz, at an idling speed of 700 rpm and a cylinder head oil temperature of 120°C where the ticking noise was detected. Figure 4 shows the spectrogram of the ticking noise, and this indicates the frequency of the ticking noise is over 10 kHz.

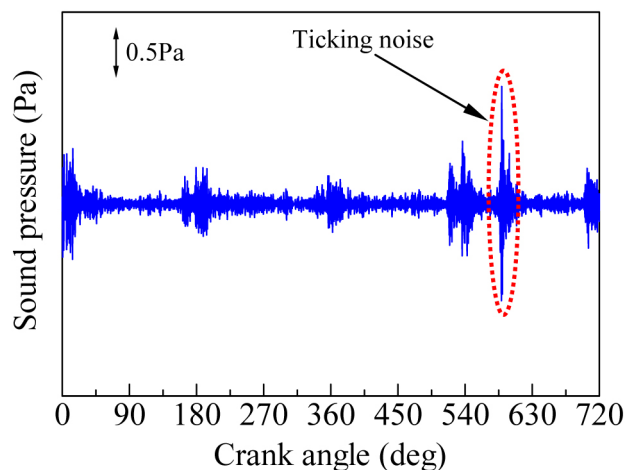


Figure 3. Sound pressure in crank angle domain

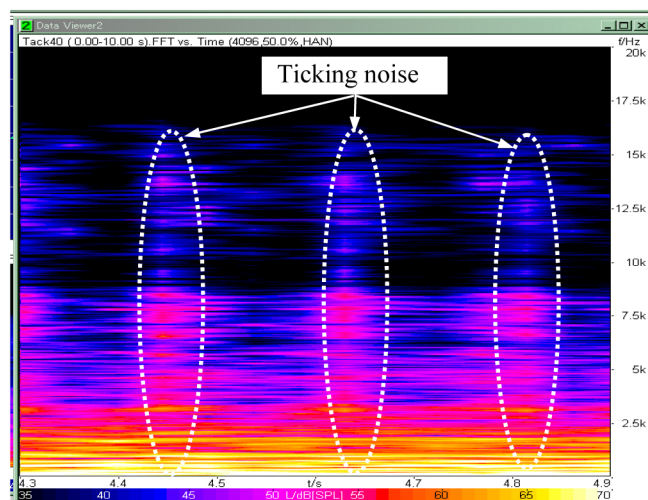


Figure 4. Sound pressure in frequency domain

TICKING NOISE TIMING AND SOURCE LOCATION

Figure 5 shows the vibration accelerations on the bearing caps of the intake camshaft and the sound pressure at an idling speed of 700 rpm and an oil temperature of 120°C when the ticking noise was detected. From Figure 5, it can be seen that the ticking noise comes from No.2 bearing because the extremely high acceleration appears only on No.2 bearing at the same timing as the ticking noise is detected, which is a crank angle of about 590° from the firing top dead center of No.1 cylinder. Ticking noise is closely related to the bearing vibration as shown in Figure 5. Therefore, the authors concluded that ticking noise could be recognized with the vibration instead of the sound pressure.

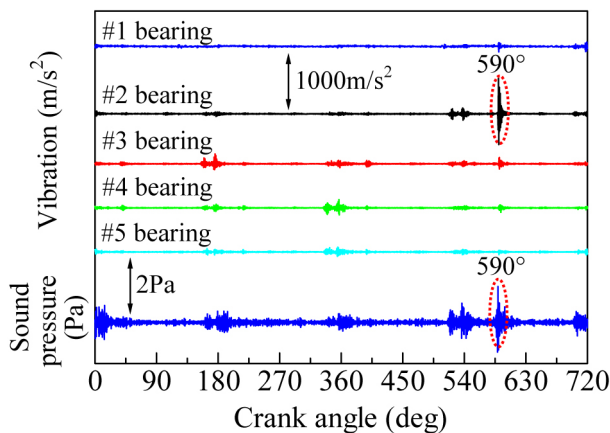


Figure 5. Ticking noise and cam bearing cap vibration

INFLUENCE OF ENGINE LOAD, ENGINE SPEED AND OIL TEMPERATURE ON TICKING NOISE

Figure 6 shows No.2 bearing vibrations under the engine operating conditions shown in Table 2. This figure also shows the effects of the following parameters on ticking noise; firing/not firing (motoring), engine speed and oil temperature.

Ticking noise also appears under the motoring conditions. No.1 in Figure 6 shows No.2 bearing vibration at a motoring speed of 800 rpm and an oil temperature of 110°C. From No. 1 in Figure 6, it can be seen that ticking noise appears. Ticking noise disappears when the oil temperature is 100°C or lower, or when the engine speed is raised to 1500 rpm or higher. No.2 in Figure 6 shows No.2 bearing vibration at an oil temperature of 30°C and an idling speed of 700 rpm. No.3 in Figure 6 shows No.2 bearing vibration at an idling speed of 1500 rpm and an oil temperature of 120°C. From No.2 and No.3 in Figure 6, it can be seen that ticking noise disappears.

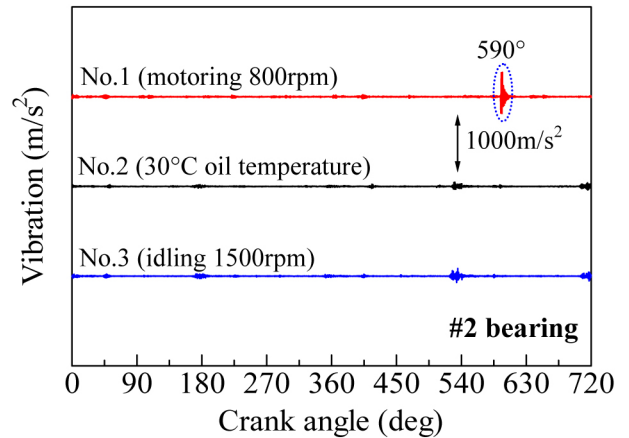


Figure 6. Vibrations under engine operating conditions shown in Table 2

Table 2. Engine operating conditions

No.	Engine speed	Engine load	Oil temperature
No.1	800rpm	Motoring	110°C
No.2	700rpm	Idling	30°C
No.3	1500rpm	Idling	120°C

MECHANISM OF TICKING NOISE

The authors assumed the generating mechanism of ticking noise from the cam bearing, based on their experiences of ticking noise from the main bearing of the crankshaft in a diesel engine, as shown in Figure 7 [2]. As the cam journal is getting close to the inner wall of the bearing under a cam force, the oil film pressure between the journal and bearing increases and reaches the maximum, and then the oil film thickness decreases and reaches the minimum. Cavity is formed when the journal leaves from the inner wall of the bearing and the oil film pressure suddenly drops to near zero because of the release of cam force. The cavity implodes forming an oil micro-jet [4] when the velocity of the journal center reaches the maximum. The impact force of the imploding cavity excites the bearing and this causes ticking noise. The possibility of cavitation occurrence in the oil film becomes higher (a) as the fluctuation of oil film pressure becomes larger, (b) as the oil film thickness becomes smaller, and (c) as the velocity of the journal leaving from the inner wall of the bearing becomes higher [2].

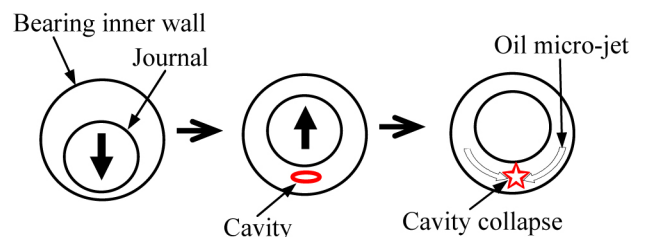


Figure 7. Mechanism of ticking noise occurrence