

Research on Extended Expansion General-Purpose Engine

- Noise Characteristics Caused by Multiple Linkage System

and Reduction of the Noise

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ABSTRACT

Research has been conducted on an extended expansion engine, using a multiple linkage system to increase the thermal efficiency of general-purpose engines. In this research, first, the test engine was subjected to an engine acoustics measurement to clarify its noise characteristics. Then, based on the analysis results of the noise characteristics, we propose the direction to reduce the noise of the multiple linkage system engine.

When the test engine was operated under a no-load firing condition, rattle noise was observed. Also it was found that the timing of the occurrence of the rattle noise was near after top dead center (ATDC) 90 degrees in crank angle (degCA).

Focusing on the gear for linkage drive as a cause of the rattle noise, the authors formulated the torque acting on the gear. Entering the cylinder pressure and angular velocity of crankshaft, which were derived from the condition that the rattle noise was occurring, in this formula, we found that the major factor of the noise was the collisions between the gears teeth resulted from the reversal of torque transmission direction, which occurred at ATDC 90 degCA.

As a result of analysis, it is effective to reduce piston acceleration during the process of expansion stroke to lower the rattle noise. Here, we have designed a new multiple linkage system of low noise specifications. The noise of it was measured -13.1 dB(A) in comparison with that of the test engine; thus, its effect has been confirmed.

INTRODUCTION

From a viewpoint of the prevention of global warming and saving of fossil fuel, it is an important issue to enhance the thermal efficiency of general-purpose engines used in the field of working machinery. In our

previous researches^{[1][2]}, we proposed an engine that realizes extended expansion thermodynamic cycle (Atkinson cycle^[3]) based on the piston- crank system with a multiple linkage system as shown in Fig.1. Also, we presented its graphic display, and reported its brake thermal efficiency, combustion characteristics, and frictions. According to these results, the brake thermal efficiency of the test engine in the EPA operation mode^[4] enhanced from 20.6% to 22.7% in comparison with that of the conventional engine with the same output, showing 12.9% of possible enhancement in fuel efficiency.

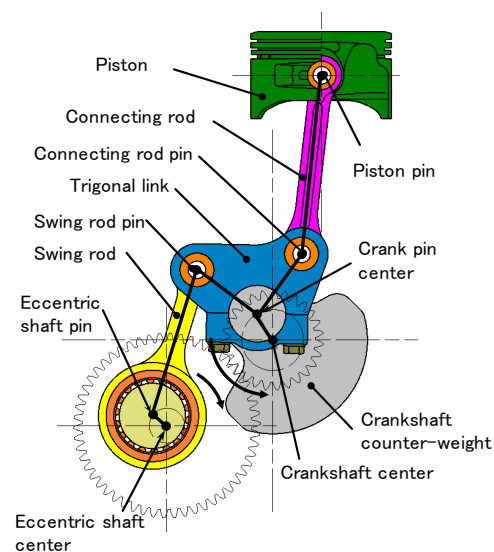


Fig.1 Multiple linkage system

Meanwhile, social demands for the reduction of noise and vibration are increasing not only in the fields of automobiles and motorcycles, but also working machinery, from a viewpoint of protecting operators and surrounding environment from any negative effects. In some countries and regions regulations for the above issues have currently been enforced^[5]. In

our previous studies^{[6] [7]}, we discussed the vibration properties of the test engine to clarify the difference from those of the conventional engine. The results showed that the maximum summation of inertia of the test engine was 1.94 times the figure in the conventional engine with the same output. According to our analysis of these factors, we observed, the test engine had a characteristics that the crank angle, which is necessary for an expansion stroke, was shortened by 3.7%, despite the fact that its expansion stroke was longer. Because of this, it was found that the maximum piston acceleration of the test engine increased to 2.7 times in comparison with that of the conventional engine. Therefore, we redesigned the multiple linkage system based on the numerical approach. It was suggested that the summation of inertia could be reduced by 46.3% in comparison with that of the test engine, by reducing the crank angle and maximum piston acceleration, which the process of expansion stroke required, in addition to making the piston acceleration in the top dead centre (TDC) and in the bottom dead center (BDC) almost the same.

Some reports on the multiple linkage system in the past^{[8] [9]} referred to its vibration^{[10] [11]}. However, none of them has reported on the noise characteristics of extended expansion engine with a multiple linkage system. Therefore in this research, we analyze the noise characteristics of the test engine. It is expected that the test engine may have characteristic machinery noises, which come from its complicated structure with a multiple linkage system, such as changes of piston's behaviors or gear for linkage drive, etc., compared to a conventional engine. Here, we first measure the engine noise under firing operation. Then, discuss the characteristics and factors of the engine noise, and finally propose the direction to reduce the noise.

MAIN SECTION

1. NOISE CHARACTERISTICS CAUSED BY EXTENDED EXPANSION ENGINE WITH MULTIPLE LINKAGE SYSTEM

1.1 Specification of test engine

The appearance and major components of the extended expansion engine with a multiple linkage system, which we previously reported, are shown in Fig.1. Its major specification is indicated in Table 1 in comparison with that of a conventional engine, which we experimentally created for this research.

As shown in Fig.2, by determining the dimension of each part to fit into the specification, we made intake-compression strokes and expansion-exhaust strokes unequal lengths to realize stroke ratio = 1.5.

For comparison, we set up the stroke volume of conventional engine, as the both engines would have almost the same W.O.T. output, assuming that the conventional engine would extend expansion.

We used the same structural parts, such as cylinder head, spark plug, intake and exhaust valve, valve train, and cylinder block, etc., and the same auxiliary parts of intake system, such as air cleaner and carburetor,

as those of the extended expansion engine with a multiple linkage system.

Table 1 Engine specification

			Test engine	Conventional engine
Engine type			Air cooled, 4 stroke, OHC, single cylinder, horizontal shaft	
Bore			64	
Stroke	Intake/Compression	[mm]	42.1	51
	Expansion/Exhaust	[mm]	63.3	
Displacement	Intake/Compression	[cm ³]	135.4	164
	Expansion/Exhaust	[cm ³]	203.6	
Compression ratio			8.5	8.5
Expansion ratio			12.3	
Fuel			Gasoline	Gasoline
Ignition timing (BTDC)			MBT(W.O.T)	

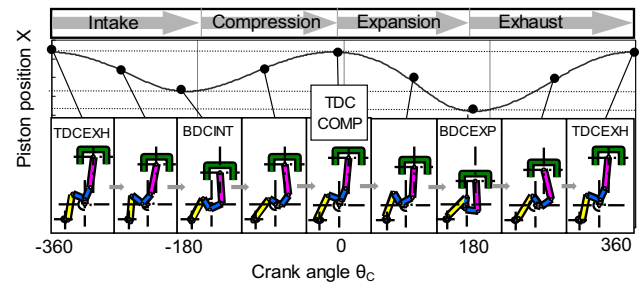


Fig.2 Piston movement through one cycle

1.2 Test conditions

Figure 3 shows the measuring environment. In this research, exhaust port of engine head was directly connected to the test-bench exhaust duct, and masked the exhaust noise, in order to mainly measure the engine's mechanical noise. Although both the engines that we used in this research were air-cooled engines, their fan and fan cover were removed to exclude the flow noises of the fans. As shown in Fig.3, with respect to the sensors, all the outputs from the microphone, engine speed sensor, and generator were simultaneously measured. In addition, the cylinder pressure was also measured, when examining the test engine. The operation mode of the engines was set to two modes, as shown in Table 2.

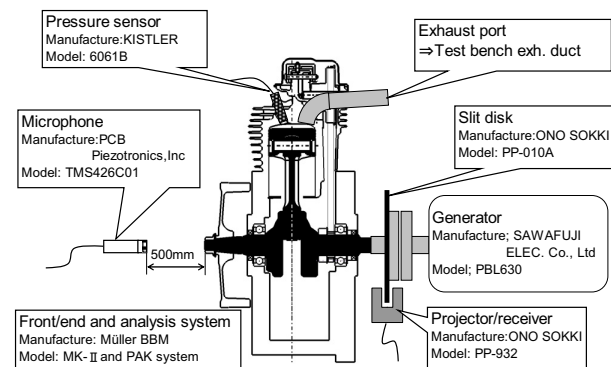


Fig.3 Measurement condition

Table 2 Driving mode

No.	Constant condition		Change condition			
				Min.	Max.	Change rate
1	Generator output	0kW	Rotational speed	1500 rpm	3200 rpm	85 rpm/s
2	Rotational speed	3000rpm	Generator output	0 kW	2 kW	0.1 kW/s

1.3 Test results

The results of the engine acoustics measurement in each operation mode were shown below.

1.3.1 Mode 1: Operation at an accelerated engine speed with no-load generator output

Figure 4 shows the sound pressure levels of the test engine and conventional engine in Mode 1. The horizontal axis indicates engine speed. The sound pressure level of the test engine increased up to 15.8 dB(A) at the speed of 3000 rpm, compared to that of the conventional engine.

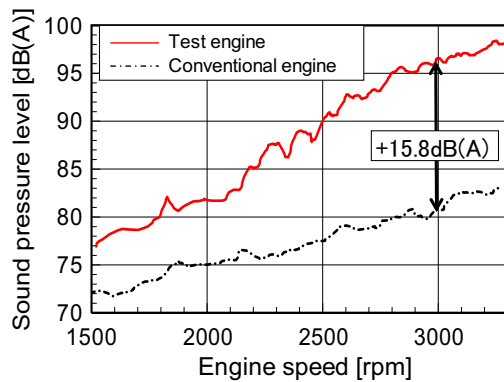


Fig.4 Engine sound pressure level (Mode 1)

Figure 5 and 6 show the frequency characteristics of each engine sound in terms of speed. According to these results, the engine sound of the test engine increased more in the broad frequency band of 500-5000 Hz than that of the conventional engine. Especially, the bands of 600-1300 Hz and 4 kHz look distinctive.

Speaking of the actual sound of the test engine, we heard nonstationary noise similar to a collision of metals starting from the minimum engine speed of 1500 rpm. In this research, we call it rattle noise. The more the speed increased, the more the frequency of the rattle noise increased. When the engine speed exceeded 2200 rpm, the noise came to occur constantly. As we could observe in Fig. 4, the discrepancy of the sound pressure level between the test engine and conventional engine tended to increase around 2200 rpm. We speculate that the distinctive frequency band aforementioned is produced from the rattle noise.

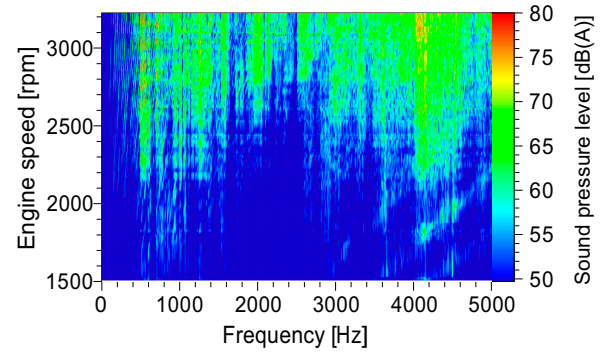


Fig.5 Spectrum of test engine (Mode1)

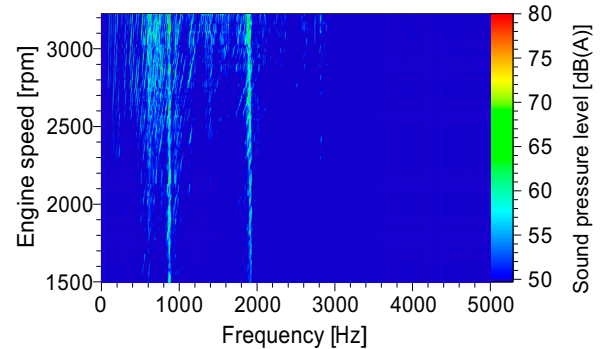


Fig.6 Spectrum of conventional engine (Mode1)

1.3.2 Mode 2: Operation at an increased generator output with engine speed of 3000 rpm

Figure 7 shows the sound pressure level per load of the test engine and of the conventional engine. The noise measurement of the test engine reaches its maximum at generator output 0-0.1 kW, exceeding the conventional engine by +15.8 dB(A). When the output of the test engine exceeds 0.1 kW, the sound pressure level decreases approximately by 6 dB(A) accordingly, and reaches its minimum value at the range of 0.3-0.8 kW. The sound pressure level tends to increase around or above 0.8 kW of output, and gets into almost equal to that of the no-load condition near 1.8 kW. Under the same operating condition, the sound pressure level of the test engine indicates +7.3 dB(A) in comparison with that of the conventional engine.

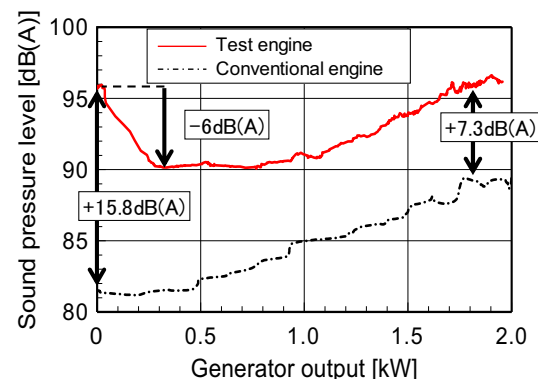


Fig.7 Engine sound pressure level (Mode 2)