Combustion Noise and Piston Slap Noise : Identification of Two Sources Responsible for Diesel Engine's Sound Signature

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Introduction

Nowadays, engines' sound quality has become an important criterion in customer's choice. Moreover, environmental agencies tend to limit the noise level emissions of motor vehicles. For these purposes, car manufacturers tend to work in two ways :

- sound design which consists in making "good" noise components appear. For example, an engine will inspire a "sporty" image to the audience by the rise of harmonic 3 and 6 because it will sound like a 6 cylinders,
- noise reduction which is more about lowering global noise level by decreasing "bad" noise components, like aerodynamic noise or combustion noise.

This work registers in the noise reduction part. It deals with combustion noise and piston slap noise that are two undesirable noise components responsible for the Diesel engine's sound signature.

Piston slap noise phenomenon appears consequently to the rapid pressure rise in the combustion chamber due to the fuel self-ignition. Around the top dead center position, the piston moves through its clearance to bore and hits the cylinder wall, causing the *piston slap noise*. This noise particularly occurs under cold conditions (e.g. cold start at low temperatures) when clearances are wider, and then decreases as the engine gets hot conditions. Clearances at cold conditions are calculated with respect to dilatation coefficients which are different for pistons (made of aluminium) and cylinder block (most of the time made of cast iron), in order to avoid scuffing while working under hot conditions.

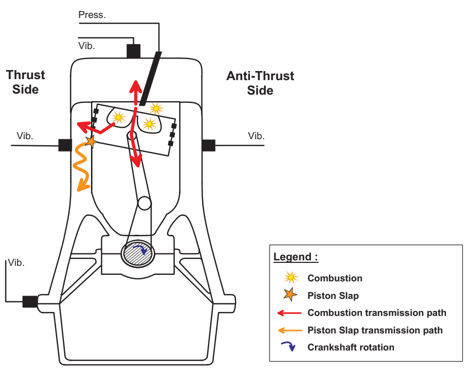

Figure 1: Schematic representation of the test apparatus (view from pulley side).

A significant difficulty concerning combustion noise and piston slap noise problems lies in the identification of these two different phenomenons that occur in a very short time delay. Many works have been carried out about piston slap noise reduction : De Luca *et al.* [1] have proposed a literature review about piston slap excitation both from an analytical and experimental point of view. Haddad *et al.* [2] have shown the importance of piston design on the vibration level of Diesel engines. Okubo *et al.* [3] have measured cylinder wall transfer function to compute a new piston design. Then they have checked its effects on the piston slap noise reduction. Ryan *et al.* [4] have planned an experiment whose purpose was to determine the effects of operational parameters such as spark timing on a petrol engine.

Test description

The engine used for the experiments was a 4 cylinders, 1.9 l. direct injection Diesel engine fixed to a test cell pallet using standard vehicle mounts. Measurements were made for the cylinder $n°3$, at 960 rpm, no load, in cold start conditions. They provided the cylinder pressure, vibrations on both thrust and anti-thrust sides of cylinder block, vibrations on cylinder head, and vibrations on cylinder block skirts.

By increasing or decreasing each source independently (namely combustion and piston slap), it has been possible to assess their respective contributions in terms of time localisation, amplitude, and frequency.

We set three types of combustion in cylinder $n°3$ by using a specific electronic control unit : one built with no combustion, the second built with a standard combustion and the third built with a severe combustion.

To control the piston slap noise source, two sets of pistons were manufactured : a "low noise piston" characterized by a low piston to bore clearance, and a "high noise piston" with a wide piston to bore clearance.

Results

A time-frequency analysis was performed on the vibrations measured on the cylinder block for each configuration. Figure 2 shows the time-frequency map for a high noise piston and no combustion in cylinder $n°3$. It shows that piston slap is responsible for vibrations around $2000\,Hz$.

Figure 3 shows the same representation for a low noise piston and a severe combustion. Frequencies between $3500\,Hz$ and $6500\,Hz$ seem to be particularly impacted by the combustion.

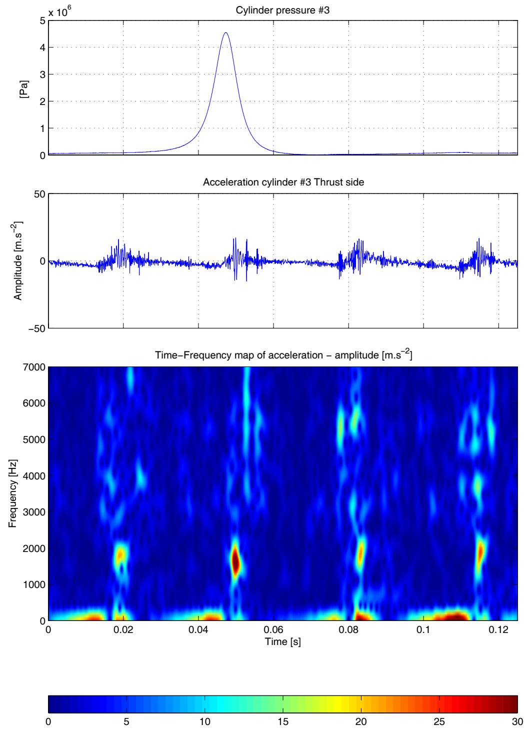

Figure 2: Time-frequency map of vibrations measured on the thrust side of the engine block. Configuration : high noise piston and no combustion in cylinder $n°3$.

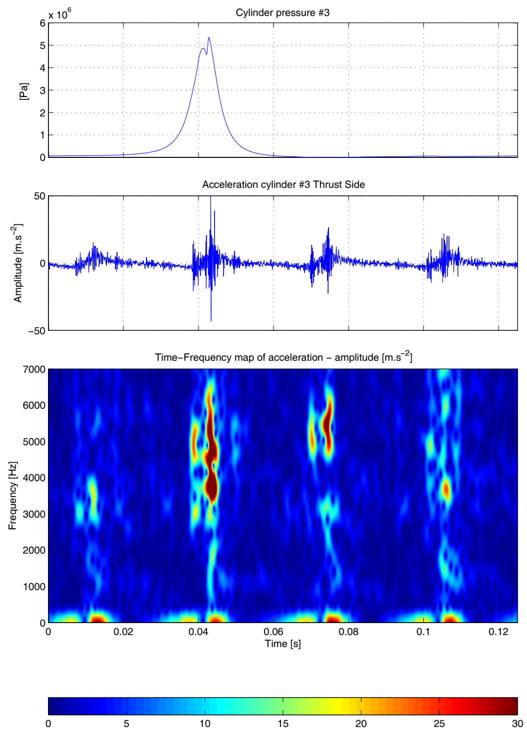

Figure 3: Time-frequency map of vibrations measured on the thrust side of the engine block. Configuration : Low noise piston and severe combustion in cylinder $n°3$.

Figure 4 summarizes the engine vibrations breakdown. Each colored area represents the mean spectrum calculated around top dead center position in cylinder $n°3$. The grey area is the spectrum calculated with a low noise piston and no combustion in cylinder $n°3$. The blue area is the spectrum for a high noise piston and no combustion in cylinder $n°3$. The red area is the spectrum for a high noise piston and a standard combustion in cylinder $n°3$, and the green area represents the spectrum calculated for a high noise piston and a severe combustion.

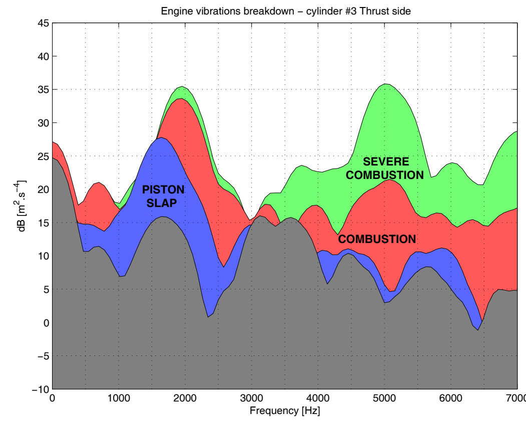

Figure 4: Engine vibrations breakdown for the thrust side on the engine block.

Conclusion

The method used to identify combustion noise and piston slap noise contributions seems to be very efficient. Its real weakness lies in the time necessary to plan such an experiment. As a matter of fact, the combustion is easily controlled by the use of a specific electronic control unit. Nevertheless the change of piston set implies a huge mechanical manipulation of the engine. In further works we will try to realise the radiated noise breakdown by the use of different signal processing tools.

References

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