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DIAGNOSIS OF ABNORMAL OPERATION IN DIESEL ENGINES USING VIBRATION OSCILLOGRAPHS AND FREQUENCY ANALYSIS

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Introduction

Increased automation coupled with inherent complexities and greater manpower movement have in the last few years necessitated the development of certain objective techniques of condition monitoring and fault diagnosis for many engineering applications - to replace the semi-subjective and subjective (intuitive skill) methods. The internal combustion piston engine is one such machine that has gained enhanced prominence in practically all fields of industry, be it road transport, marine propulsion, stationary application, and other industrial applications - with increasing demands on optimum performance, maximum utility and reliable operation. To meet these demands it has therefore become increasingly useful and economical to monitor its condition during operation, to detect the onset of any abnormal operation before serious breakdowns occur. Most of these condition monitoring methods employ either conventional measurements (such as cylinder pressure, temperature, fuel pressure and injector needle lift) or other proven measurements such as close microphone engine noise and engine structural vibration (refs. 1,2).

This paper concentrates on the use of vibration measurements to identify abnormal operation in automotive type diesel engines.

The Mechanism of Vibration Generation in a Piston Engine

The origin of vibration in a piston engine is rather complex due to the fact that the whole engine structure is simultaneously excited by a number of forces of widely different characteristics, broadly classified as primary combustin forces, secondary mechanical forces and other accessory forces. These forces excite the engine structure and produce normal vibration response that is related both to the type of force and engine structure impedance at the point of force application.

If these forcing inputs change magnitude or nature (due to variation in operation) then the resulting vibration response would change and the deviation from the previously established healthy response range could be quantified. Coupled with the availability of accurate vibration measuring equipment this method is rapidly becoming an effective, non-destructive, easy-to-use and reliable method for engine diagnostics.

Vibration response measurements can be taken on any part of the engine structure and recorded as an overall (weighted or unweighted) value, filtered or frequency analysed (Fourier, narrow band, octave, ⅓-octave, etc.).

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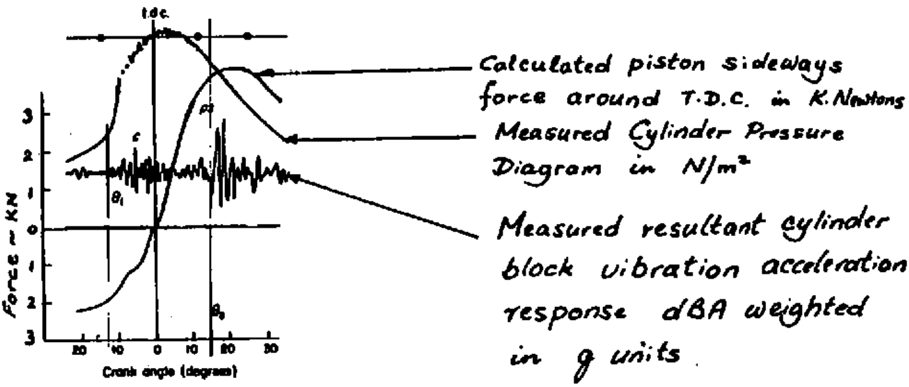

FIG. 1 The Concept of Vibration Oscillographs for a Running Engine

For most applications the oscillographic and $\frac{1}{3}$-octave analysis are sufficient and these are described here.

Vibration Oscillographs

Fig.1 shows a typical measured cylinder pressure development, calculated piston sideways force and the measured resultant overall vibration acceleration response of an engine structure at block level. It can be seen that two response signals may be distinguished; the first at θ_1 coincides with the start of combustion and the second at θ_2 coincides with the start of piston slap.

Fig.2 illustrates the oscillographic principle applied to a V8 automotive diesel engine to detect variation in the severity of piston impacts with changing piston to bore clearance (ref.4). It can be seen that increased clearance produces a much larger piston slap impulse due to the increased sideways impact velocity as the piston has a larger

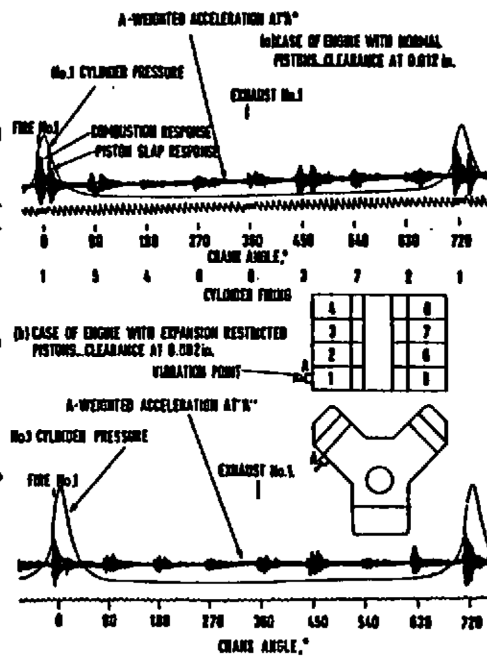

Fig.2 Oscillographs of diesel engine vibration response when fitted with normal and expansion restricted pistons.

distance to travel laterally. Therefore, excessive piston-liner wear can easily be detected in this way. Also, any abnormal change in the combustion response impulse can equally be quantitied and compared with the normal healthy impulse in relation to magnitude and nature.

Vibration oscillographs can yield more accurate and reliable information when measurements are taken nearest to the points of force application; say at main bearings for combustion and bearing impacts, at thrust side of liner for piston slap, at fuel injection pump for F.I.E. operation, at turbocharger bearings for T/C malfunctions, etc.

Fig.3 shows an example of typical oscillographs used to detect more accurately the severity and incidence of piston impacts. Sketch 3.1 shows the measuring positions where the engine block was drilled at two points opposite the top and bottom of the piston skirt where the piston is expected to execute the major slaps. Two short studs were cemented to the liner water jacket side. At the other end rubber "O" rings were used to provide effective sealing through the water jacket terminating with threaded parts for mounting two accelerometers. It can be seen that the corresponding oscillographic records shown in Figs. 3.2 and 3.3 - dBA weighted and filtered (through a high frequency band to facilitate better detection of impacts) - give clearer analysis for impact incidence and magnitude than those taken previously on the cylinder block. This is because, at block surface, the signals have an indirect transmission path which tends to alter the response with some degree of non-linearity.

Third Octave Vibration Analysis

Frequency analysis of engine vibration response is a further sophistication in detecting engine operational events. In fact most of these events can be identified in the vibration signature to fall within certain frequency ranges or bands, sufficiently defined by the ⅓-octave frequency analysis for diesel engine abnormal operation.

Fig.4 shows two examples of third-octave vibration analysis where excessive piston slap is seen to result in progressive increases in vibration levels in the frequency region 1250Hz upwards, and partially seized bearings on a blower installed on a diesel engine resulting in increase of vibration levels in the region 400 to 800Hz. In such analysis, approximate calculations of the frequency ranges of these events can be made as well as the measurements.

Finer analysis can be used to identify certain isolated events such as gear passing frequencies (ref.3).

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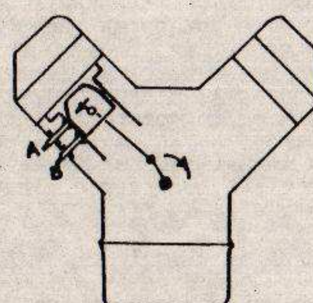
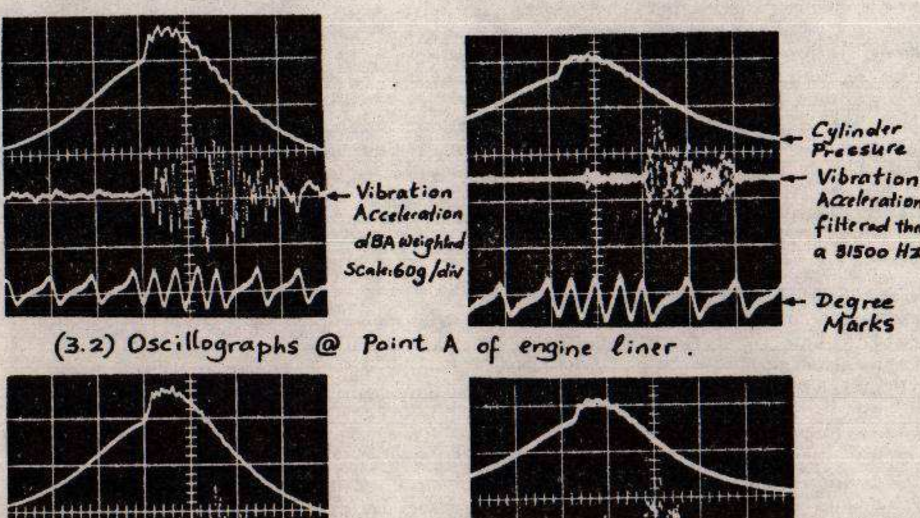
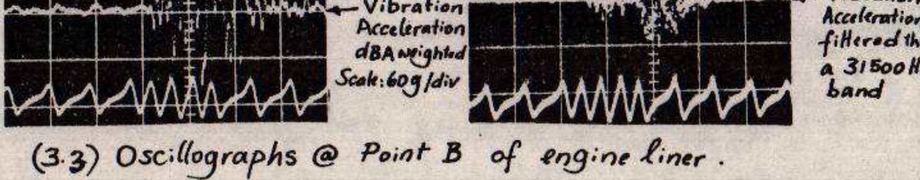
(3.1) Sketch showing positions of the two accelerometers to measure vibration response on engine liner due to piston impacts





(3.2) Oscillographs @ Point A of engine liner.



(3.3) Oscillographs @ Point B of engine liner.

FIG. 3 Vibration Oscillographs on Engine Liner to Detect Severity & Incidence of Piston Slap in a V8 Diesel Engine Running at 1500revs/min. on Light Load

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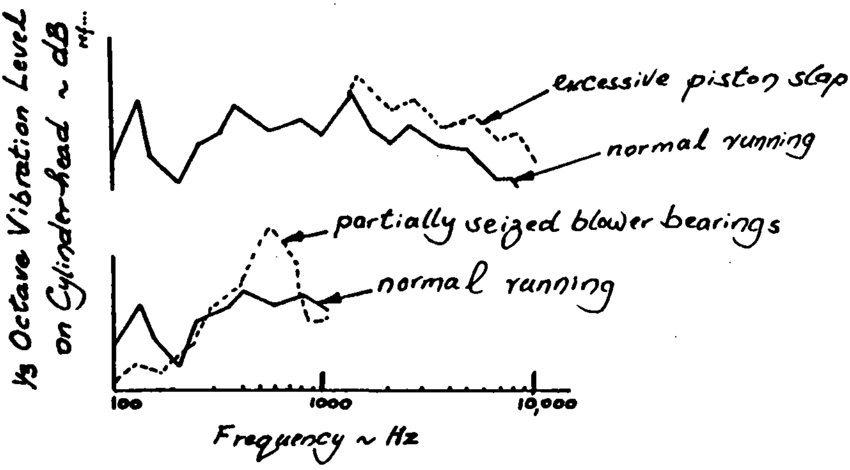

FIG. 4 Two Examples of Vibration Analyses to Detect the Onset of Two Faults in a Diesel Engine

Conclusions

This paper has shown that, in addition to other conventional methods, vibration measurements can be used easily and reliably to diagnose abnormal operation in diesel engines by means of

1. Vibration oscillographs (weighted or filtered), preferably taken nearest to the points of force application.
2. Vibration frequency analysis, .. this doesn't require sophisticated instrumentation as third-octave filters are sufficient.

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