NOISE OF SMALL PETROL ENGINES

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INTRODUCTION

Petrol engine noise is not generally considered to be a major environmental problem but the requirements of anti-pollution legislation and the public's demand for increasingly powerful vehicles may significantly change this state of affairs. Work at the Institute of Sound and Vibration Research has established that combustion is not the most significant source of petrol engine noise but that engine speed is the single most important parameter in its determination.

1. THE EFFECT OF SPEED AND LOAD ON NOISE

Figure 1 illustrates the change in noise level as engine speed is increased on two petrol engines; one of 1.5 litres x 4 cylinders, the other 2 litres x 6 cylinders. The relationship is typical of engines of this class and shows that beyond a certain speed noise rises sharply with increase of speed and that load has little effect beyond this transition point. An analysis of the exciting characteristics of combustion shows that a very large reduction in each Fourier component occurs as load is reduced (Figure 2). By referring to the

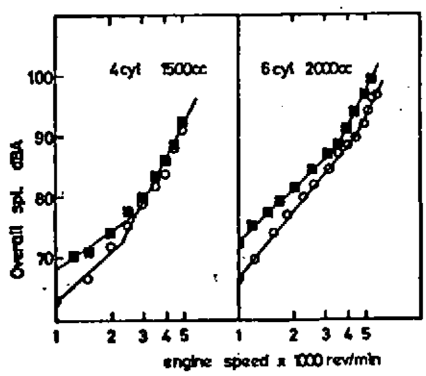

Fig.1 EFFECT OF SPEED ON ENGINE NOISE: no load o—o, full load ■—■.

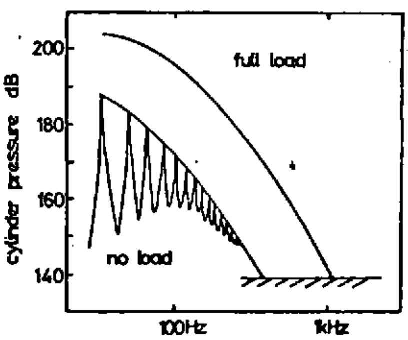

Fig.2 Combustion analysis of petrol engine

noise spectra of the engine at speeds throughout the normal range it can be shown that the correlation between combustion excitation and emitted noise is very poor, also that the apparent relationship between the noise/speed slope beyond the transition point is erroneous. This indicates therefore that another mechanism is responsible for structural excitation. This mechanism produces noise according to relations of the form :

$$I_{noise} \sim N^{2-3} \quad \text{at speeds below the transition point}$$

$$I_{noise} \sim N^{5.2-5.5} \quad \text{at speeds above the transition point}$$

In confirmation of this, tests carried out on a motored, headless 1500 c.c. petrol engine have shown that the same noise/speed characteristics are evident and that overall noise is much the same as at full load, (Figure 3).

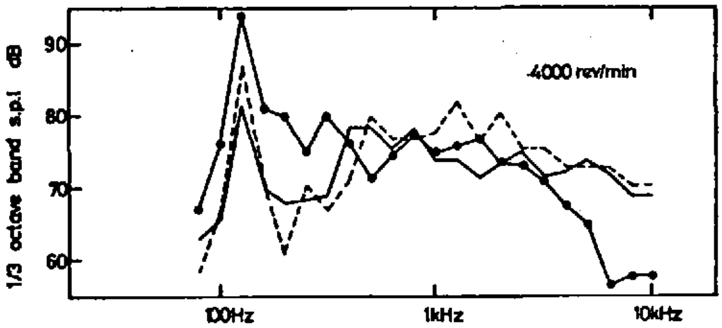

Fig. 3 Noise spectra of motored 1500cc petrol engine, headless •—• 88.5dBA engine A, 1500cc ---- 89dBA, engine B, 1500cc —— 85dBA, both at full load.

2. VIBRATION OF THE MAIN BEARINGS

Measurements of the vertical vibration acceleration of the main bearing caps show a high degree of correlation with emitted engine noise and the slopes of the overall noise/speed curves are reflected in the overall vibration/speed curves. This indicates that much of the structural vibration energy is fed into the structure at the main bearing supports. Darby (1) has shown that even in a diesel engine with its characteristically noisy combustion most of the noise-producing energy travels down the connecting rod and into the structure through the main bearings. The mechanism of energy transfer in the main bearings is complicated, however, by the lubricating oil film and the dynamic variations in the clearance dimension. Tests have shown that the lubricating oil film in a running engine markedly reduces the amount of excitation of the engine structure when compared with the situation of boundary layer lubrication only. Figure 4 shows the variation in overall noise level during start for a 1500cc petrol engine. The engine had been allowed to stand for two days to allow

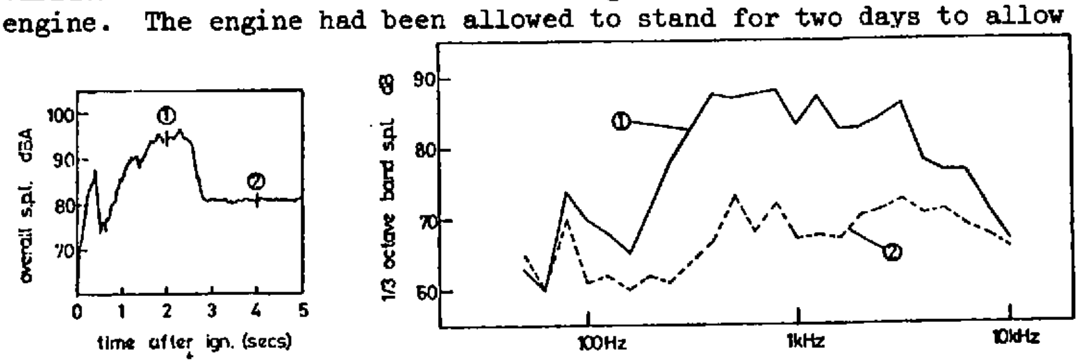

Fig. 4. Effect of oil priming on engine noise during start

the oilways to drain and thus the first few seconds relate to conditions of boundary layer lubrication at the main journals. On repeating this test a few minutes later the noise level rose only to the lower level.

3. CRANKSHAFT MOVEMENTS IN SPACE

There are several methods for calculating the dynamic excursion of reciprocating journal bearings and they are extensively reported in the literature. The Glacier Metal Co. supported an investigation into journal movements at the Institute and supplied computed orbit diagrams for comparison (2). The experimental method consisted of a single inductance gauge cemented into the bearing surface of a main bearing cap in line with the cylinder bore axis. Figure 5 shows a typical oscillogram of journal movement recorded by the device and the corresponding computed orbit diagram. Although correlation is good up to medium speeds the high speed traces are significantly different from those predicted by computer analysis; a much more vigorous excursion is illustrated in practice. Further, high frequency movements of the journal are indicated on the oscollographs and these cannot be predicted by computation since practical digitisation intervals are too

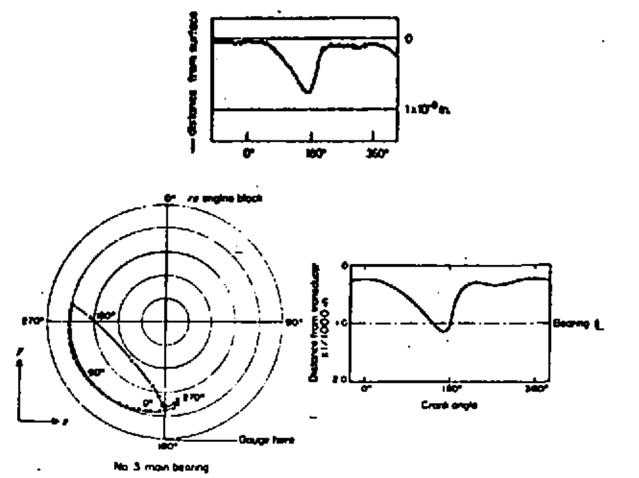

Fig. 5 Correlation between measured and computed orbit diagram for 1500 cc petrol engine, 2000 rev/min full load. Crankshaft main journal centre at centre main bearing.

4. DYNAMIC OIL FILM PRESSURE

It is well known that radial journal motion produces squeeze film pressures in the supporting oil film; a test was conducted therefore to establish the existence of high frequency relative motion between the journal and the bearing surface. A miniature piezo-electric pressure transducer was installed in the centre main bearing cap of a 1500cc petrol engine and a fine hole was drilled through the bearing surface to communicate with a small oil reservoir formed over the surface of the gauge. Figure 6 shows a typical oil film pressure profile recorded in a running engine at 4000 rev/min full load. It is immediately obvious that large and abrupt pressure variations occur. Spectral analysis of these variations shows that high frequency components exist and comparison with the combustion analysis envelopes indicates that oil film pressure excitation exceeds that due to combustion. It can be shown that the pressure fluctuations measured at a point on the bearing circumference represent the forcing function in that zone. A rotatable bearing bush incorporating a pressure transducer was assembled into a two litre experimental diesel engine and measurements of the dynamic oil film pressure variations were made at intervals around the circumference. These measurements showed that pressure fluctuations of the type shown in Figure 6 are in phase around significant bearing arcs and therefore represent relative motion between the journal and bearing surface. Careful analysis of the instantaneous circumferential pressure profile shows that the bearing housing distorts under load leading to pressure developments on opposite sides of the journal. This type of hole distortion, particularly in the vertical and horizontal directions may lead to excitation of the complete structure and then give rise to vibration modes of the type reported by Priede et al (3). In the case of diesel combustion the abrupt cylinder pressure rise can be identified with journal movement and pressure rise in the oil film; variations in the combustion development, for example advanced or retarded ignition, are reflected in the intensity of oil film pressure fluctuations. It can be shown, however, that oil film pressure fluctuations continue long after combustion and therefore do not represent a combustion-forced condition. Moreover, in the experiments so far, no clear correlation has been established between cylinder pressure oscillations and the frequency of oil film pressure disturbances. It is considered therefore that only very severe cylinder pressure oscillations will be communicated directly and give rise to major oil film pressure oscillation at the same frequency. Hodgetts (4) has identified high frequency whirl on small engine crankshafts and estimates of the bearing support stiffness lie in the region equivalent to typical squeeze film stiffness. It appears therefore that whirl, radial journal motion, lubricant film behaviour and noise are closely related.

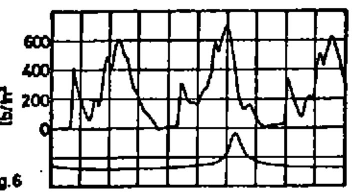

Fig.6

5. BEARING DESIGN VARIATIONS

The behaviour of the lubricant film obviously depends upon the diametral clearance dimension. Experiments at the Institute have shown that small increases of clearance dimension - up to .005" on a typical petrol engine - have little effect either on overall noise levels or spectrum. Increases to .010" present very much increased noise levels at high speeds but below the transition point hardly affect the situation. Reducing tolerances to values as low as .0005" on all journals has an insignificant affect on overall levels, though may improve subjective response. Crankshaft axis alignment may also change noise levels and the author was able to effect improved overall noise levels at high speed by permanently setting the crankshaft axis by .020" in line with the webs.

6. CONCLUSIONS

1. Petrol engine noise is controlled by excitation of the structure at the main bearing supports caused by relative motion between the journal and bearing surfaces: combustion has little influence.

2. The complex noise/speed relationship indicates a very high rate of increase of noise with speed above some transition point, probably caused by crankshaft excitation.

3. Minor design changes to clearance dimensions and crankshaft alignment are not effective means for controlling noise, very massive bearing supports would be required to reduce bearing deformation under impact load.

ACKNOWLEDGMENTS

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LOUDSPEAKERS AND MULTI-CHANNEL REPRODUCTION

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Up to the present, the majority of evaluation of loudspeaker systems has been on the basis of sine wave response. Toneburst testing has been used to evaluate transient response, but this is restricted in its application.

It now appears that the major stumbling-block to progress has been the previously-accepted statement that the human ear is insensitive to phase difference. This is most definitely not the case, and there are serious repercussions from this assumption. In particular it is possible to design crossover networks that, whilst giving a 'flat' frequency response, introduce phase errors of up to 180°. The step response is seriously in error and moreover the effect is very obvious in listening tests.

This paper examines some of the problems involved and their possible methods of solution. These effects also have repercussions on the positional perception of multi-channel images, and may well explain the poor stereo image produced by some systems that have otherwise both good frequency and polar response characteristics. Demonstrations of these effects will be included with the presentation of the paper.

BRITISH ACOUSTICAL SOCIETY: Meeting at the Institution of Mechanical Engineers, 1, Birdcage Walk, London, SW1.
On Friday, 11th May, 1973

DEVELOPMENTS IN HIGH FIDELITY SYSTEMS

STEREO TECHNIQUES IN STUDIOS

D.G.M. Stripp (British Broadcasting Corporation)

This is a practical rather than theoretical appraisal of the basic alternative stereo microphone techniques, to show the reasoning behind the BBC's choice of particular systems. The following points will be discussed.

Spaced Microphones

The earliest known stereo disc still in existence. Pros and cons of spaced microphones.

Co-incident Microphones

Brief theory of crossed figure - 8 and crossed cardioid systems. Blumlein's original recording. Pros and cons of co-incident microphone systems. Back-to-back cardioid system.

ORTF system and Artificial Head Systems

Adding close and distant microphones to the main pair.

Multimicrophone technique.

The talk will be illustrated with recordings.