BRITISH ACOUSTICAL SOCIETY: Meeting at the Institute of Sound and Vibration Research, Southampton on 9th-10th July 73.

NOISE FROM PRIME MOVERS.

SOME INVESTIGATIONS INTO THE EFFECT OF PISTON SLAP ON THE NOISE AND VIBRATION OF DIESEL ENGINES

S.D. Haddad and H.L. Pullen
Institute of Sound and Vibration Research
University of Southampton

INTRODUCTION

The diesel engine is recognised as a major noise nuisance in urban areas. Various sources have been investigated, one of these is piston slap which may predominate. Slaps initiated by change in direction of piston side thrust are most obvious at top and bottom d.c. Other slaps are normally of secondary importance. Various parameters affecting incidence and intensity of slap have been investigated (1-5).

Recently an investigation of piston slap was carried out at ISVR directed along two channels - experimental investigations on a running diesel engine and simulated slaps on a non-running engine.

CYLINDER PRESSURE DEVELOPMENT, SIDE FORCE CHARACTERISTICS AND RESULTANT RESPONSE

Figure 1 shows the typical cylinder pressure development, piston side force and the resultant vibration response of the engine structure at block level. It can be seen that two response signals can be distinguished, the first coincides with the start of combustion at θ_1 b.t.d.c. and the second occurs at θ_2 after t.d.c. around the point where piston slap would be expected to occur.

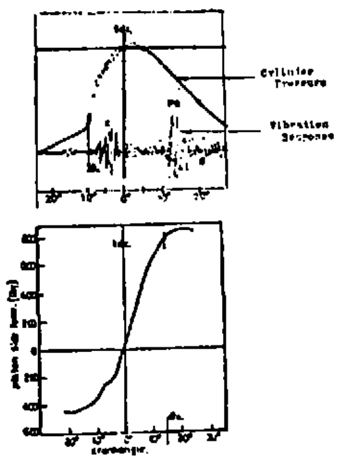

FIG. 1 Characteristics of cylinder pressure, side force and the resultant response for a diesel engine.

INDUCING VARIOUS CONDITIONS OF PISTON SLAP IN A RUNNING ENGINE

This was done by the following modifications to the pistons and liners of a standard multi-cylinder diesel engine.

(a) Minimising piston sideways force by fitting P.T.F.E. oil control rings:

To minimise the sideways movement of the pistons in the liners the two oil control rings of each piston of a multi-cylinder inline engine were replaced by close-fitting P.T.F.E. rings as shown in Figure 2. This figure also presents comparison of third octave noise spectra for the standard engine and the engine with modified pistons at two typical speeds of 1500 and 2500 rev#min respectively. It can be seen from the figures that piston slap has greater effect on the noise in the frequency range of 800 Hz and upwards.

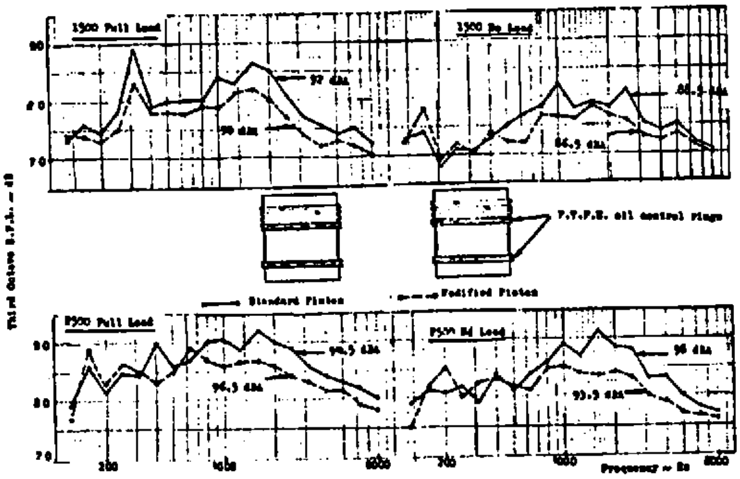

FIG. 2 Comparison of side noise spectra for a multi-cylinder in-line diesel engine when fitted with standard and modified pistons.

(b) <u>Increasing piston slap force by increasing piston to bore clearance:</u>

Piston to bore clearances were increased by progressive honing of the bore.

Figure 3(a) shows the increase in the spectrum level of noise for two extreme conditions of rebore.

Figure 3(b) shows the vertical vibration responses of the engine structure for the two conditions of rebore at 1600 Hz. A similar trend of vibration pattern was observed for other frequency bands. It can be seen that as the piston to bore clearances were increased, the vibration response at block level is significantly affected.

Figure 3(c) summarises the overall noise effect with increasing clearance.

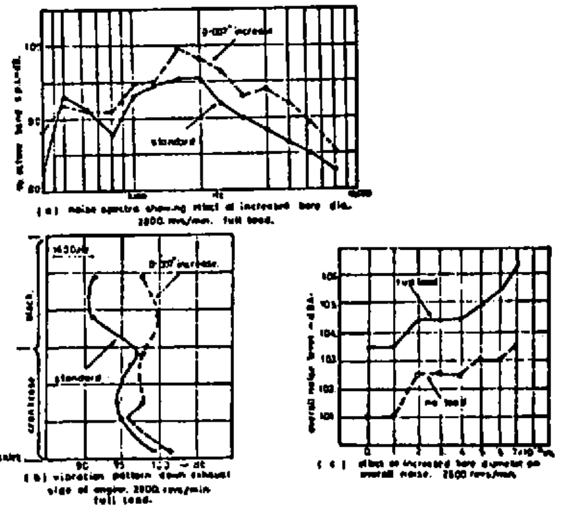

FIG. 3 Noise and Vibration Characteristics with changing piston to bore clearance in a multi-cylinder in-line diesel engine.

<u>THE CONTRIBUTION OF PISTON SLAP TO ENGINE NOISE AND VIBRATION</u>

In order to separate the individual events in the engine cycle, an oscillographic technique is employed. For this, three signals are usually displayed; (1) degree marks to locate the sequence of firing cylinders, (2) pressure diagram to locate the reference firing cylinder, and (3) either noise or vibration of the engine.

The following information can be obtained from oscillographs:

1. Maximum and instantaneous vibration amplitudes for each case of cylinder firing.
2. Incidence of combustion and piston slap.
3. Amount and nature of cycle to cycle variation.
4. Phase relationships.

The oscillographic technique was used to study the contribution of piston slap in four engines (inline and Vee types). Typical results are presented in this paper for the case of a V8 engine. Figure 4 shows typical oscillographs for the same point on the engine when fitted in turn with both expansion restricted and normal pistons respectively. Although all eight cylinders were firing normally only the pressure development in No. 1 cylinder is shown. From Figure 4(a) it can be seen that the expansion restricted pistons produce a much smaller second impulse due to the reduction of sideways impact velocity, as the piston has a smaller distance to travel laterally.

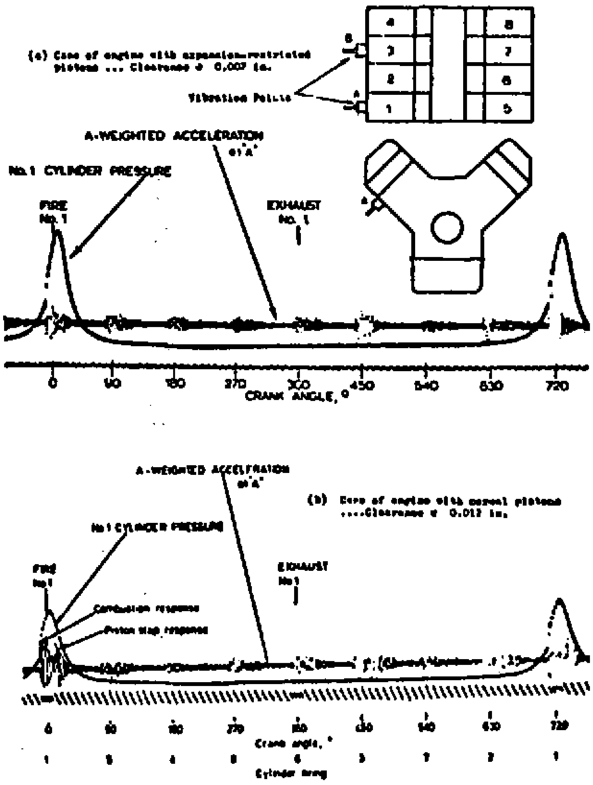

FIG. 4 Oscillographs of diesel engine vibration response when fitted with normal and expansion restricted pistons.

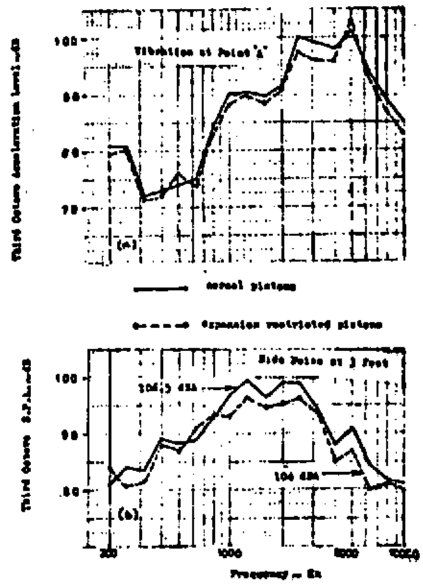

FIG. 5 Comparison of noise and vibration for a V8 diesel engine at 3000 r.p.m. full load when fitted with normal and expansion restricted pistons.

Figure 5 compares typical noise and vibration spectra at 3000 rev/min full load for this engine. It can be seen that the expansion restricted pistons give reductions in overall noise levels of the order of 2 - 2½ dBA. Most of this reduction is obtained over the acoustically important frequency range 1000 Hz to 5000 Hz.

SIMULATION OF PISTON SLAP USING A SHAKER

To study the piston slap event and its contribution to overall noise and vibration of the engine, a simulation technique was developed to induce piston impact alone. A shaker applies a force through a force transducer to the slapping piston via two back-to-back connecting rods using the crankshaft as a pivot.

The side force at a certain condition of the engine was calculated using the formula given in (6) with conventional notation:

$$\text{Side force} = A \sin\theta \frac{Pr}{\ell} + B\sin\theta\left[(M + m_p)\,\omega^2 r \frac{r^2}{2\ell^2} + m(k^2 - ab)\frac{\omega^2 r}{\ell^2}\right] - B\sin 2\theta\left[(M + m_p)\frac{\omega^2 r^2}{2\ell}\right] - B\sin 3\theta\left[(M + m_p)\frac{\omega^2 r^3}{2\ell^2}\right]$$

Figure 6(a) shows a typical side force time history calculated from the above formula together with an idealised excitation waveform.

Figure 6(b) shows that this idealised waveform can be achieved in practice.

These and other tests showed that the engine vibration response (in dB) is proportional to log (rate of piston side force rise).

Figure 6(c) shows comparison of measured and simulated vibration spectra for one engine speed at point (B) of the engine structure. It can be seen that there is close agreement indicating that piston slap alone is a major source of engine vibration (and subsequently noise).

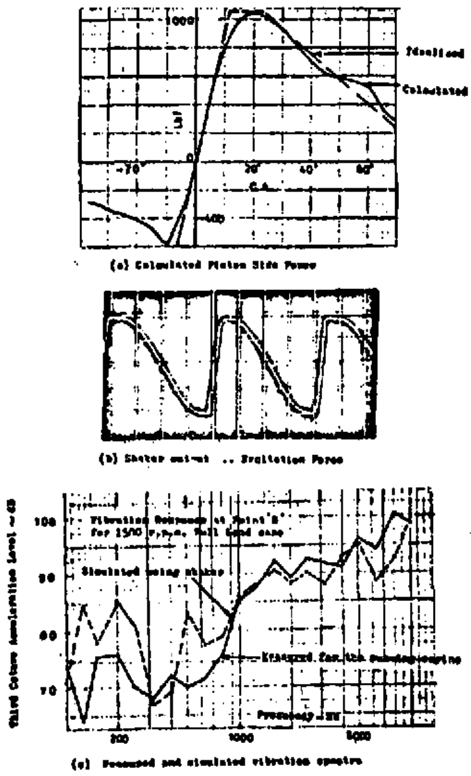

FIG. 6 Typical Piston Slap Simulation and Results

CONCLUSIONS

It has been shown that piston slap is an important source of vibration and noise of diesel engines, and its effect can be simulated.

REFERENCES

1. Meier, A. 'The Kinematics of Piston Noises' Article in ATZ, 1952, 54(6), 123-8 June
2. Zinchenko, V.I. 'Noise of Marine Diesel Engines' Sudpromgiz 1957 (B B N T I R No. 61 July 1962)
3. Hempel, W. 'Ein Beitrag Zur Kenntnis der Seitenbewegung des Tauchkolbens' ATZ Vol 2 January 1966, pp 5-10
4. Priede, T. 'Some Studies into the Origins of Automotive Diesel Engine Noise and Its Control' FISITA 1966, Paper C12
5. Fielding, B.J. 'Identification of Mechanical Sources of Noise in a Diesel Engine' 1968 Ph.D. Thesis, Manchester University
6. Griffiths, W.J. and Skorecki, J. 'Some Aspects of Vibration of a Single Cylinder Diesel Engine' J.Sound Vib. (1964) I (4), pp 345-364