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AN INVESTIGATION INTO A DIESEL ENGINE WITH LOWER MECHANICAL NOISE

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Introduction

Since the onset of the energy crisis we have seen an increasing trend to use the diesel engine to power light-duty vehicles and passenger cars, in addition to its ever-increasing use in commercial automotive vehicles - mainly because of its greater reliability and efficiency as compared with its gasoline counterpart. However, the diesel engine operates at higher peak pressures, higher rates of pressure rise, greater piston sideways forces and within relatively larger clearances resulting in noisier operation. To meet the former demand therefore, considerable research has been carried out to produce low noise diesel units.

Noise Sources in a Diesel Engine

From the start, researchers in this field realised the complexity of controlling the numerous interacting noise sources as is the case in a diesel engine and for that matter in most other prime movers. However it is possible to identify two major exciting forces, viz. (1) combustion-induced noise due to the firing process in the engine and (2) mechanically-induced noise due to the various impacts within the engine with piston slap predominating otherrelatively minor mechanical sources such as bearing impacts, fuel injection equipment operation, timing gear rattle, valve mechanism impacts, crankshaft torsional vibrations, accessories operation, etc.

Combustion-induced Noise

In normally-aspirated engines (as is the case with nearly all older generation diesels) the combustion-induced noise usually predominates over the other sources and therefore tend to control the overall noise level. As a result earlier research concentrated on understanding the fundamentals of combustion excitation resulting in numerous methods to control it 'at source' - some practical whilst others need further development. These include turbocharging, fumigation, pilot injection, retardation, special combustion chamber designs (squish lip), optimizing fuel injector design (no. of sprays and sack volume), optimum heat release (especially of 1st peak), certain indirect injection chamber designs, fuel type (cetane no.), etc. Turbocharging has been accepted as being the most practical especially because of the added power advantage as well as the lower engine exhaust emissions, so much so that most current production medium and large-scale diesel engines are turbocharged. Some small-size, high-speed diesel engines are serious contenders for turbocharging provided a better matched turbocharger is produced to operate well throughout the speed range. Current research in this field is looking into effective pressure-charging both at low speed (town driving) and high speed (perhaps without a waste-gate system). In other words, pressure-charging is likely to dominate the scene.

Mechanically-induced Noise (m.i.n.)

Now in the turbocharged engines, despite the very smooth cylinder pressure development, the rate of piston sideways force and its peak value (especially around T.D.C. where it matters most) are markedly increased as compared to the original normally-aspirated version. This is mainly a direct result of high cylinder pressures persisting during the initial part of the expansion stroke. The considerations therefore indicate that with the introduction of pressure-charged engines the problem of diesel engine noise will lie in better understanding of mechanical sources of noise.

Realising this need we and others set about pursuing a comprehensive programme to study piston slap-induced and other mechanically-induced noises of the diesel engine - culminating in the establishment of a computer-aided prediction tool to optimize piston design for low piston slap-induced noise.

This prediction programme is based on the basic theory of the piston-con.rod dynamics together with experimentally-derived engine block structural response as shown in the simplified model of Fig.1.
Using this program it was possible to predict various piston design features for low m.i.n. These include (i) offsetting the gudgeon pin normally to thrust side, (ii) reducing the piston-liner clearances, (iii) using articulated pistons (cross head), (iv) lengthening the piston skirt, (v) oil cushions, (vi) PTFE buttons, (vii) isolating the liner from engine block, etc.

Some of the above were actually tested on running engines showing good agreement with predictions - bearing in mind that the theory incorporated within the said computer programme is currently being upgraded to take account of certain parameters which were originally assumed small or neglected. When this is complete, we hope for even better correlation between predicted and experimental results.

Possible Minimum Mechanically-induced Noise in Diesel Engines

A preliminary prediction and experimental analysis has been conducted to evaluate the present level of mechanical noise together with projected minimum levels. This study was made for a four-cylinder, 3.6 litre, naturally-aspirated diesel engine and the results presented in Fig. 2. Detailed analysis showed the predominance of combustion-induced noise. This was optimized to produce nearly smooth combustion diagram by a fumigation technique and slight retardation. At this stage the overall engine noise was measured and the mechanically-induced noise was calculated using the prediction method. It is seen that the m.i.n. in this case contributes as much as combustion, if not more - especially in the lower speed range. With further more sophisticated techniques available to reduce the combustion-induced noise in the engine the mechanical noise (especially that due to piston slap) could become the major source of excitation producing the overall noise of the engine. Previous work has shown that the available techniques to reduce the m.i.n. can give at least about 5dBA reduction in engine noise. If this is assumed to apply throughout the speed range a projected level of m.i.n. could be established as shown in Fig. 2.d to which level the combustion should be pushed down to for full optimization.

Optimum M.I.N. Versus Engine Frictional Losses

With current generation diesel engines it is possible to introduce some methods to control piston slap-induced noise and other m.i.n. sources with minor adverse effects on engine performance (as a result of increased frictional and lubricating oil drag forces). Also it is known that the engine frictional losses increase with engine speed. Therefore it is important to monitor the engine frictional power especially with the introduction of more elaborate, precision design features to achieve the projected m.i.n. levels shown earlier (Fig. 2), with acceptable engine performance.

Table 1 Typical Effect of Changing GP Offset and μ's on Piston Slap Severity for Engine A @ 2800rpm, Full Load

FRICTION COEFFS. (μ)			GP OFFSET ins. to thrust	Cycle KE in-lbf.
Piston to GP	Piston to liner	Top ring to groove		
0.0	0.0	0.0	0.0 +0.06	17.7 16.7
0.007	0.01	0.001	0.0 +0.06	17.9 15.5
0.007	0.1	0.2	0.0 +0.06	13.0 12.6

Table 1 shows an example of the predicted effect of changing GP offset and frictional coefficients on piston slap severity.

In the prediction programme shown in Fig.1 the total kinetic energy lost during the cycle impacts is taken as a direct measure of the resultant piston slap-induced noise and therefore Table 1 shows how favourable piston design for low noise can result in increased frictional losses.

This work is currently in progress to complete the predictions and later to test optimum piston design features (and other engine mechanical components) for lower mechanically-induced noise without or with acceptable adverse effects on engine performance.

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Conclusions

1. The diesel engine can be optimized for combustion-induced noise.
2. The mechanically-induced noise needing attention; piston slap being most important.
3. Therefore a programme was developed to predict optimum piston design features for low noise but at the same time to account for effect on engine frictional losses - still in progress.

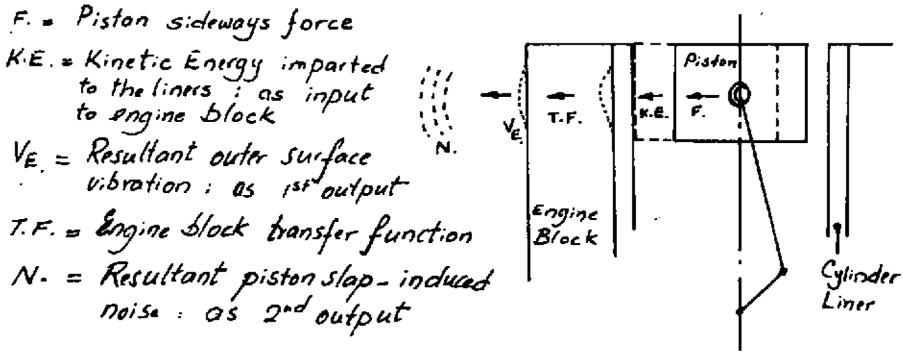

FIG.1 Basic Model incorporated into a computer programme to predict piston slap-induced noise in diesel engines

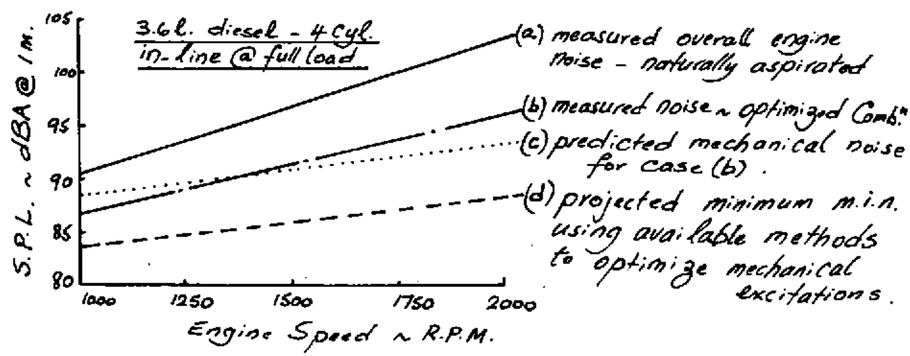

FIG. 2 Measured overall engine noise, predicted & minimum possible m.i.n. in a diesel engine.