BL-Lean burn combustion research

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Versuche der BL mit Magermotoren
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1. Introduction

To meet future emission levels whilst maintaining good specific fuel consumption in spark ignition engines BL Technology Ltd. have engaged upon a programme work to investigate the lean burn potential of various combustion chambers.

The work has involved extensive single cylinder testing and the development of specific chambers for multi-cylinder in-vehicle assessment.

This paper reports on some of the findings of this research. The performance characteristics of certain chamber types are discussed and some factors affecting lean burn operation are identified

2. Lean Burn Strategy

Lean burn technology involves the design of combustion chambers capable of burning the charge with high levels of dilution. Figure 1 shows the effect of charge dilution on economy, NOx and HC emissions for MBT ignition at fixed speed and load. As dilution is increased flame speed is reduced as evidenced by the increasing ignition

advance required. BSFC decreases due to a combination of lower pumping losses, reduced dissociation and a reduction in γ resulting from lower charge temperatures. At large dilution, where misfire or partial (late) burning may occur, BSFC increases.
NOx formation is critically dependent on flame temperature and an adequate supply of air. Maximum NOx concentrations occur at mixture strengths leaner than the stoichiometric value of the fuel due to the balance between achieving adequate flame temperature and sufficient oxygen. NOx is reduced substantially at lean mixture ratios due to lower flame temperatures.
HC concentrations will typically hold constant with air dilution until such a point where abnormal combustion occurs when levels turn up sharply. This is due to either total misfire or partial burning during the expansion stroke resulting from low flame propogation speeds. Base HC levels are believed to be a function of a number of factors including crevice volumes, absorption/desorption into the oil film, and wall quenching.
Lean Burn strategy therefore involves the design of combustion systems which will

allow operation in a region where both the benefits of low NOx emissions and improved economy are obtained whilst HC levels are contained.

For optimum tuning to meet emission regulations the following criteria are suggested which a good lean burn combustion chamber should feature:

(a) The tuning point should be in a region not susceptible to abnormal combustion e.g. a nominal number of AFR's richer than the point of unstable combustion.

(b) The optimum tuning point for emissions should coincide with the point of minimum bsfc.

(c) At the optimum tune point both emissions and bsfc should ideally be insensitive to changes in AFR.

Points (a) and (c) relate to the desirability of relaxing the need for sophisticated fuelling control both for the purpose of emission control and maintaining economy. Point (b) relates to the desirability of reducing emissions without compromising fuel economy.

It is suggested that the above criteria form a basis against which the lean burn

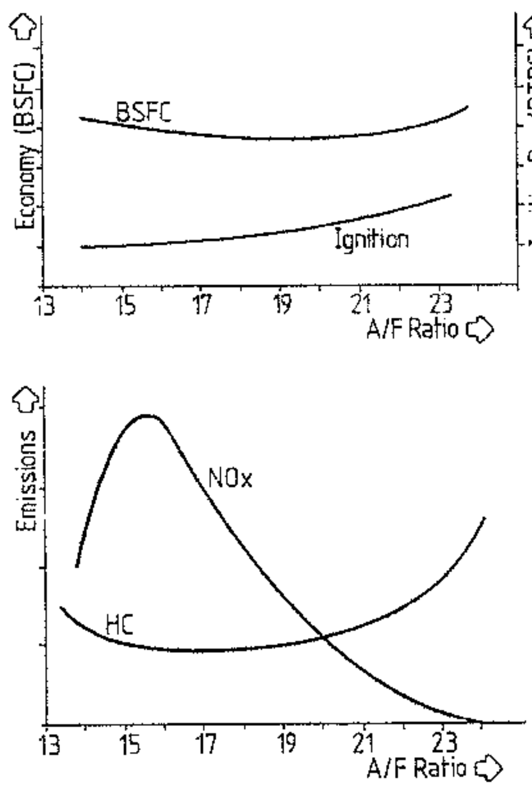


Fig. 1. The effect of varying air/fuel ratio on BSFC, ignition HC and NOx emissions.

performance of a chamber may be assessed and comparisons made with others.

Whilst lean burn offers the prospect of reducing emissions other strategies may be invoked, apart from employing catalysts. Both EGR and ignition retard are known to reduce NOx levels and present alternative options. These must be balanced against their overall effect on both HC emissions and fuel consumption. Figure 2 shows a set of comparisons between these alternative strategies. The percentage changes in both (HC + NOx) and BSFC are shown for a 60% reduction in NOx through lean burn, EGR, or ignition retard. In this particular case it is clear that the lean burn approach would provide benefits in terms of both economy and emissions. The characteristic 'trade offs' will depend on chamber type and operating condition but the twin benefits

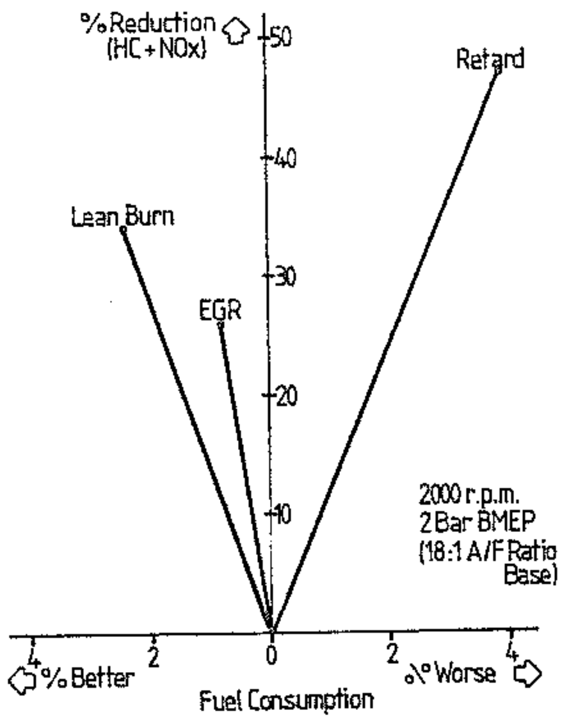


Fig. 2. Comparisons of the percentage change in (HC + NOx) and BSFC for 60% reduction in NOx with lean burn, EGR, and ignition retard.

afforded by good lean burn will generally apply. In practice a combination of alternatives could be applied and the trade-offs established for any particular application.

3. Chamber Type

To compare the lean burn potential of various chamber types results from several chambers are presented below:

The chambers may be broadly classified as:

Chamber	Type
A	Open
B	Compact
C	High Swirl
D	Disc

Results presented below for these chambers refer to 12:1 compression ratio unless stated otherwise.

Figure 3 provides plots of emissions against BSFC as a function of AFR for these chambers. Emissions are shown for both NOx and for HC + NOx. The latter reflecting the emission directive criteria. The results are presented for engine operation at 2000 rpm, 2 bar BMEP.

Both chambers A and B achieve low levels of NOx by operating at lean mixture ratios. The AFR needed to attain a given NOx level

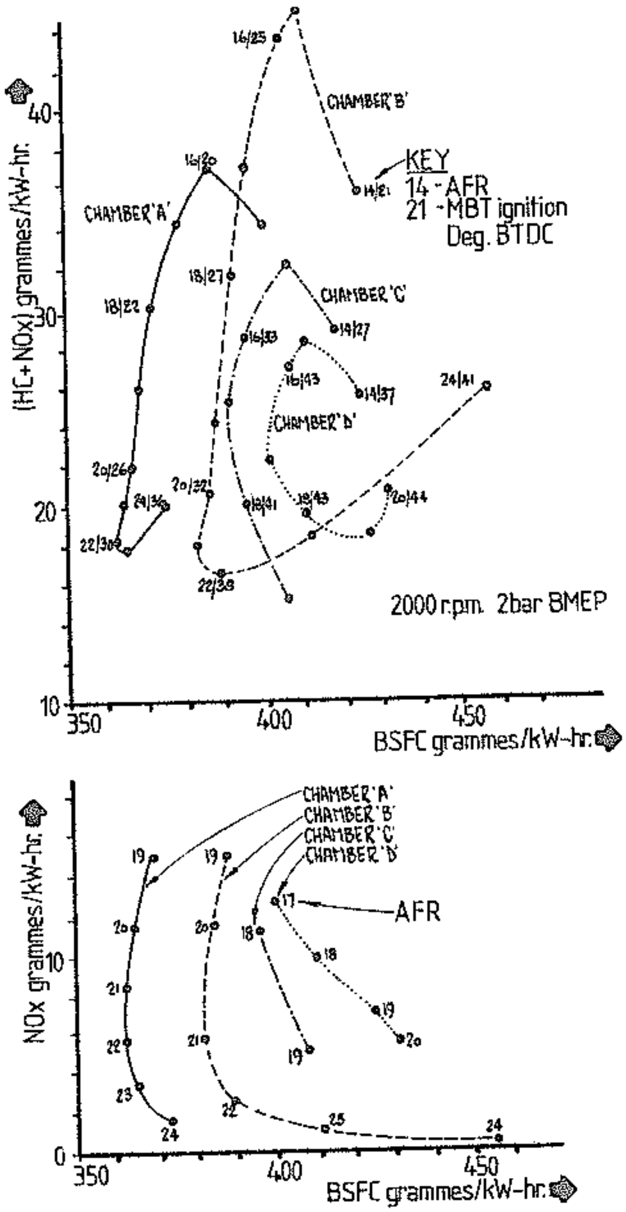


Fig. 3. Relationship between emissions and BSFC as a function of air/fuel ratio on four chambers.

however is higher for both chambers. The graph showing (HC + NOx) against fuel consumption shows that these chambers satisfy the criteria outlined in Section 2 for good lean burn potential.

In contrast chamber C cannot be tuned for optimised 'lean burn' performance. The stability requirement would necessitate tuning at relatively high levels of (HC+NOx) albeit at the point of minimum BSFC.

Chamber D could be tuned to give comparable emissions of (HC + NOx) to chambers A and B at the expense of inferior part load economy.

These results provide a basis for the selection of potentially viable chambers suitable for the application of a lean burn control strategy. To understand the reasons for the variety of chamber behaviour displayed in Figure 3 is a formidable task. The remainder of this paper details several studies aimed at identifying some of the controlling parameters important for a good lean burn chamber.

4. Factors Affecting Lean Burn Potential

4.1 Compression Ratio

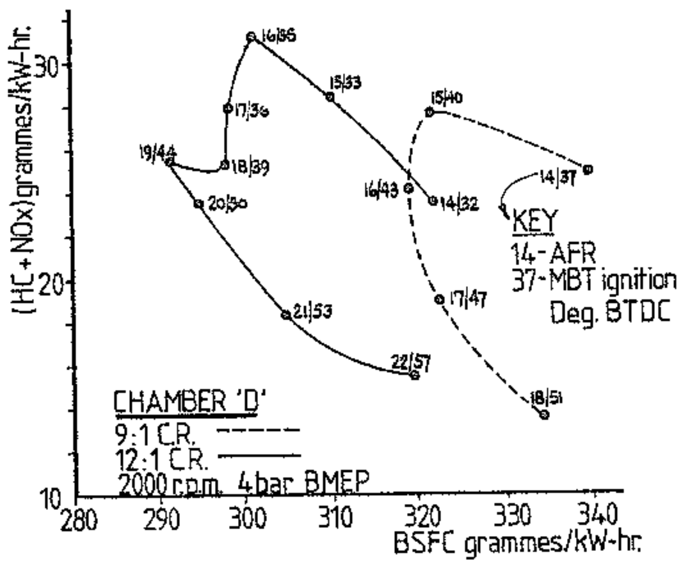
Increasing compression ratio offers the prospect of burning lean through reducing ignition delay and cyclic variability. Figure 4 provides an example of the effects of increasing compression ratio from 9:1 to 12:1 on a disc chamber at engine condition 2000 rpm, 4 bar BMEP.

Gains of 8% in BSFC are obtained at this particular condition. However whilst the chamber did burn leaner the net effect on emission reduction was minimal because both NOx and HC increased with compression ratio. To obtain the same level of NOx the figure shows that it was necessary to burn 3 AFR leaner at the higher compression ratio. It is interesting to note the ignition timings at the same NOx level are similar for both chambers.

On this particular chamber the benefits of increasing compression ratio whilst providing an absolute improvement in BSFC and extending the lean burn do not reduce emissions or improve the chamber's lean burn characteristics as outlined in Section 2. Other factors e.g. chamber geometry or low activity may prove more critical in this particular case.

4.2 Mixture Motion

Various studies have drawn attention to the relationship between cyclic variability



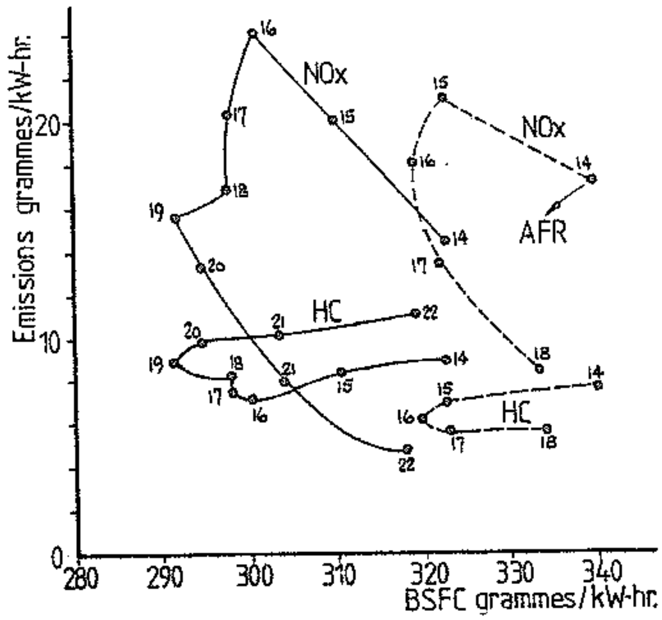


Fig. 4. The effect of compression ratio on a disc chamber.

and lean burn. It is believed that one method of reducing cyclic variations is to adopt a 'fast burn' approach. For a slow burning chamber there is presumably a narrower tolerance band on burn duration variability to avoid either misfire or partial burn on individual cycles. Fast burn is also necessary at weak mixture ratios to compensate for the reduction in flame speeds.

Burn speed may be increased either through geometric changes (to reduce burn paths) or through increased mixture motion.

Chamber geometry may involve either optimising the spark plug position and/or the development of specific chamber types designed for increasing flame front areas (e.g. compact chambers).

Chamber activity may be increased either through inducing swirl during intake or squish during compression. Intake swirl generation will cause flow restriction. Figure 5 shows specific power against inlet restriction for various engines and illustrates the trade offs which may be required.

Squish generated flows should not in principle provide such a compromise. However the

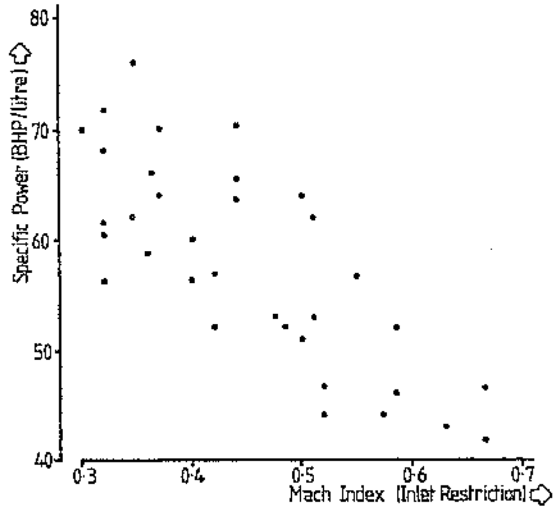


Fig. 5. Specific power output against inlet restriction for various engines.

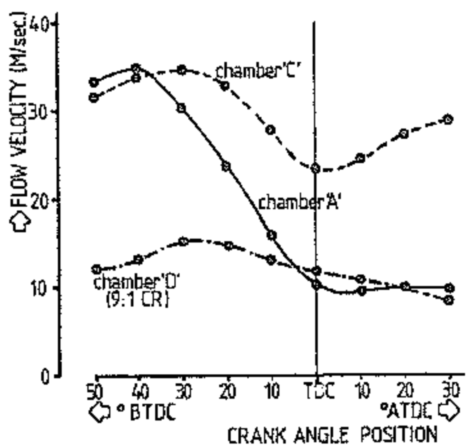


Fig. 6. The mean flow field at the spark plug under motoring conditions on three chambers. Operating condition is 2000 rpm, 2 Bar BMEP.

potential for squish generated flows to impact on flame development is limited as squish occurs late within the compression stroke.

Figure 6 shows results obtained using hot wire anemometer probes to measure the flow field at the spark plug under motoring conditions for three of the chambers types described in Section 3. Mean gas velocities are shown between 50 BTDC and 30 ATDC as obtained from triple wire probes. Due to the difficulties associated with unscrambling turbulence from cyclic variations no turbulence data is presented here. It is suggested that the rate of decay of the mean velocity field could be used to provide a qualitative measure of the turbulent energy field.

The disc chamber (D) exhibits a low velocity throughout the period and this is reflected in advanced ignition requirement for this chamber.

Both the open chamber (A) and high swirl chamber (C) exhibit high velocities at 30 to 40° BTDC but thereafter the characteristics of the flows are dissimilar. The high swirl chamber maintains a high velocity throughout the burn period whereas the open chamber exhibits a marked reduction in speed to a relatively low level at TDC and beyond. Both these chambers were 'fast burning' but the high swirl chamber failed to burn lean. It is suggested that the high velocity associated with the swirl chamber is detrimental to flame growth at weak mixtures. The open chamber however appears to undergo a radical restructuring of the flow (possibly to smaller scales) which may be more beneficial to initial flame development.

4.3 Increased Activity

Further investigations have been performed on other open chambers similar to those discussed above. Figure 7 shows the effect of increasing activity in two of these chambers (Chambers E and F).

In chamber E it is clear that the increase in activity has both improved lean burn whilst reducing BSFC. In particular economy/ emissions characteristics have been improved. In contrast chamber F demonstrates that the gains in economy are minimal and that lean burn characteristics have not been enhanced through increased activity.

It is interesting to note that chamber E was initially a slow burning chamber

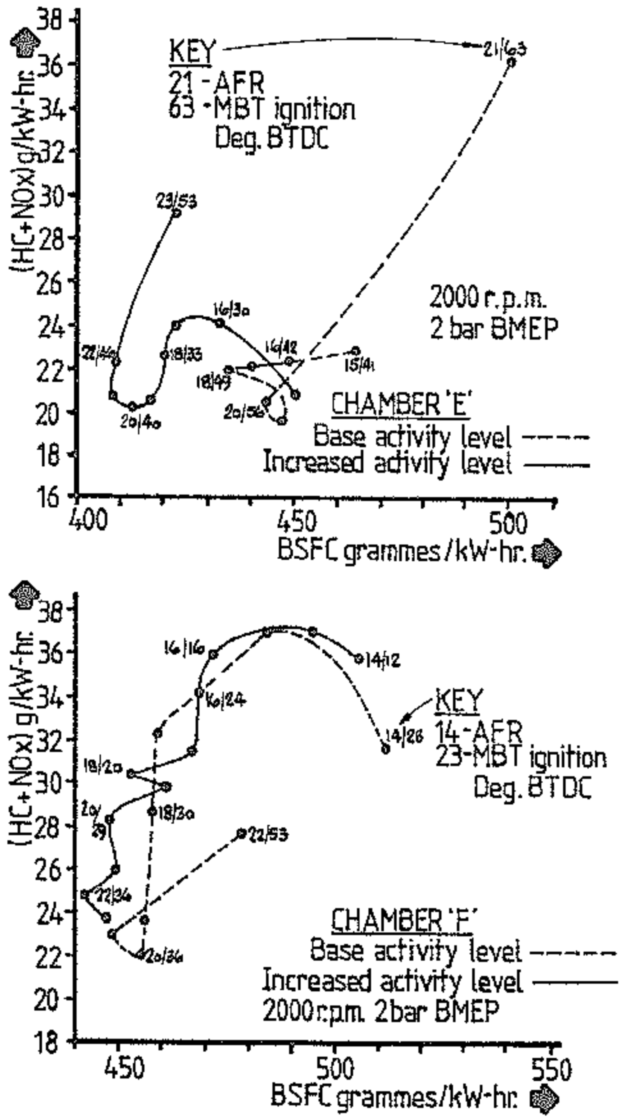


Fig. 7. The effect of increasing chamber activity on two chambers.

in contrast to chamber F. This suggests that there is an optimum swirl level above which little is to be gained in either specific fuel consumption or the economy/

emissions tune for these chamber types.

4.4 Plug Position

Changing the plug position effectively alters both the chamber geometry and the flow field during early flame development.

Both factors can affect initial and main flame development. One aspect of these investigations has been the influence of plug intrusion. Figure 8 shows the effect of extending the plug into two chambers. The ignition curves for chamber G show that less advance was required as the plug was extended into the chamber giving improved lean burn and small gains in economy. The results from the second (similar) chamber (G) show that improvements were only marginal. Velocity measurements obtained on other chambers have shown that there is a significant change in flow field as seen at the plug gap for relatively small changes in plug protrusion. The above results suggest that for inactive chambers exhibiting poor lean burn exposing the flame kernel to the flow field may be beneficial through enhancing early flame growth. For more active chambers the gains become less significant and could prove detrimental.

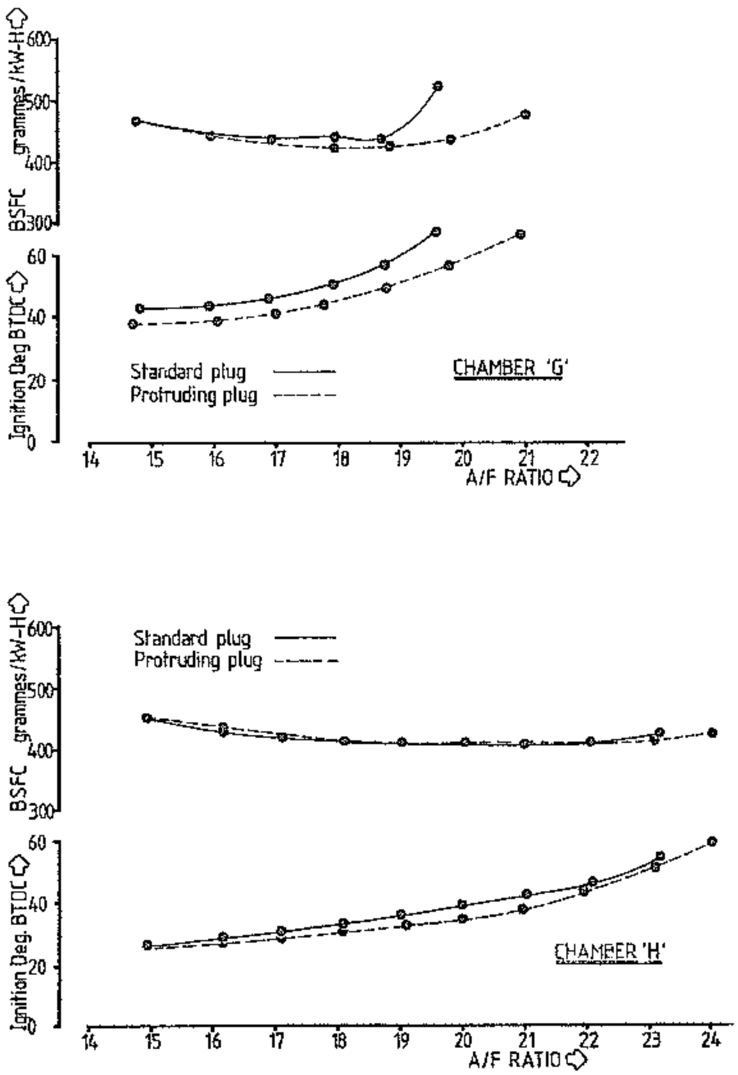


Fig. 8. The effect of spark plug intrusion in two chambers.

5. Conclusions

Lean burn technology offers the prospect of both reducing emissions and improving fuel economy.

Chamber types have been investigated and those exhibiting characteristics for optimum tuning can be identified.

Investigations into the parameters which may affect lean burn have been conducted and have provided a basis for further refinement and development of specific chamber types. The development of the chambers for multi cylinder application has indeed confirmed the reduced emissions level potential but emphasises an increased requirement on transient fuel and air control for low transient emissions and good driveability.

To date emphasis has been largely placed on reducing NOx levels through extended lean burn. Future activity and challenges will centre on the problems of reducing HC levels.

6. Acknowledgement

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