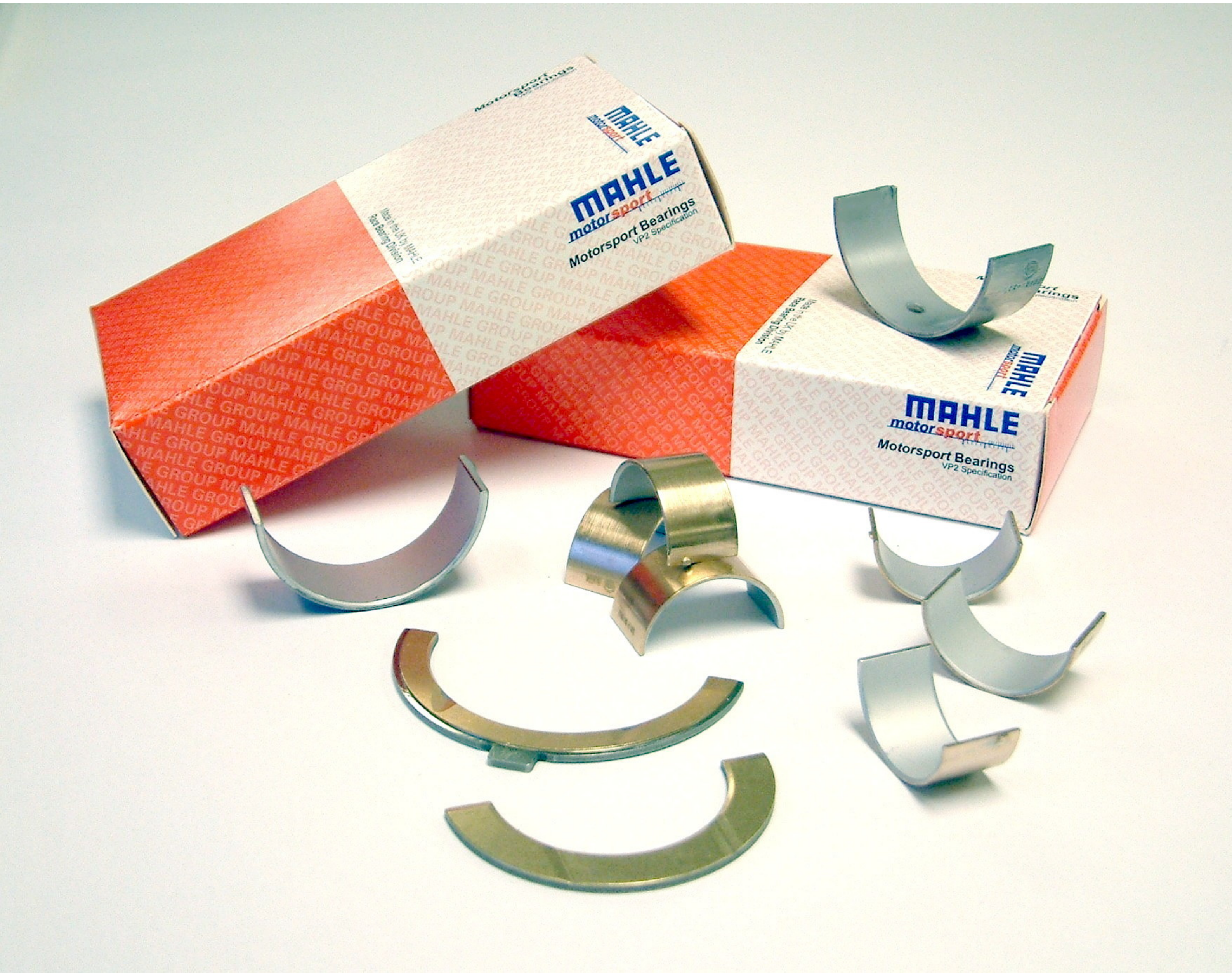
The Influence of Main Bearing Grooves on Bearing Performance



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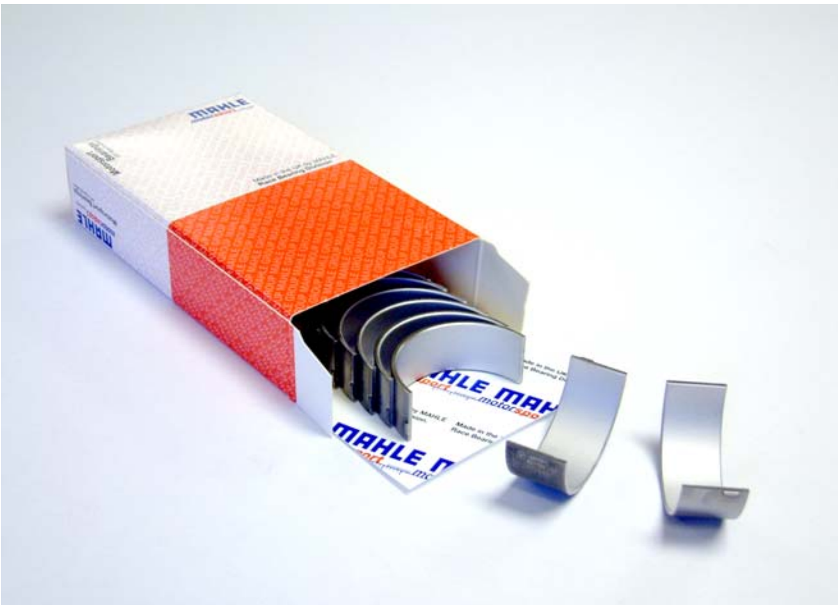

Introduction:

The main bearing oil groove is required for the sole purpose of supplying oil to the connecting rod big end bearing. At one time it was common to have a full 360° groove on the main bearing to provide an uninterrupted supply of oil to the big end by means of a single drilling from the main journal. This was achieved by having identical upper and lower bearing shells.

As bearing loads increased this design proved unsustainable as the oil film thickness, on which every crankshaft bearing relies, became insufficient for reliable main bearing operation. The solution was to increase the bearing area on the more heavily loaded lower-half bearing by reducing the extent of the groove to around 230° or even 180° in order to provide a single bearing land of greater width. Any increase in bearing width enables a higher oil film pressure to be sustained as the distance from the centre of the bearing to the edges, which cannot sustain an oil pressure, is increased. This in effect allows the generation of a thicker oil film with which to separate the shaft and bearing shell.

The reduced oil groove extent would sometimes be compensated by a cross-drilling on the main journal in an attempt to maintain an uninterrupted supply of oil to the big end bearing. However, in many cases it was found that the big end could cope very well with the subsequent intermittent oil flow offered by a single drilling from a 180° groove.

Nowadays, with the use of computer simulation and engine testing the optimum extent of the groove may be determined. It is not now just a case of allowing the big end to survive but that the efficiency of the bearing system can actually be improved by due attention to the groove geometry. This is because the big end bearing, like any hydrodynamic lubricated bearing, will use as much oil as it needs to generate an oil film for any given operating condition. Any less than this amount risks disrupting the oil film and ultimately starving the bearing of oil, but equally, feeding excessive oil to the bearing simply results in additional leakage, and reduced efficiency. Therefore, the oil groove, like many other features on a bearing shell, can be optimised.

Oil Film Analysis of Main Bearings Using SABRE-M Software:

An oil film analysis using MAHLE's SABRE-M software was undertaken to investigate how the oil groove extents influence the performance of the bearing system. A modern 1.6L turbocharged engine was selected and groove extents of 180°, 230° and 270° were compared.

Figures 1 to 4 show the effect that the oil groove extents have on the following main bearing parameters:

- Minimum Oil Film Thickness (MOFT)
- Direct Contact Reactivity (Wear Estimate)
- Oil Flow
- Power Loss

The bearing system performance can be broken down into reliability and efficiency. The MOFT and DCR are useful for judging the reliability of the bearing system. A greater MOFT indicates a more secure bearing system by means of greater separation of bearing shell and shaft. A smaller DCR value indicates a lower risk of bearing wear.

Oil Flow and Power Loss are useful for judging the efficiency of the bearing system. Reduced oil flow allows a reduced oil pump capacity and reduced power losses indicate less energy lost through oil shearing in the bearing.

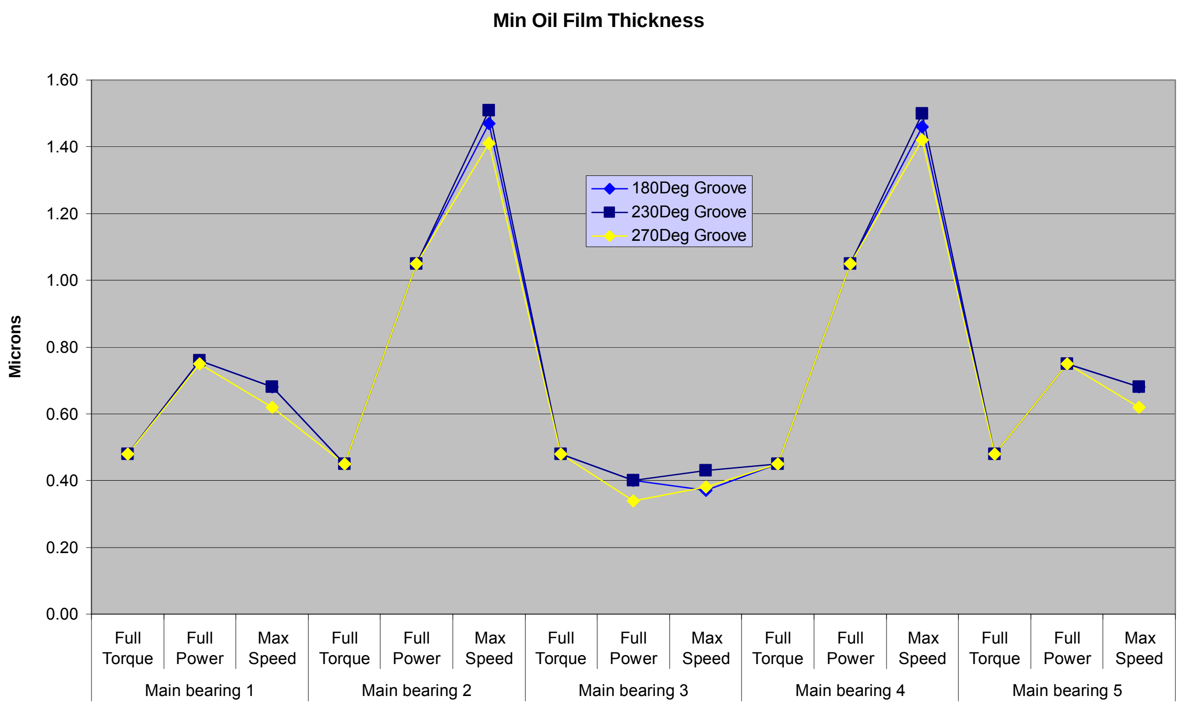

Fig. 1 – Min Oil Film Thickness

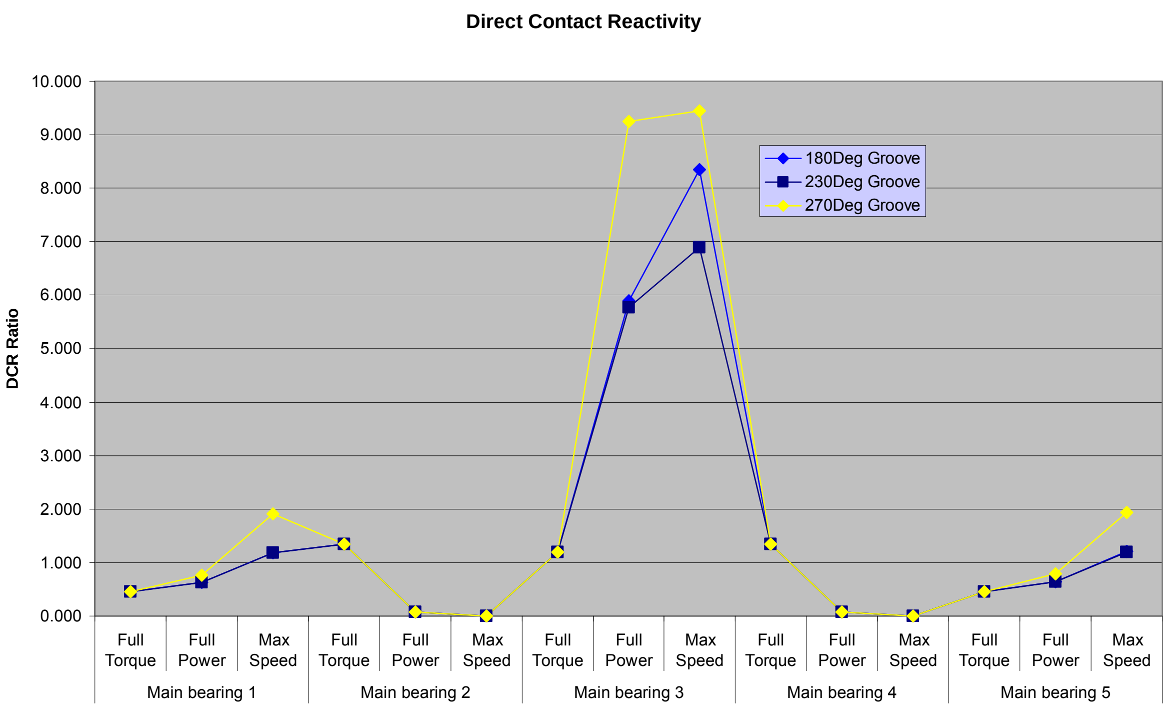

Fig. 2 – Direct Contact Reactivity

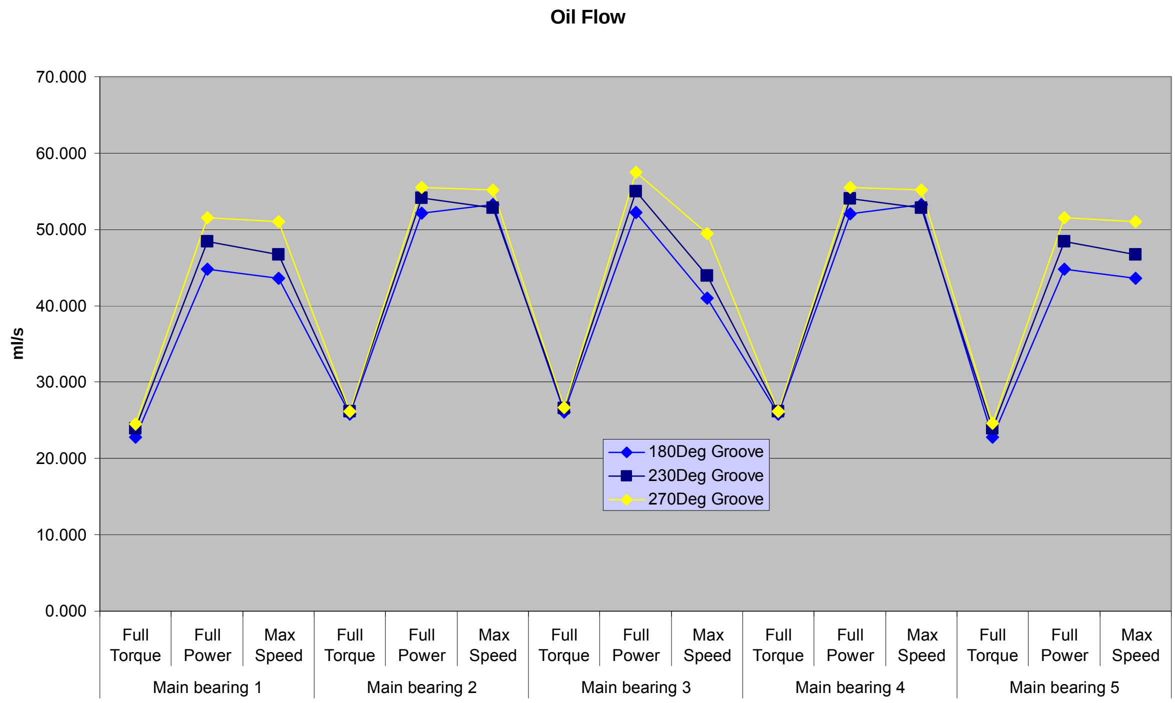

Fig. 3 – Oil Flow

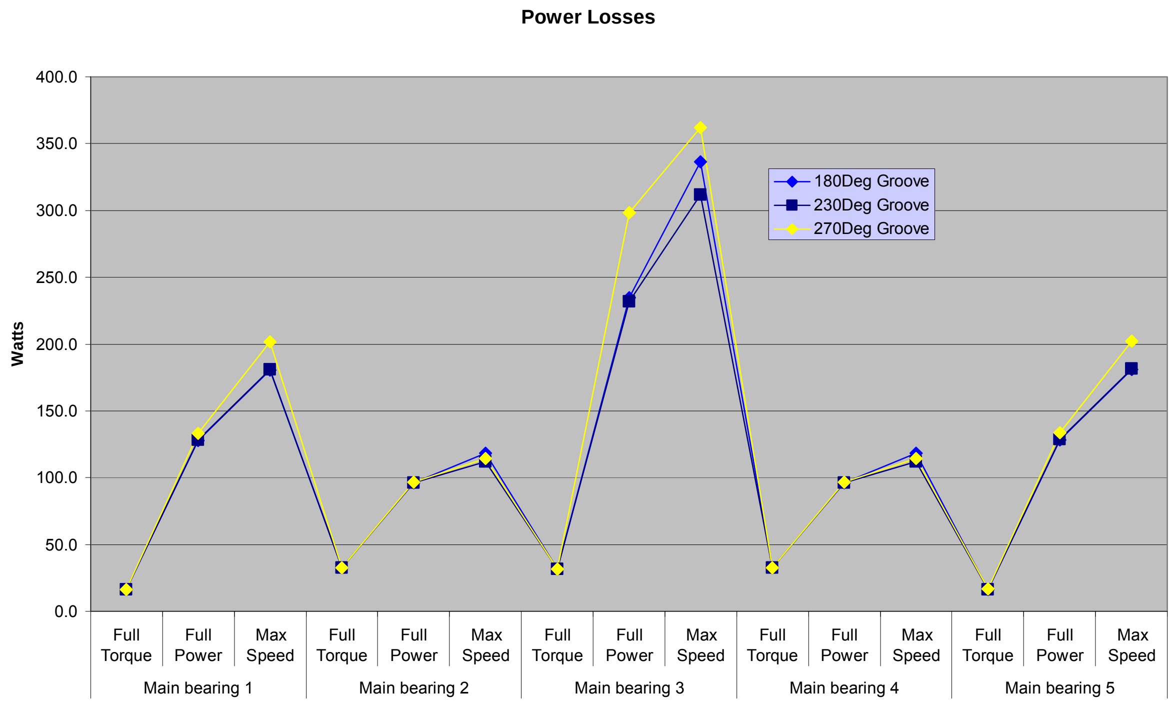

Fig. 4 – Power Loss

Main bearing 3 is shown to be the most critical bearing and so was selected to compare the groove design. It can be seen from the charts that the greater groove extent has the effect of reducing the MOFT by up to 15%, increasing oil flow by up to 13%, increasing power loss by up to 16% and significantly increasing the DCR value.

The effect of the groove on the MOFT can in some cases be critical. If the groove encroaches on the part of the bearing which experiences the MOFT then it will significantly reduce it simply by dividing the bearing land into 2 much smaller bearing lands. This is best shown by the Journal Orbit Diagrams shown in Figure 5. The yellow region denotes the groove extents and the arrow denotes the position of the MOFT.

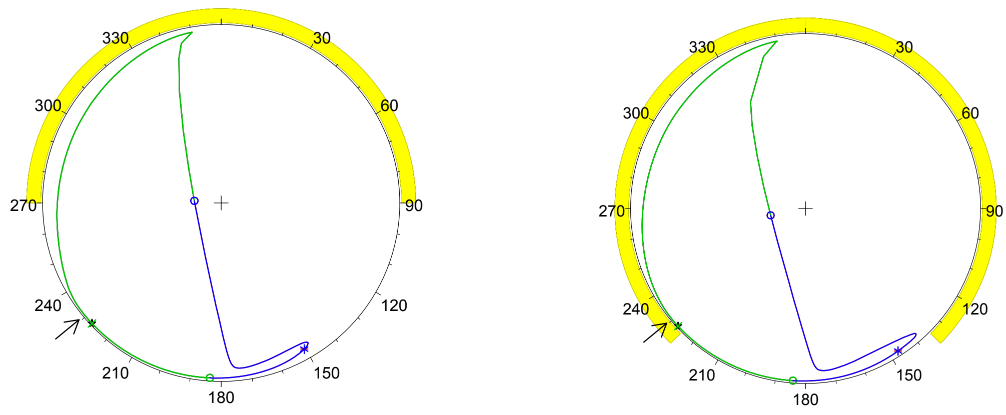

Fig. 5 – Polar Load Diagram comparing the 180° groove and the 270°groove

The same effect can be seen in the graphical representations of the DCR in Figure 6 whereby the presence of the groove increases the predicted wear.

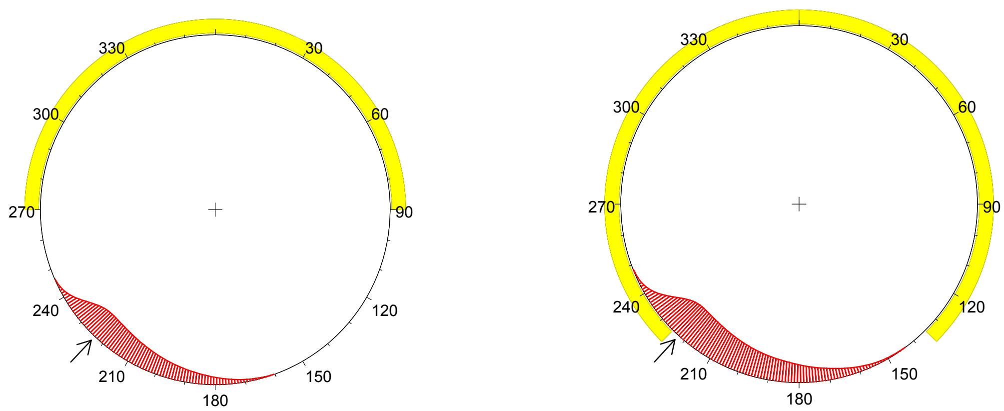

Fig. 6 – DCR Representation comparing the 180° groove with the 27°groove

The Developed Pressure Map shown in Figure 7 also demonstrates how the groove can influence the MOFT by encroaching on to the most critical part of the bearing in terms of MOFT.

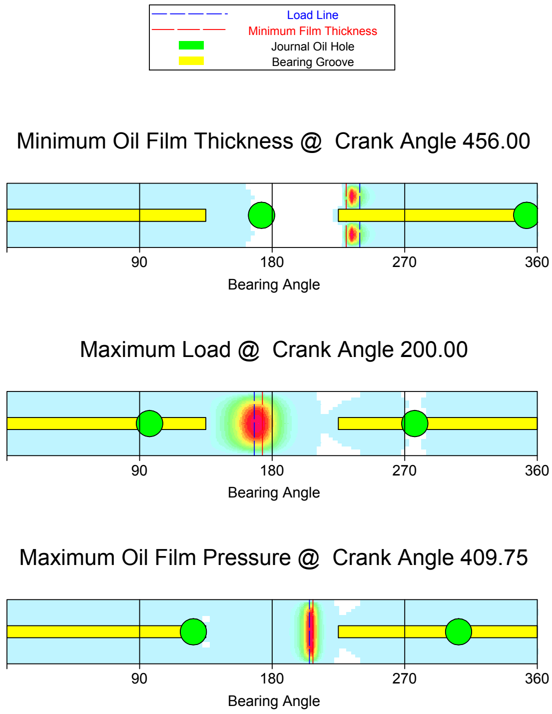

Fig. 7 – Developed Pressure Map Showing MOFT, ML and MOFP (2 holes indicate cross-drilling)

Oil Film Analysis of Rod Bearings Using SABRE-FD Software:

It is clear that the groove extent compromises the performance of the main bearing but this must be balanced with the oil feed requirement of the big end bearing. Using the same 1.6L turbocharged engine data, the Finite Difference (SABRE-FD) method was used to compare the effect that the 180° and 270° grooves have on the big end bearing. For the purpose of this exercise the cross-drilling was removed to simulate an intermittent oil flow. Figure 8 shows the results tabulated for comparison.

SABRE-FD Results	**Big End Bearing fed by 180° Groove**	**Big End Bearing fed by 270° Groove**
Max Load (kN)	31.221	31.221
Max Specific Load (MPa)	37.20	37.20
Min Oil Film Thickness (µm)	0.47	0.47
Max Oil Film Pressure (MPa)	208.71	208.55
DC Severity Factor (MPa.m/s)	3.18	3.22
Operating Temperature (°C)	151.9	151.9
Power Loss (W)	252.4	253.1
Oil Flow (ml/s)	15.09	15.85

Fig. 8 – Table of SABRE-FD Results

In this case the results show that the difference between the 180° and 270° groove extents make very little difference to the big end bearing performance. The main difference is a slight increase in oil flow but the most critical parameter – the MOFT – is the same in both cases. The subtlety of the difference can barely be picked up from the film pressure maps in Figure 9.

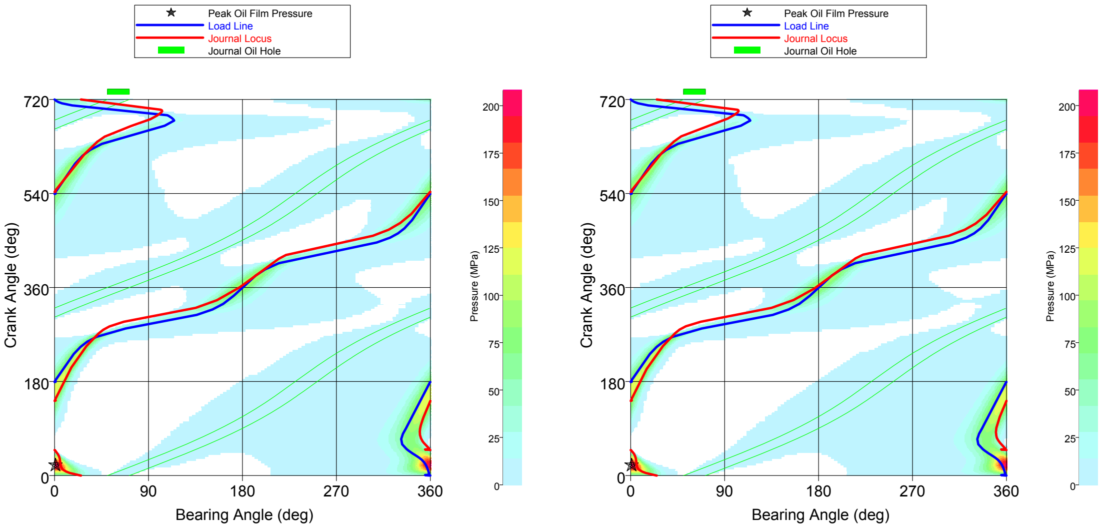

Fig. 9 – Oil Film Pressure Maps of big ends (180° groove on the left, 270° groove on the right)

Discussion:

This analysis has shown how the main bearing groove can influence the performance of the bearing system. A full 360° groove significantly reduces the reliability of the main bearing but ensures a good, but possibly excessive, supply of oil to the big end bearing. A compromise can be reached by reducing the extent of the groove but this must be balanced against the requirement of the big end bearing and this is dependent on the application.

This is the key point about the bearing groove design and indeed any bearing feature - the optimum design is entirely specific to the engine type and regime it is operating under. It is not correct to make a general assumption about the optimum groove design and apply it across a range of engines and operating environments. What is suitable for one engine may not be suitable for another. The engine analysed in this study had a main bearing that was sensitive to the difference in groove extents of 180° to 270° but a rod bearing that was not. This, of course could be entirely different for another apparently similar engine.

The way a bearing operates is complex and the design of a single feature will influence numerous operating parameters. Therefore, it is not possible to design a bearing feature in isolation of all other bearing features just as it is not possible to design a bearing shell in isolation of all the other components in the bearing system. Take the bearing clearance for example. The oil flow increases exponentially with clearance so the main bearing groove extent is directly influenced by the big end bearing clearance. In effect, a tighter big end bearing clearance will allow a reduced groove extent and width.

With so many parameters influencing the bearing system, the benefits of utilising computers to aid the design process is clear. However, the software has limitations and the validation of the overall bearing design must be realised by a carefully designed programme of engine tests. This is done at length when an engine manufacturer develops a new engine and so when fitting replacement parts it is critical to replicate the original equipment if the engine is operating under the same regime as it was designed for.

However, if an engine is being developed for racing then this must include the bearing system and due care must be given, not only to the bearing material, but also to the detailed geometry and features of the bearing including the bearing groove.