

Investigating the Potential to Reduce Crankshaft Main Bearing Friction During Engine Warm-up by Raising Oil Feed Temperature

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ABSTRACT

Reducing friction in crankshaft bearings during cold engine operation by heating the oil supply to the main gallery has been investigated through experimental investigations and computational modelling. The experimental work was undertaken on a 2.4l DI diesel engine set up with an external heat source to supply hot oil to the gallery. The aim was to raise the film temperature in the main bearings early in the warm up, producing a reduction in oil viscosity and through this, a reduction in friction losses. The effectiveness of this approach depends on the management of heat losses from the oil. Heat transfer along the oil pathway to the bearings, and within the bearings to the journals and shells, reduces the benefit of the upstream heating. Results show that step increases in temperature produced at the gallery inlet can be maintained along the pathway to the bearing inlets, but heat transfer from the oil film in the bearings outwards through the bearing shells and inwards to the bearing journal greatly reduces the benefit. Simulations show that insulating the film from both the bearing shells and journal is necessary to realize the potential of pre-heating the oil.

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INTRODUCTION

Improving the fuel efficiency of internal combustion engines continues to be a major goal for the automotive industry and reducing frictional losses is one of the key areas attracting attention. Engine friction generally follows a power law dependence on bulk oil viscosity except in the early seconds of engine operation, as illustrated in [Figure 1](#). The losses during cold operation are particularly significant. Various ways of promoting fast warm-up to minimise these have been pursued [1] [2] [3]. Law et al [4] explored the possibility of supplying hotter oil to the engine rubbing surfaces by increasing the temperature stratification in the sump and feeding hotter oil to the pump inlet. For a -10°C start, a peak increase in oil temperature of 12°C was produced in the main gallery and friction reductions of more than 10% were achieved in the first minutes of engine operation. Other concepts include the use of heat storage devices to shorten the engine warm-up phase [5]. Kuze et al [6] describe a coolant reservoir capable of storing coolant

above 50°C for three days, used for pre-heating the intake port walls of a gasoline engine during cold-starts. Reductions in fuel consumption were achieved through a combination of reduced engine friction and a shorter fast-idle period.

Friction in the crankshaft main bearings is the target of work reported in this study. Friction in the crankshaft bearings and seals accounts for approximately one third of total engine friction. The thermal-friction interactions within the bearings during warm-up and the effectiveness of supplying pre-heated oil to the main gallery as a way to accelerate the reduction in friction losses are investigated. A hot coolant store was used to source heat input to the oil entering the main gallery and crankshaft bearings. Oil temperature measurements show the rise in temperature produced by this persists in damped form at the inlets to the main bearings. The reduction of friction achieved and the effectiveness and limitations of the approach are explored in the following.

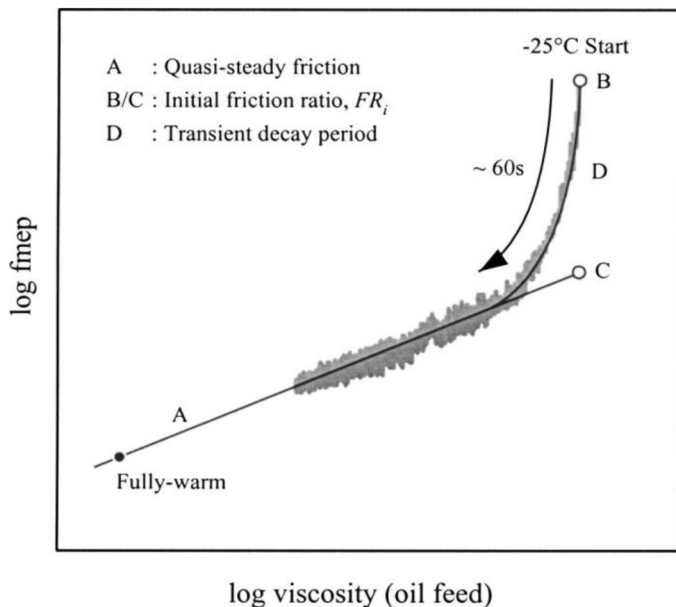


Figure 1. Friction behaviour during engine warm up [8]

EXPERIMENTAL SETUP

The engine used for the investigation is a modern 2.4l DI diesel engine with 5 crankshaft main bearings. Each of the bearing caps was modified to insert two 0.5mm K-type thermocouples, one on the back of the lower shell (on the bearing cap side), the other measuring oil film temperature, in the same way as described by Shayler et al [8]. The engine external coolant circuit in original form is illustrated in Figure 2. The Filter Cooler Assembly (FCA) is an oil filter unit with an integral oil-to-coolant heat exchanger. While its prime purpose is to limit fully-warm oil temperatures, the oil cooler also has significant influence on the warm-up characteristics of the engine [1]. In the baseline setup, coolant flow through the FCA is controlled by a thermostat valve which opens when the 'engine out' coolant temperature reaches around 70°C. After modification, the engine coolant flow was disconnected from the FCA and replaced by an arrangement which allowed the flow of hot coolant drawn from a separate pre-heated reservoir tank to be switched in or out.

The modified circuit is shown in Figure 3. The reservoir tank of coolant was heated with an integral 3kW electric heater and when switched in, circulated between the tank and the FCA at a steady 3.75l/min using a 12V electric pump. The coolant was pre-heated to 90°C before the start of a test. Warm up tests were run at a constant engine speed and load of 2000rev/min and 3bar BMEP, respectively, from a cold start temperature of typically 20°C; the hot coolant flow was switched on 45s after engine start-up. The temperature of coolant in the reservoir tank, and at the inlet and outlet of the FCA were measured. Oil temperatures were measured in the

sump, at the inlet and outlet of the FCA and at the feed to the main gallery.

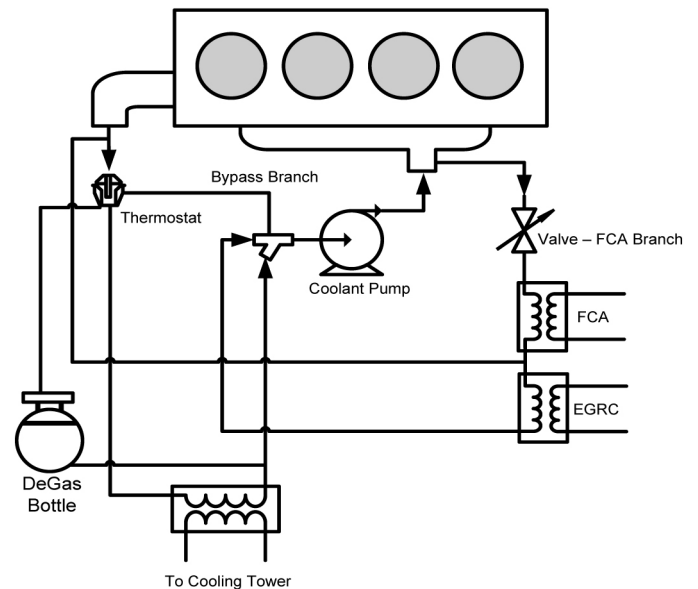


Figure 2. Original configuration of the engine coolant circuit

MAIN BEARING THERMAL MODEL

Thermal conditions in and around the main bearings have been modeled within PROMETS [7] using a network of seven lumped thermal elements representing the crankshaft journal, bearing cap, part of the bearing support walls and the local section of the crankcase wall (Figure 4). Heat exchange between these elements and the oil mist in the crankcase is calculated using the exposed surface area and a heat transfer coefficient of 50W/m²K based on previous empirical investigations of oil mist to crankcase heat exchange [1] [7]. A higher value is assigned to the crankshaft journal element to account for its rotation and higher heat transfer rates to the oil mist.

The thermal inertia of oil in the bearing is small and the film temperature is controlled by the energy balance within a control volume surrounding the film in which frictional dissipation balances heat removal by conduction and convection. Frictional heat dissipation in the first few seconds of engine operation rapidly heats the oil film and adjacent metal components and because the oil viscosity-temperature gradient is steep at cold oil temperatures, the film temperature rise produces a sharp drop in oil viscosity and friction. The numerical computation of temperature and frictional dissipation in the film is prone to become unstable in explicit time-marching schemes but an iterative solution simultaneously satisfying film energy balance and consistency of temperature and frictional dissipation proved to be stable and computationally efficient. The values of thermal resistance to heat transfer between the oil film and the bearing journal and the bearing shells were set by

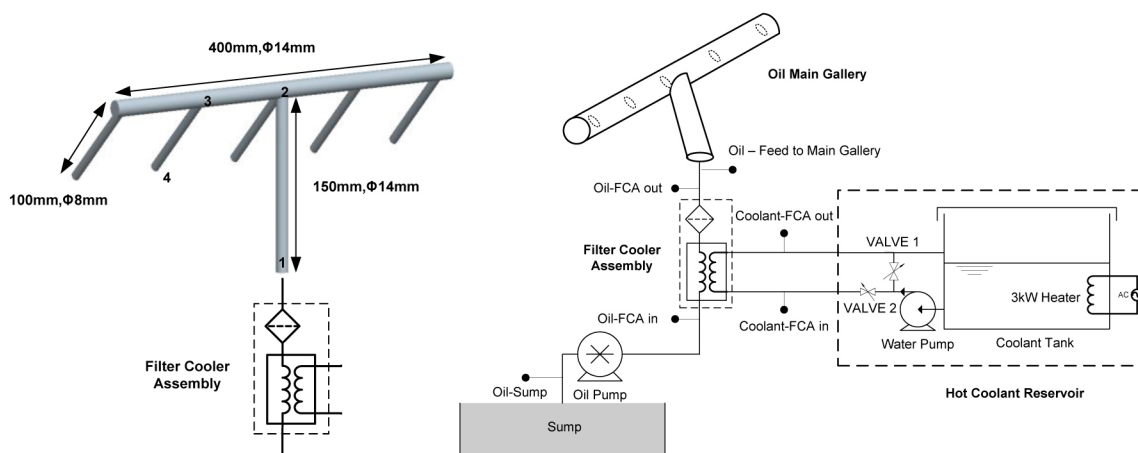


Figure 3. Heat store circuit and oil gallery dimensions

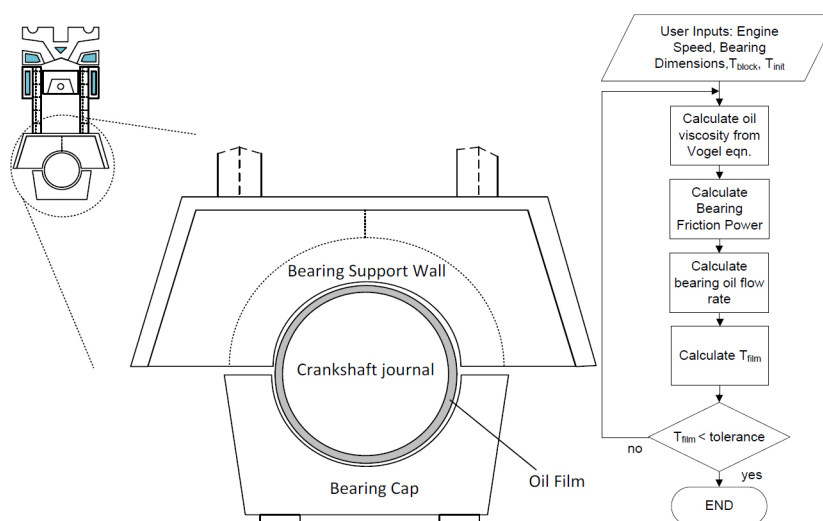


Figure 4. Oil Gallery Schematic

comparing model predictions with experimental data. Oil flow rate through the bearing was calculated using the formulations developed by Cameron [9] as the sum of two components: hydrodynamic and pressure-fed flows. Friction is calculated from the correlations developed by Leong [10] from engine tear down tests.

In Figure 5, experimental results are presented for a warm-up test at constant speed and brake load (2000 rev/min, 3 bar BMEP) with the FCA connected to the engine coolant circuit as illustrated in Figure 2, that is to say, as in the standard configuration. At around 280s into the test, the coolant loop thermostat opens and coolant is streamed into the FCA increasing the rate of oil warm up in the sump and bearing film. Model predictions for bulk and oil film temperatures from an ambient temperature start compare well with trends measured on the test bed. The corresponding variation with time of the components of an energy balance for the oil film within the main bearing is illustrated in Figure 6. The strong thermal coupling between the oil film and

metallic surfaces means that initially up to 80% of the energy dissipated by frictional heating is conducted into the crankshaft journal and bearing shells. The remainder is retained in the oil film and convected away by the oil flow through the bearings. The balance of energy transfers steadily changes and the proportion of friction heat dissipated into the oil flow increases to just under 80% for the fully warm state. Jarrier [11] observed a similar variation. The perturbation observed at around 280s is caused by streaming of coolant in the FCA. The oil feed temperature to the bearing is momentarily increased relative to the bulk oil. In response to a higher inlet temperature the heat transfer to the journal and bearing shells increases limiting the oil temperature rise across the bearing. For comparison, the corresponding variations of heat flow when no coolant flows through the FCA, is shown in Figure 7.