DESIGNING AUTOMOTIVE ENGINE LUBRICATING SYSTEMS

1. Introduction

The primary purpose of the lubrication system is to lubricate sliding surfaces and reduce friction losses in the engine, whilst secondary issues are involved with heat transfer. It is recognised that the lubricating oil, which, after fuel, is the most variable engine 'part' of any internal combustion engine, and is probably the most open to abuse. The possibility of the use of inferior specification oils, and/or for periods exceeding the recommended drainage intervals, coupled with the possibility of excessive engine wear, has led to considerable emphasis being placed in lubrication system design and development.

The optimisation of engine lubrication systems traditionally involved much hardware testing, which was expensive and time-consuming.

Basic lubrication systems use a positive displacement oil pump feeding all bearings with full flow oil filtration, whilst more complex systems can include pressure relief valves, by-pass filtration, piston cooling, hydraulic lash adjusters and hydraulically activated cam phasing mechanisms. The main factors to be considered in the lubrication system design process are flow balancing and pump sizing (volumetric flow rate of oil) required for satisfactory operation. Items such as hydraulic lash adjusters and chain tensioners also require a minimum oil pressure at low engine speeds for adequate operation, which can have a significant affect on the oil pump size. Traditionally, the volumetric capacity of the oil pump (and pump speed) was determined according to the power rating, swept volume of the engine and design experience with a further allowance to account for the worn engine condition, but as engine lubrication systems became more complex a more analytical approach was required. A one dimensional fluid flow network can be generated to simulate the oil flow with specific models for galleries (pipes), filters, pressure controlled valves, bearings, piston cooling jets, orifices etc and further used to optimise the flow characteristics (oil velocity, volumetric flow rate and pressure) in the system.

2. Design of Lubrication Systems

2.1 GENERAL CONSIDERATIONS FOR THE LUBRICATION CIRCUIT

Typically oil velocities in excess of 3m/s in the pick-up pipe can result in cavitation reducing engine and oil pump life. However, at low temperatures the pressure in the lubrication system is high due to high oil viscosity and a majority of the oil is then re-circulated or directed back to sump via the pressure relief valve. To illustrate the difference in viscosity, for a typical 15W40 oil the kinematic viscosity at 120°C is 8.45 cSt increasing to 8546 cSt at -20°C.

Aeration is another of concern, which is caused by crankshaft churning (exacerbated by too high sump levels), oil break up (typically by a chain), high oil return velocities (from the cylinder head) and long suction lengths.

If the oil level is too low the pick-up pipe is not fully flooded under all conditions, again causing air bubbles to be mixed with the oil by the oil pump and circulated around the lubrication system. For drainage, if the oil velocity is in excess of 0.5m/s, air is mixed into the oil, which is the main reason for re-circulating oil from the pump relief valve rather than directing it straight back to sump at high speed.

Another important criterion to consider is the engine running temperature (or the average oil temperature in the sump), which ranges from 120°C-150°C for light duty automotive applications. If localised temperatures are too high, i.e. above 220°C for mineral hydrocarbon oils and above 300°C for synthetic oils, the oil is likely to carbonise into solid matter, which can accumulate in critical areas of the engine.

2.2 PUMP SPECIFICATION

Pump delivery requirements can be estimated using typical demand data for all component oil consumers, together with an allowance for worn conditions. As some of the bearings will wear, the clearances between the rotating shaft and bearing shell increase, thereby allowing more oil flow (although the minimum bearing flow requirement does not change) and therefore upsetting the flow balance in the circuit. Other parts of the engine which have not worn to the same degree will still require the same oil flow for satisfactory operation, hence the demand on the oil pump increases. However, for crankshaft bearings the flow requirement is based on temperature rise through the bearing and as the engine wears the oil temperature rise is reduced since increased clearances allow more oil flow.

The pump itself is most commonly a positive displacement oil pump of a gear or gerotor design and driven by the crankshaft directly or via a gear or chain. Current designs also have an integral relief valve (pressure actuated via a spring) to prevent very high oil pressures building up in the system, particularly at cold start.

2.3 RELIEF AND BY-PASS VALVES

Typically the oil pump relief valve would be set to open at