[1]High-speed video observation and phase Doppler anemometry measurements of oil break-up in a model engine crankcase

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Abstract

A unique experimental study of the characteristics of the liquid phase of oil in a rotating model engine crankcase was undertaken using non-intrusive optical measurement techniques. The primary objective of the study was to investigate the mechanisms of oil film break-up at the edge of the crankshaft webbing, fed by oil from the main journal bearing. High-speed photographic visualisation and phase Doppler anemometry (PDA) data were used to determine three oil break-up regimes that varied with rotational speed. The oil particles were ejected from the crank edges and followed well-known curved trajectories. The disk Bond number, Bo_D was calculated for a range of characteristic diameters, distributed over the irregular crank web circumference in the regions where oil particles were ejected. The diameter ratio was evaluated at the limits of the ranges of particle size and velocity in the corresponding regions. The results were compared with the universal power law for the so-called primary particles formed by a spinning disk aerosol generator. The values of the Bo_D and empirical constant, K were estimated at 2.21 and in the range of 1.82 to 2.39 respectively. The windage effect agitated the surface of the oil on the baffle tray, induced funneling in the sump and created moving oil films on the crankcase walls and oil foams.

Introduction

The generation of an oil aerosol and the aeration of engine oil occur in the typical operation of an internal combustion engine. As an aerosol, the oil contributes as a source of pollution that must be filtered out. When air or combustion gases are trapped in the oil, it has an adverse affect upon the efficiency of the oil to lubricate, cool and actuate engine components and systems. Generally, the greatest affect occurs in the engine crankcase where ejected oil splashes against the oil films deposited on the chamber surfaces and the rotational and reciprocating motions induce pumping windage of the oil surfaces [1-3]. Here, the oil break-up process was considered analogous to that of a spinning-disk atomizer. The diameter of the aerosol particles has been shown to be a function of rotational speed, liquid and disk properties and a range of empirical constants [4-7].

Materials and Methods

A model crankcase and crankshaft were designed and manufactured to investigate the mechanism of oil break-up. It was assembled using production engine crankshaft components, mechanical tolerances and standard oil conditions. It was driven by an electric motor at speeds of up to 100 Hz. A moulded, polycarbonate shroud was used to mimic the interior geometry of the production crankcase. The assembly was mounted within a rectangular case, incorporating glass windows and shutters, to provide observation of the sump and crankshaft for the video and PDA. The optimisation of the techniques formed an important part of the study.

Results and Discussion

The mechanism of break-up of the oil into ligaments and particles varied with engine speed. One such phase is shown in Figure 1, using an image from a high-speed video, for an engine speed of 1800 rpm. A series of consecutive, involute-shaped, ligaments were formed that remained attached to the trailing edge of the crankshaft web. At higher rotational speeds, larger, discrete droplets and fine clouds were observed. The oil particle size and velocity data, recorded using the PDA technique, typically exhibited broad distributions. An example of the axial and radial particle velocities and diameter histograms, recorded over consecutive cycles at a rotational frequency of 100 Hz are shown in Figure 2. The measurement point was coincident with the machined front surface of the crank and at the height of the crank axis. For all points, the maximum range of measured particle size was between 2 and 130 µm. The maximum mean oil particle velocities recorded were of the order of 25 ms^{-1}.

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Conclusions

The experimental study showed that the break-up processes in the engine crankcase varied with speed, spatial location, within an individual rotation and from one cycle to the next. Oil was expelled in a discontinuous manner along the circumference as a series of sinuous ligaments. At crankshaft speeds between 1,800 and 4,200 rpm, large, discrete particles were observed and at the highest speeds, a fine aerosol of oil particles filled the crankcase. Generally, away from the walls, the oil droplet-laden flows exhibited some steady flow behaviour, in phase with the fundamental and harmonic frequencies of rotation. For the upper limit of droplet sizes measured, the ratio of the droplet diameter to the characteristic crankshaft web diameter at which oil was expelled, *d/D* and the disk Bond number, Bo_D were shown to compare favourably with the universal power law for droplet generation by a spinning disk aerosol generator. It is thought that a better fit to the law may be achieved using a moment mean or equivalent diameter.

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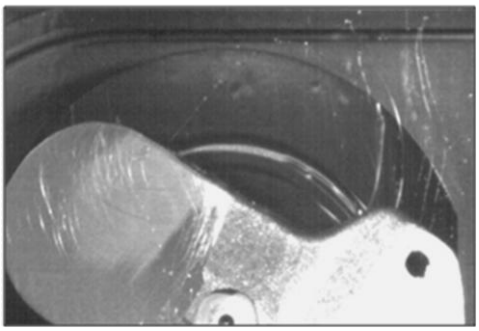

Figure 1. Break-away of multiple oil ligaments at 1800 rpm at change in diameter

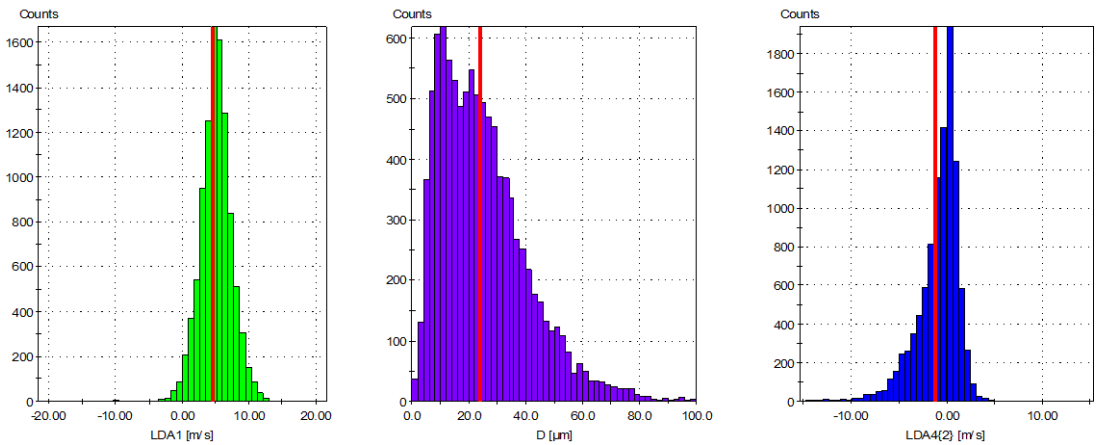

Figure 2. Distribution of axial velocity component (LDA1), droplet diameter (D) and radial velocity component (LDA4) at 6000 rpm at a location coincident with the crankshaft face