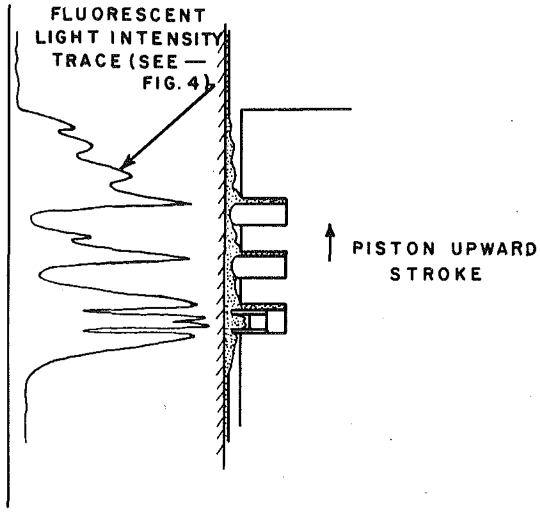

Fig. 11 Fluorescent light intensity signal trace and oil distribution pattern

engine oil consumption is not established presently, but there is no doubt that it is one of the important factors critically affecting the amount of the oil lost through the piston ring pack.

Based on the fluorescent light intensity trace shown in Fig. 4, oil distribution during an upward stroke motion may be qualitatively constructed as shown in Fig. 11. The magnitude of the piston ring oil film thickness is greatly exaggerated. This type oil distribution is generally in agreement with our visual studies using high speed movie technique. Improved trace resolution, using a smaller light spot size, is likely to show whether the piston rings operate under fully flooded or partially filled conditions. This probably can settle the argument as to what kind of oil film pressure boundary condition is the most reasonable for solving the Reynolds equation [13]. However, it seems that the use of Gumbel boundary condition gives more realistic piston ring oil film thickness prediction than the use of Swift-Stieber boundary condition [1, 2, 3, and 14]. On the other hand, double-sloped ring oil film pressure distributions measured by Brown and Hamilton [4] clearly show that hydrodynamic pressure is developed mainly in the convergent portion of the ring wedge. This indicates that it is acceptable to use the Gumbel approximation so far as the determination of the hydrodynamic load is concerned. The other obvious advantage of using the Gumbel approximation is that it is the easiest one to employ. As a matter of fact, the idea of the partially lubricated piston ring [4] does not seem to differ much from the assumption of neglecting the pressure change in the divergent portion of the ring wedge [1].

Finally, it must be pointed out that the present laser fluorescent method and the transparent sleeve engine apparatus offer the best possibility that the continuous piston ring oil film thickness change can be successfully and accurately measured. This could be done by developing a device which can move the laser beam synchronous with the piston so that the film thickness or clearance space oil accumulation at any given point of the piston can be measured for a complete stroke cycle.

V Conclusion

A laser excited oil fluorescence technique has been developed for measuring the oil film thickness change between piston rings and a transparent cylinder sleeve wall, as well as the oil accumulation in piston-cylinder clearance spaces. Consistent signals of oil fluorescence light intensity change representing the ring oil film thickness change and the clearance space oil accumulation variation, due to the passage of piston and piston rings through the laser beam path, have been obtained. Some typical light intensity signal trace results corresponding to engine speeds of 200, 400, and 600 rpm are presented. They clearly demonstrate how the piston ring oil film thickness changes with engine speed in agreement with the piston ring lubrication theory. They also show the nature of oil distribution in piston-cylinder clearance spaces and the skirt area which is of value in the future engine oil loss behavior studies. It should be easy to obtain quantitative data from these signal traces once the fluorescent light intensity is calibrated.

Acknowledgment

The author wishes to express his appreciation to Dr. J. E. Mayer, Jr. of Engineering and Research Staff, Ford Motor Company, for his suggestions and comments during the course of this study.

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DISCUSSION

S. L. Moore[1]

This is an interesting paper using a refinement of some of the techniques developed by the early workers referred to by the author. I feel, however, that the method is better suited to the study of oil consumption and oil distribution around the piston than it is to piston ring film thickness measurements. This is because the sensitivity of the measuring system is greatest when the oil film is thick, as between a piston and liner, and lowest when the oil film is thin, as between a piston ring and liner. This is the opposite to the electrical capacitance system with which the author compares his method. In addition, the capacitance system can be readily applied to a working engine which

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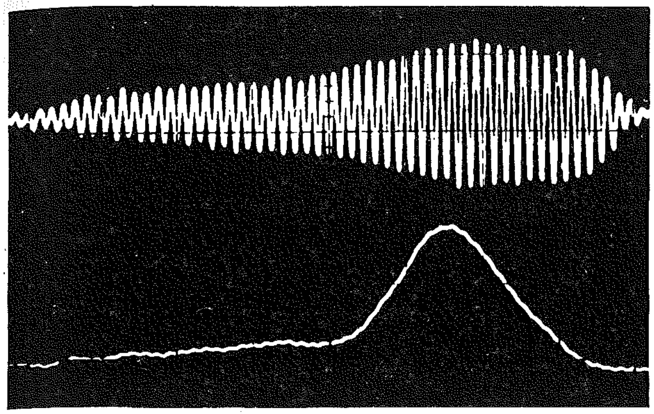

Fig. 12 Oscilloscope trace showing combined output from capacitance gauge (upper trace) and pressure gauge (lower trace). The delayed rise in pressure on the left-hand side shows oil starvation in the ring inlet.

would be difficult with the optical method as this relies on a transparent cylinder liner.

I would like to know what the resolving power of the optical system was. What was the spot size compared to the ring width? Also, how did the author overcome the problem of running in the piston rings in the rig? How was oil supplied to the rings, was it by conventional splash lubrication?

I look forward to seeing future publications from this work, in particular results from an improved resolving power system. As the author states, this should show the oil filling conditions in the ring inlet. Some of my own results from a combined capacitance/pressure gauge (see Fig. 12) show that the hydrodynamic pressure rise (lower trace) is delayed compared to the width of the piston ring (upper trace). This suggests that the inlet of the ring, which is on the left-hand side of the figure is highly starved of oil.

C. A. Foord[2]

It is pleasing to see new measurement techniques used in engineering research but disappointing to see oil film thickness measured in volts instead of microns. Has the author made any attempt to calibrate his system or assess its performance in any quantitative way. This type of system can have a frequency response to greater than 1MHz and very fine spatial resolution. The calibration is basically nonlinear and tends to a constant signal level with increasing film thickness if the concentration of fluorescent material is too great for the film thickness being investigated. In carrying out the stepped piston ring calibration as suggested by the author it would be necessary to make sure that the surface of the step is identical to that of the normal ring because the reflectivity of the surface does have a significant influence in the region of approximately linear calibration. This is anlayzed in reference [10].

Presumably the tests were carried out at room temperature or just above in which case the SAE 30 oil would be rather viscous for the representation of normal piston ring lubrication. Was any thought given to using a thinner oil to simulate the viscosity of hot SAE 30.

[2] Rolls-Royce Ltd., Derby DE2-8BJ, England

Author's Closure

The author wishes to thank the discussers for their useful and discerning comments. The remark made by Dr. Foord regarding the frequency response and spatial resolution of measuring system is certainly very welcome. Since the purpose of this paper is to introduce a new piston ring oil film thickness measuring technique and to demonstrate that it works, only the qualitative results are therefore presented. As mentioned in the paper, film thickness measured in microns should be readily obtainable once the fluorescent light intensity is calibrated. The author agrees with Dr. Foord that in carrying out the stepped piston ring calibration, the surface of the step must be made to be identical to that of the normal ring in order to maintain the same surface reflectivity.

The tests were indeed carried out at the room temperature, but we can also conduct tests at higher temperatures to simulate normal piston ring lubrication oil viscosities. This is because the crankcase section of this test rig has a built-in heating coil system so the oil can be heated to some high temperature levels as desired.

Dr. Moore's recent experimental results showing high oil starvation in the ring inlet region are extremely interesting. It is very kind of him to show one of the oscilloscope pictures. Perhaps additional experimental evidence supporting Dr. Moore's finding can be obtained by the use of some optical methods such as the one presented in this paper. Regarding the comment that our method is better suited to the study of oil consumption and oil distribution around the piston than to piston ring film thickness measurements, we are inclined to disagree. Based on our experience to use this method to measure the thin oil film thickness change in a wedge formed by two microslides and in light of Dr. Foord's comment, we believe that this method can work equally well for measuring the oil film thickness changes both between piston and liner and between piston rings and the liner.

The diameter of the light spot calculated using blue light wavelength, beam diameter, and the focal length of the lens was 0.1475 mm. The widths of the top ring, second ring and the oil ring segments are 2.368, 1.968 and 0.952 mm, respectively. We did not intend to use this rig to perform the piston ring running-in because the cylinder sleeve was made from a soft plastic material. However, we can use the rings removed from engines which have been in service and install them in this rig and study the effect of the ring face profile change on its lubrication behavior. Regarding the method of supplying oil to the piston rings, it was the conventional splash lubrication method.