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Testing lubricating oils by friction and wear tests on engines.

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Research

The properties of engine lubricating oils of equal viscosity which oppose friction and wear have not been investigated as fully as the exigencies of practical working require.

Tests were therefore made on single cylinder test bed engines under test conditions corresponding to the unfavourable working condition of an air-cooled engine at take-off or climb. Lubricating oils of the most varied origin or composition had only slight differences in friction behaviour, whereas the wear-inhibiting properties vary considerably.

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I. Reasons for the D.V.L. tests.

Every machine, and thus every internal combustion engine, has parts which slide against each other. The friction and material losses which occur - in spite of the presence of lubricants - at these points are so important for the efficiency and life of engines and their components, that it is necessary to know their exact magnitude. This calls for a clear and complete knowledge of the friction and wear occurring in engines or their components, which has seldom been possible up to the present, as generally speaking factors came into the picture which completely distorted the results. An American (1), with the exaggeration which is so common on the other side of the Atlantic summed up the position as follows:-

"There is so little reliable information about engine wear that it belongs in the same category as religion and politics." Also, "the problem of the lubricated surface dominates construction problems in the further developments of the modern aero-engine, and is the main factor imposing a limit on engine design(2)."

Also since the few published reports about the preservation of lubricating oils in the engine in practice are lacking in clarity, and it is by no means certain that the results obtained with lubricating oil test apparatus apply to other conditions, it was thought that engine tests made on a test bed might produce valuable information. These facts were the reason for carrying out engine tests on a test bed at D.V.L., so as to establish values for friction and wear by using various oils, and so rating the lubricating properties of the investigated oils.

II. Engine friction and wear tests made in other quarters.

Before discussing the D.V.L. tests, mention should be made of the friction and wear tests made in other quarters. These tests were intended to provide facts either about the effects of various influences, or about the lubricating points, and lubricants.

Thus, Williams (3) investigated the influence of engine temperature on cylinder wear, and Beck and Bopp (4) the effects of temperature and speed of starting on piston ring wear. At very low cylinder wall temperatures a corresponding rise in wear was observed. The lubricating properties of materials and the influence of the surface properties were investigated by Englisch (5), who found that the hardness of the cylinder liners is not in direct relationship to their wear behaviour. Tests by Bridgeman and Leidig (6) confirmed this, and also showed that the favourable effect of the surface quality is limited and indeed that a further improvement in quality may lead to roughening in service.

The influence of the viscosity of lubricating oil on engine power was tested at the I.G. Farben engine test station Oppan (7) and by Paul (8), and in both cases oils of different viscosities gave considerable differences in power. As regards the effect of different viscosities on the piston-ring and cylinder wear, Williams (9) found that there was a very slight reduction in wear with rising oil viscosity.

Bock (10) attempted to trace the influence of the ageing of lubricating oil on the process of running wear, and concluded "that the ageing of the oil which occurs during the running of the engine causes an increasing rate of wear."

Endurance tests were made by Bopp (11) at the same research station with lubricating oils of the same viscosity at 50°C to discover the influence of their different origin on wear, but no large or clear differences were observed. The addition of castor oil and colloidal graphite caused a certain reduction in the wear on the first piston ring.

Measurements by Boerlage and Gravesteyn (12) showed practically no difference in wear when different brands of oil were used under normal conditions.

A work by Vogelpohl (13) contains a reference in a foot-note, quoting Ruegenberg, to an investigation by Fenning, in which it was found that there was no difference in the piston ring wear as between working with a fatty oil and a corresponding mineral oil.

In conclusion, the results published so far of friction and wear tests have not entirely disposed of the problem of the lubricating properties of lubricants. Thus there is all the more reason for further work in thisdirection.

III. Engine friction and wear tests by D.V.L.

In view of the great scope of the investigations it is only possible here to refer to the more important features of the method and the measurements in the D.V.L. test.

A. Test Method

A critical appreciation of the test results obtained in other quarters led to the conclusion that tests in this direction, if they are to be successful, require more constant working conditions, and a more rigid exclusion of external influences. Since the one variable in the D.V.L. tests is the lubricating capacity of the various lubricating oils, it was necessary to be certain that apart from the working conditions the lubricating properties of the materials and the lubricating points should be kept constant.

This requirement could only be complied with to any extent in laboratory tests on a single-cylinder engine; therefore, in the D.V.L. the tests were carried out on three single-cylinder engines, one of them being a large single -cylinder aero engine.

In laying down the values to be measured, the main consideration to be taken into account was that the critical point as regards lubrication is the surface of the cylinder where it is in contact with the piston rings. A study of the test conditions led to the conclusion that the characteristic of the partial lubrication at this point is indicated by the proportion of high temperature boundary lubrication taking place. Therefore the decisive test condition chosen was the maximum thermal load on the cylinder which is caused in an air-cooled aero-engine during take-off and climb by the fact that in these two cases the engine must work at full power under inadequate cooling due to the reduction in the cooling air flow.

All the other test conditions were contrived so as to produce the most stringent conditions for the lubrication of the engine when under power.

The values measured were the friction-power and the wear of the cylinder, piston, and piston rings, and those properties of the lubricants investigated, which inhibit friction and wear, were assessed.

In order that these properties should appear clearly and without distortion, external influences such as pollution of the oil by foreign bodies from outside sources, corrosion during working, and especially during stationary periods, the influence of excess fuel in the combustion chamber, and so on, were eliminated.

On the other hand, it must be emphasised that these results are not characteristic of the momentary condition of an engine, but that they include the influence of changes in the oil due to the gradual formation of products of oxydation, and also the influence of engine wear.

Special attention must be devoted to the questions of engine cleaning and the fitting of replacement parts, as well as their running in.

The best measuring apparatus available and the most accurate measuring methods were used in order to make the results obtained as dependable as possible.

As already mentioned, the influence of variations in viscosity was to be eliminated by investigating lubricating oils with roughly the same viscosity. The oils selected and tested nearly all belong to the viscosity range 17-19°E at 50°C, corresponding to Rotring D, the aero engine lubricant which is in commonest use today. In such tests obviously it is not the viscosity at 50°C which is decisive, but the viscosity at the temperatures prevailing at the lubricating points. Under the severe test conditions prevailing, these were in the region of 150 to 300°C. The values, when entered in the viscosity-temperature table of Ubbelohde (Fig.1) show that at 150°C, the viscosities of all the oils investigated, apart from two synthetic lubricating oils, were about 1.4 to 1.5°E. The differences are, however, no greater than the tolerances of ±10% which are permissible at a temperature of 100°C.

B. Test results and their evaluation

The results of these very extensive tests can best be shown diagrammatically. These show, firstly, the results of the wear tests on the two smaller engines. Thus Fig.2 shows, that the amount of wear did not increase to any great extent in the Siemens oil-test engine as the spark-plug-ring temperature was raised.

Nor were the results of tests with different running times very satisfactory, and this is also true of the test runs with various oils under constant conditions, see Fig. 3.

There were similar, negative results in the tests on the N.S.U. single cylinder engine. The reproducibility was poor, and the differences when various lubricating oils were used were very slight, Fig.4.

The reason for the not very satisfactory results of the tests on the two smaller test engines is to be found in the small amount of wear, since under these conditions the moving rings are fairly well cleaned with the removal of very little weight of material but with pronounced effect on the test results. Also, the small piston rings are only manufactured with a moderate degree of accuracy. On account of this all further tests at D.V.L. were carried out on the large single cylinder BMW.132 aero-engine. On account of the greater dimensions of all the parts, it was easier to regulate the working conditions and to keep them constant. Moreover, the parts are very accurately made, and the friction and wear are much higher than in the smaller engines.

Firstly, the results of wear measurements on the BMW.132 single cylinder are shown. Fig. 5 shows the wear as a function of running temperature, and Fig. 6 shows the wear of individual parts as a function of running time.

Fig. 7 shows similar curves for the total wear of all the piston rings.

Still more revealing is the dependence of hourly piston ring and cylinder wear on the running time, Figs. 8 and 9.

To obtain a standard of comparison for the numerical evaluation, the properties of the common aero engine oil Rotring D were given the arbitrary wear-prohibiting value 50; a theoretical, ideal lubricant, such as would entirely prohibit wear in the engine, was given the value 100. The wear-prohibiting values of all the lubricating oils tested were calculated and compared.

Fig.10 shows the results of three runs with Rotring D, and Figs. 11 to 13 show the anti-wear rating of several other lubricating oils.

Fig. 14 shows that with some oils the results agree well as regards the wear of individual parts.

Figs. 15 and 16 which represent the wear on different engine parts, give a good indication of the differences between the individual lubricating oils tested.

An evaluation on the basis of the total wear on all the piston rings gave by far the best reproducibility, so that this result was eventually regarded as the crucial one for final assessment of the lubricating oils. Fig. 17. This diagram shows that when colloidal graphite is added to Rotring D there is an increase in the anti-wear value from 50 to 88. The best value was that obtained with Kompressol weiss, which can be considered as practically pure castor oil. Aero Shell Mittel also gave a very good value of 91; it has a fatty oil content of about 4%. The aero-engine oil Stanavo 100 and the mixed oil NP_2 had only slightly less wear than Rotring D, as is shown by their values of 51 and 55. On the other hand, the synthetic lubricating oils A and B are very favourable, with values of 66 and 90. The worst wear-prohibiting value was that of 23, which was found with the captured oil Gulfpride. The common refined machine oil DA 200 had a value of 91, which shows that crude oils when mildly treated have good lubricating properties; on the other hand, the light Diesel lubricating oil SDR 200 showed by its moderate value of 41 the results of a high degree of refining. The wear-resisting values of used Rotring D showed that ageing by a high thermal load can improve the wear-resisting properties of a lubricating oil.

Figs. 18 to 21 give a very good idea of the wear occurring at the piston rings; these show the running surfaces of the piston rings before and after test runs with various lubricating oils.

Results of some tests are included, which show friction horsepower with various lubricating oils. Figs. 22 and 23 give the corrected values of brake horse powers (at 20°C and 760 mm Hg) obtained from the measured values, and the friction horse powers.

The results show that the differences in the friction resisting properties of the ordinary aero-engine-and other- lubricating oils of about the same viscosity, were, with one exception, not accompanied by differences in engine power greater than the ordinary working variations of a few per cent.

On the other hand, the differences in the wear resisting ratings obtained from the cylinder- and piston-ring wear measurements are very great, and their reproducibility is adequate for testing and assessing the wear resisting properties of aero-engine lubricating oils, Fig. 24.

By comparing the wear-resisting values with the results of tests to determine the tendency of lubricating oils to ring-sticking, Fig.25, it is possible to prove that in most lubricating oils good wear-resisting properties and good high temperature stability are mutually opposed. Only one synthetic lubricating oil is an important exception to this rule.

Summary

The friction and wear measurements which were carried out at D.V.L. on several single-cylinder test engines, using various lubricating oils of approximately equal viscosity, were briefly described, and by means of tests on a large single cylinder aero-engine, it was shown that it is possible to rate the wear-resisting properties of lubricating oils on the basis of such an engine test, as well as to determine the differences in friction properties.

Titles of Diagrams

Fig.1 Viscosity - Temperature chart of oils tested.
Fig.2 Wear Tests on Siemens Oil Test Engine.
Fig.3 Wear values from test runs with various oils on Siemens Oil Test Engine.
Fig.4 Results of Wear Tests on NSU Engine.
Fig.5 Wear in Relation to Running Temperature.
Fig.6 Wear in Relation to Running Time.
Fig.7 Wear in Relation to Running Time.
Fig.8 Hourly Ring Wear in Relation to Running Time.
Fig.9 Hourly Cylinder Wear in Relation to Running Time.
Fig.10 Wear-prohibiting values obtained from test runs with Rotring D.
Fig.11 Wear-prohibiting values from test runs with Rotring D (average value) and Rotring D + graphite.
Fig.12 Wear-prohibiting values from test runs with various lubricating oils.
Fig.13 Wear-prohibiting values from test runs with various lubricating oils.
Fig.14 Wear-prohibiting values of lubricating oils, calculated from the wear on various parts.
Fig.15 Wear-prohibiting values of lubricating oils, calculated on the basis of the wear on the first piston ring.
Fig.16 (left) Wear-prohibiting values of lubricating oils, calculated on the basis of the wear on the cylinder running surfaces.
Fig.17 Wear-prohibiting values of lubricating oils, calculated on the basis of the wear on the cylinder running surfaces.
Fig.18 Running surface of the first (upper) piston ring.
Fig.19 Running Surface of the first ring at the thrust.
Fig.20 Running surface of the 2 piston ring.
Fig.21 Running surface of the second ring at the thrust.
Figs.18 to 21. Running surface of piston ring before and after test runs with various lubricating oils.

1. new ring. 2. compressol white
3. Rotring D + graphite 4. Rotring D.
5. Gulfpride.

Fig.22 Brake Horse-Power with various lubricating oils.
Fig.23 Friction Horse-Power with various Lubricating Oils.
Fig.24 Comparison of Wear Resisting Values and Brake Horse Power.
Fig.25 Comparison of Wear Resisting Values and Temperature Stability Values.

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