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Investigation into the stability of aero-engine lubricants at low temperatures

Oppau Report No. 453

Synopsis: Tests were carried out to determine the conduct of greased journal and ball-bearings at low temperatures. Both types of bearing were installed in the I.G. cold box and in Schweiger's apparatus. In the I.G. cold box the same order in quality of performance was obtained with both types of bearing. The same order also resulted when using Schweiger's apparatus but only for journal bearings, using peripheral speeds approaching those employed in the I.G. cold room. It was moreover necessary to use a smaller shaft and larger suspension loads since the standard shaft and load produced only very low shearing speeds, resulting in a totally different order of merit. The tests on ball bearings carried out in the Schweiger machine produced only approximately the same order as that obtained with the I.G. cold box. Ball bearings yielded more widely divergent results in both the cold room and the Schweiger's apparatus.

Object of the Tests

The I.G. cold box and Schweiger's apparatus showed close agreement of results when oil was under test, whereas vastly different results were obtained for grease. The object of these tests was to clear up these contradictory experimental results in the case of grease; and furthermore to contribute towards the development of suitable test methods for aero-engine lubricants.

Description of apparatus:

The I.G. cold box was used as testing machine, and a schematic diagram is reproduced in illustration No.1. With its aid it is possible to determine the force required to turn a shaft moistened encased in a journal lubricated with the lubricant under test. Measurement here takes place at the moment when the shaft is suddenly set in motion. From the maximum value of the force recorded on the indicator and knowledge of the lubricated area (circumference x length of journal), the friction drag is is obtained in kg/sq.cm. For a detailed description of the I.G. cold box see Report No. 269 of the "Technical Test Laboratory". The testing of grease, however, is suitably carried out not only in journal bearings but also in ball bearings. For this purpose two double-sided ball bearings SKF.1305, 25 ∅/62∅ x 24, are installed (Translator's note, ∅ stands for "diameter").

The low-temperature viscometer (built on the design produced by Schweiger) is available as a further testing machine. Shaft and journal (80 mm diameter, 0.06 mm allowance for lubricating film) are vertically arranged in this case (illustration No.2). The shaft is set in rotation by means of a hanging weight (standard 900 gms), the rope of which passes over a horizontal pulley wheel. When the weight has travelled over a certain initial distance, the time required for half a revolution to take place is measured. A more detailed description of the Schweiger viscometer will be found in the reference books quoted.

For the testing of grease lubricants a small shaft having a journal length of 25 mm and 0.12 mm play was made in addition to the standard shaft. Instead of these two journal bearings it is possible to install two ball bearings, SKF. 2207 35∅ x 72∅ x 23 combined in a single casing, in the apparatus.

Method of Test

1. I.G. Cold Box

The shaft was smeared with the grease under test and was installed in the machine together with its journal. In order to obtain identical conditions for all trials the shaft was rotated by the motor for a period of 10 secs; the tank was then brought to the temperature at which the test was to take place and this was maintained for 1 hour. At the end of that time the motor was started and the claw clutch let in, thus causing the film of lubricant to break free. The greatest measured movement of the indicator thus obtained formed the basis of subsequent calculations. The temperature of the tank was then raised electrically, the tank opened and the bearing removed. Fresh grease was applied and the procedure repeated.

Ball bearings were tested in a similar way. The ball races were completely filled with grease, rotated 10 times at room temperature and then cooled. Heating took place at the end of the trial but the bearings were not removed: instead, the temperature was kept at 25°C for ½ hour's duration. After a further 10 revolutions the bearing and shaft were again cooled for a further test, without fresh grease being applied to the bearing.

2. Schaiger's Viscometer

The journal having been smeared with the grease under test, the apparatus was assembled. The shaft was then rotated twice and the testing gear cooled to the lowest experimental temperature. This temperature was maintained for half an hour, using a contact thermometer, and the test proper was then carried out. The next temperature selected was higher and was obtained by switching off the freezing plant, and gradually warming the apparatus. Again the temperature was maintained for half an hour before the test. Further tests at constant temperature were carried out, at intervals of half an hour each, but it was impracticable in this case to renew the grease at the termination of each test. The tests carried out, using ball bearings, were conducted in a similar manner.

Five aero-engine lubricants provided by the Luftwaffe Research Station in Travemunde were subjected to the test: their properties are given in the table.

Table 1

No. of Lubricant	1	2	3	4	5
Type of grease	Standard aero-engine grease				
Detailed Classification	Aero-grease blue	1416 blue	1417	Cal. K	Cal. 129
Manufacturer	Rhenania Osseg	Irteva	Irteva	Calypsol G.m.b.H	Calypsol G.m.b.H
Drop point °C	104	96	92	97	145
Neutralisation Factor	3.0	2.6	0.7	0.2	0
Gumming Factor	6.0	2.9	2.0	2.2	0
Ash %	1.84	2.06	1.08	3.96	1.60
Water %	0.25	0.25	0	4	0

Results:

1. Tests carried out with journal bearings

The first results obtained in the I.G. cold box are shown in illustration No.3. From this it is seen that grease No.4 shows the greatest amount of frictional drag followed by lubricants Nos. 1, 2 and 3. Grease No.5 produces a graph crossing those produced by 2 and 3.

The results obtained in Schwaiger's apparatus using the standard shaft and load are in direct contrast to those just mentioned. Illustration No.4 shows the results obtained in centipoises, calculated from the expression Viscosity (in cp) = time (in secs.) x coefficient of the apparatus ($\frac{g}{cm.sec.^2}$). It can be seen that only grease No.5 retains its former position in the list over the higher range of temperatures, while all the other lubricants are now arranged in a different order. At first, these contradictions were puzzling since when oils were tested both pieces of apparatus yielded results that were in good agreement, and since both are similar in principle. They differ considerably in one respect, however, viz. that the circumferential speeds produced are quite dissimilar. The results shown in the graph were obtained in the I.G. cold box using a peripheral speed of 18.8 cms/sec., while in the Schwaiger apparatus that speed was less than 4 cms/sec. It seemed reasonable to suppose that this might account for the discrepancy between the results obtained. Preliminary tests of short duration were carried out with the Schwaiger viscometer at a temperature of 0°C., using double the standard weight (1800 grammes as compared with 900 gms.). In these it was found that grease lubricants do not in any way obey the law whose validity is assumed in the Schwaiger viscometer. With an ideal liquid this doubling of the weight ought to result in twice the peripheral speed being obtained. In the case of oils this conformity with the law is easily and quite satisfactorily established but in the case of grease lubricants the speed is increased manifold.

In order to investigate this phenomenon more closely and at lower temperatures it would have been necessary, when using the standard bearing, to employ very high loads. A second shaft was therefore made which had a play of 0.12 mm on the standard journal, and a journal length of only 25 mm so as not to subject the apparatus to undue strain (see illustration No.2). Using this shaft and the standard journal the five grease lubricants were again tested, employing weights of 0.5, 1.5 and 3 kg., producing a torque of 1.75, 5.25 and 10.5 cm.kg., respectively.

The results are shown in illustration No.5. It is seen that a torque of 1.75 cm.kg. produces a series corresponding to that first obtained when expressed in centipoises. The peripheral speeds developed range from 0.1 to 0.001 cm/sec. Using three times the previous torque, i.e. 5.25 cm.kg. the speed is not trebled but becomes about 100 times as great, resulting in a completely different assessment of the properties of the grease lubricants. Their order very nearly, but not quite, corresponds with that obtained in the I.G. cold box. A further increase in the torque from 5.25 to 10.5 cm.kg. actually results in the order expected (see illustration No.2). Particularly remarkable is the behaviour of grease No.2 which at a torque of 1.75 cm.kg. occupies by far the highest position, sinks to second place with a torque of 5.25 cm.kg. and finally occupies the third place with a torque of 10.5 cm.kg. On the other hand, grease No.5 occupies the same position in all these trials.

Two conclusions may be drawn from these tests:

1. The expression underlying Schwaiger's apparatus,

$$P = \frac{p.F.v.}{h}$$

where P = frictional resistance in kg.; p = kinematic viscosity in $\frac{kg.sec.}{m^2}$

F = wetted area in m^2: v = peripheral velocity in m/sec: h = thickness of lubrication film in metres.

obviously no longer applies, for the frictional resistance P and velocity v must remain in direct proportion for the expression to be correct, a condition which is not fulfilled in the case of grease lubricants, the reason being that grease is not a fluid and consequently the question of viscosity does not arise. The relationship stated above is derived from the law $P = p.F.\frac{dv}{dh}$ and applies only when $\frac{dv}{dh} = \frac{v}{h}$, i.e. when linear distribution of velocity may be assumed throughout the lubricating film. This is the case where an ideal liquid is concerned and is very nearly true for oils. But with grease lubricants the relationship no longer applies and a different velocity distribution must therefore be assumed.

2. Furthermore these tests lead to the conclusion that the various grease lubricants behave very differently at different speeds. For instance, grease No.2 is particularly strongly affected in that respect, in contrast with grease No.5. This difference in behaviour may be attributed to the internal structure. Thus grease No.5 appears to be of especially homogeneous and oil-like structure, though it was not possible to establish a connection between this deduction and analytical data obtained. It would be instructive to check the manner in which the numerous

grease lubricants react at various shearing velocities, but an investigation into that sphere must be left until later.

Having succeeded in approximately synchronising the results obtained with the I.G. freezing tank and Schweiger's apparatus by raising the loads and hence the peripheral speeds in the latter; it ought to be possible, in reverse, to bring those obtained with the I.G. freezing tank into accord with those yielded by Schweiger's apparatus, by reducing the peripheral speed (see illustration 3).

It was found that a reduction of speed from 18.8 cms/sec. to 6 cms/sec. produced no appreciable change (see illustration No. 6). Several preliminary tests at 2 cms/sec. led one to expect a similar absence of variation. A further reduction of the peripheral speed would undoubtedly result in the anticipated shifting in the order of quality but the forces that would be met with are unsufficiently great to be capable of measurement with the indicator available.

The assessment of the five grease lubricants, based on tests with the journal bearing, is shown in table 2, results obtained with both instruments being given. The temperature of -25°C. was selected since results at this temperature were available for both pieces of apparatus. From this table changes in the order of quality brought about by a variation in torque, is clearly visible. Incidentally it is noticed that the arrangement in order of quality obtained with a greater torque in the I.G. cold box and Schweiger's apparatus agrees with that in order of water content.

Table 2

5 grease lubricants arranged in order of quality, using journal bearings, in Schweiger's apparatus and the I.G. cold box, at a temperature of -25°C.

	Schweiger's Apparatus				I.G. Cold Box		Water Content	
	Length of shaft 49 mm	Length of shaft 25 mm			Peripheral speed cms/sec.			
	Torque in cm. kg.							
Grease No.	3.15	1.75	5.25	10.5	18.8	6.0	Order	%
5	5	5	5	5	5	5 or	5 or	0
1	1	3	3	3	3	3	3	0
4	4	1	2	2	2	2	2 or	0.25
3	3	2	1	1	1	1	1	0.25
2	2	4	4	4	4	4	4	4

2) Tests carried out with ball bearings

Generally speaking, the order obtained in tests carried out with ball bearings in the I.G. cold box was the same as that obtained with journal bearings (illustration No. 7). As might have been expected, however, the experimental points, when plotted, are considerably more scattered: nevertheless, an indisputable differentiation between the lubricants was possible. The forces met with were so small, however, that they were hardly recordable above a temperature of -30°C.

On plotting, the trials with Schweiger's apparatus also produced greater scattering of experimental points, mainly caused by the unevenness with which the suspended weight turned the shaft when released. Here the turning action does not take place with constant angular velocity as it does in a journal bearing, but is unsteady, producing acceleration and retardation of the motion at random. This was particularly evident in the case of grease No.2 which produced a motion so unsteady that no useful measurements could be obtained.

Tests with a torque of 0.875 cm.kg. yield only approximately the same arrangement of the lubricants as that obtained with the smallest load in journal bearings (cf. illustration No. 8). An increase of the torque to 1.4 cm.kg. once again pushed grease No.4 to the first place (illustration No. 9). A further increase in the suspended load was not possible as the time taken by the wiehgt to drop became too short for measurement. It may, however, be assumed that if such trials had been possible the same judgement of the lubricants would have been provoked as that pronounced in the "breaking" tests in the I.G. cold box.

Conclusion

The tests show that there is very close agreement between the "breaking" tests in the I.G. cold box and the trials carried out with the Schwaiger apparatus, when higher peripheral speeds are employed. Completely different conditions, however, prevail when the peripheral speed falls below approximately 2 cms/sec. as is quite usual in the case of Schwaiger's apparatus.

As far as the "break" test is concerned, at least, there is close agreement between the tests on journal and ball bearings. The test using journal bearings is perhaps to be preferred on account of its greater consistency regarding results: while the unsatisfactory conduct of ball bearings for test purposes is particularly noticeable in the tests carried out with Schwaiger's apparatus.

The tests in the I.G. cold box probably bear the closer relationship of the two, to conditions met with in actual practice. The measurement of viscosity obtained in Schwaiger's apparatus when using a small turning moment can hardly be of importance as regards its bearing upon the problem dealt with, as the forces met with are extraordinarily small.

Illustrations

1. I.G. cold box.
2. Schwaiger's low temperature viscometer
3. "Breaking" tests with the I.G. cold box.
4. Tests with Schwaiger's apparatus.
5. Trials with Schwaiger's apparatus using different turning moments.
6. & 7. "Breaking" tests with I.G. cold box.
8. & 9. Tests with the Schwaiger apparatus.