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by
Dipl. Ing. R. Halder

An Apparatus used to Determine Metallic Abrasion during Lubrication.

Synopsis:

The apparatus described permits the metallic abrasion on lubricated surfaces in rubbing contact with one another, to be measured. The results obtained are repeatable and enable easy differentation between the various lubricants to be made. in particular, surface active measures: e.g. vegetable oils produce the greatest amount of metal abrasion. The degree to which abrasion depends on the various metals is very considerable. A relationship can be found between metal abrasion and friction coefficient, from which, within certain limits, a low coefficient of friction may be deduced from a high amount of abrasion, and vice versa.

Object of the Tests:

The tests on wear (c.f.reports Nos. 478 and 518) have shown that, apart from the lubricant, the results depend on a great number of factors and that the problem of metallic abrasion during lubrication still requires further clarification. It was recognised that complex phenomena of this nature are incapable of investigation by means of one single apparatus which can only cover a limited part of the subject. The apparatus described below was consequently developed to complement the machine employed to produce wear, which is already available.

Arrangement of Apparatus:

The apparatus works on the principle of the Skoda-Sawin machine (illustration 1). A disc of 29.6 m/m diameter and 2 m/m in width is rotated by means of a motor equipped with toothed wheel drive and variable transmission. The disc is made of a hard metal, "Titanit G.1.", and was made by the Deutsche Edelstahlwerke A.G. of Frankfort-on-Main. A test cylinder of 106 m/m diameter which may be made of various materials is pressed against the disc. The load is applied through a bellcrank lever having a 1:3 ratio. The test cylinder and the bellcrank lever together with the load may be moved in an axial direction by means of an adjustment screw. In this manner the grinding cuts made during the test may be arranged next to one another, so that for each test a new face of the cylinder is available for testing. Moreover the cylinder may be rotated by $^1/_{32}$ part of its circumference so that altogether 32 x 14 = 448 cuts may be made per cylinder. An oil container is fixed above the hard metal disc from which the lubricant under test, drops on to the point of contact to be lubricated. A spring-loaded felt pad, held against the disc, serves to remove the abraded particles.

Method of Test:

Three different speeds of revolution were employed during the tests viz. 70, 210 and 560 Revs./min., corresponding to circumferential speeds of 10.8, 32.5 and 86.7 cms/sec. respectively. Loads Q ranged from 1 to 8 Kg. As the pressure exerted by the bellcrank lever on the hard metal disc amounts to 1 kg., the actual test load was (P = 3 x Q + 1). The disc was set in rotation unloaded, the oil supply was adjusted to from 8 to 10 drops per min. and the load was then applied to the disc. At the end of the testing period, in most cases fixed at 10 mins., the load was removed before stopping the disc. The felt pad was cleaned and dried, and a new surface portion of the cylinder was adjusted for the next test. On terminating the series of tests the cylinder was dismantled and the length of the cuts determined by means of a measuring microscope, the volume of abrasion being calculated from the length of the cut. A rectangular section of the disc was assumed, thus ignoring a radius of 0.5 m/m given to the edges of the disc. It is then found that a connection exists between the measured length of the chord and the volume ground off, as shown in illustration No. 2. The specific surface pressure was calculated on the same assumption, and this is demonstrated for a series of different loads (ill. No.3). From this it is seen that the initially high surface

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pressure decreases very rapidly into an order of magnitude found in actual practice.

Results:

Illustrations Nos. 4 and 5 show the resulting abrasion in relation to load, for tests carried out over different intervals of time. As might have been expected the volume of abrasion increases with rising load, resulting in slightly bent S-shaped curves which apparently tend to reach a certain limiting value at very great loads. Viscous hydrocarbon oil H 140, compared with non-viscous H 16, produces less abrasion especially in the low-pressure region from which it may be concluded that in that region the effect of viscosity is still noticeable. At higher loads the difference becomes less, and extrapolation of the graphs even leads one to suspect a reversal of the results. In Illustration No. 6 the large amount of wear encountered with the use of bone oil, is particularly striking. As in the Wear machine (cf. Reports Nos. 478 and 518), the lubricants which are specially surface active produce much abrasion also in this case. A decrease in the number of revolutions from 560 to 210 revs/min. (illustration No. 7) changes the general picture only with regard to the depth of the cut which diminishes approximately in proportion to the speed. This fact is not at all self-evident and thus demands closer investigation.

Tests at different speeds and of varying duration were carried out with H 16, H 140 and bone oil, the volume of abrasion being plotted against the total number of revolutions made per test: the results are as shown in illustrations Nos. 8, 9 and 10. In the case of H 16 the curves obtained with different numbers of revolutions nearly coincide, i.e. the depth of the cut depends solely on the distance travelled and is almost independent of the speed at which this distance is covered. In the case of H 140 a high number of revolutions causes an increase in abrasion and the same tendency may be observed in bone oil. Presumably this may be attributed to the higher temperature developed around the lubricated spot at higher speeds. It illustrates the fact that no conclusions can be drawn from circumferential speed and load alone, as regards the state of lubrication. In a normal bearing at a circumferential speed of 86.7 cms/sec. and the loads met with under such conditions, one expects to find hydrodynamic lubrication without any wear. Limiting friction, coupled with wear, is only met with at lower speeds. In this particular case, however, there can be no question of hydrodynamic lubrication, and one might perhaps be inclined to explain the phenomenon as follows. At the start of the test the pressure at the lubricated portion is very high, limiting friction takes place and produces abrasion. With increasing running time, though the specific surface pressure decreases, the expected hydrodynamic lubrication does not take place nevertheless as the metal particles sticking to the test disc, which can never be completely removed, support the continued wear through abrasive action. The inaccuracy of this assumption is proved by the following test. A test with Wehrmachtseinhert oil was interrupted after 10 mins., the length of the cut was measured (6.9 m/m) and all parts were carefully freed of metal particles sticking to them. The load was then reduced, so that a specific surface pressure of only 13 Kg/sq.cm. was obtained on calculation. Despite the reduced load and the purity of the lubricant, abrasion proceeded when the test was continued on the cut already ground out. The above explanation is therefore erroneous. The reason for the absence of hydrodynamic lubrication must presumably be sought in the roughness of the disc and the geometrical shape of the cylinder portion under test. While there is always a certain amount of play on a bearing, allowing the formation of a lubricating film, in this case the shaft, represented by the disc, creates its own bed, the resulting cut forming an exact fit for the shaft. This perfect fit prevents the creation of a lubricating film at the point requiring lubrication, which would be sufficiently strong to guarantee hydrodynamic lubrication. These tests, therefore, show that with this apparatus the region of limiting friction coupled with metal abrasion becomes prevalent.

Apart from the state of lubrication, the repeatability of the results obtained in the tests is of interest. With this apparatus the latter depends on the uniformity of material, oil-feed and removal of metal detritus and furthermore on the variation in the roughness of the disc surface. The first three requirements can be met comparatively easily so that repeatability depends above all on the manner in which the condition of the disc changes in course of time. It was found that after more than 1000 tests, using all kinds of materials and lubricants there is no inconsistency of

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results, proving that the disc has retained its roughness. Several results obtained with various lubricants are demonstrated in illustration No. 11, vide. From illustration No. 11 it is seen that very considerable differences are obtained between the measurements taken. Like bone oil, rape oil also produces a very large amount of abrasion while castor oil shows such behaviour only with very high loads. Fairly similar results are produced when using E 426. E 515 and S-ester behave almost the same, whilst a mixture of the two is noticeable on account of the strong abrasion it produces: it is thus a case of an effect produced by mixing, which in the case of this lubricant was also observed in other test apparatus. If this investigation is carried out on cast iron instead of steel, a noticeably different set of conditions is obtained. In this case the action of castor oil is already more clearly defined, likewise that of E 426. Bearing metal consisting of tin, lead and antimony with traces of sulphur, shows strong abrasion, especially in the case of sulphur-containing oils, while here the vegetable oils show a reversal of behaviour. Similar characteristic curves result from the use of castor oil, rape oil and E.426 on bronze (copper plus approx. 10% tin and 10% zinc) (see illustration 14), where the highest values are those obtained with castor oil. Owing to its affinity to copper, a high amount of abrasion can be expected from S -ester in this case. Judging from the shape of the graphs this only takes place with higher loads, the higher temperatures thus produced strongly increasing the activity of the sulphur. Similar conditions to those applying to bearing metal also apply to light alloy (illustration No. 15). The small abrasion caused when using castor oil is remarkable. Above all, these results are meant to show that the solubility in these tests is very considerable and that this method produces great differences between the various lubricants.

The effect of additives is shown in illustrations 16 and 17. For instance, while in the case of the "Kettenmaschine" (cf. Report No. 512) the addition to refrigerator oil of 5% rape oil produces a considerable lowering of the coefficient of friction, the effect now becomes less apparent. Illustration No.17 shows results obtained when using "Wehrmachtseinheits oil" with and without additions. "Autokollag" is completely ineffective here, while on the other hand the addition of 2% of an organic sulphur compound produces a considerable increase in abrasion. The effect of 2% fatty acid is most surprising: judging by results obtained so far one should have expected an increase in the size of the scars, while the opposite was actually the case. In order to explain this state of affairs more clearly further tests with variations in the quantities added, are desirable.

The particularly great dependence of the results on the test materials was noticeable in the tests illustrated in drawings Nos. 11,12,13,14 and 15. Consequently the effect of a large number of lubricants on five different materials was tested and the results are grouped in illustration No. 18. The order in which the various lubricants are arranged is that in which the results were obtained on the steel cylinder, rape oil occupying the last place, as it produced the largest scars. Using cast iron as test material, in contrast to steel, there are considerable changes: although rape oil still occupies the last place on the list, S - ester now occupies the first. Using bronze, the highest abrasion is obtained with BH 4, in direct contrast with the result obtained on a steel cylinder. Castor oil, too, is now distinguished by increased abrasion, and likewise again, rape oil. IK 2200 produces the least amount of abrasion while the greatest differences between the various lubricants are manifest in the case of light alloy. In this case LK 2200 and M 620 in particular are distinguished by high abrasion, followed by S - ester and SS 902 F 25. In the case of bearing metal the sulphur content in particular furthers metal abrasion. From these tests it is seen that it is impossible to pronounce judgment of any kind on the behaviour of a lubricant as regards wear, without keeping the bearing material in mind. A somewhat curious question crops up in that connection: in order to be favourably assessed, should an oil produce a large or small amount of abrasion on a certain material? In reply it must be stated that going on experience so far obtained, high abrasion under the conditions of the above testing machine must be considered a favourable sign. High metallic abrasion in this apparatus leads one to suppose that in practical cases the mutual "running-in" of rubbing surfaces would take place particularly soon. This would therefore result in a more rapid switch from a state of limiting friction to that of "semi-fluid" and, eventually, "fluid friction". The correctness of this method of assessment is demonstrated by the cases of rape

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oil, bone oil and castor oil which in actual practice are known to provide satisfactory lubrication but produce a very deep cut on almost every metal when tested in this apparatus. This phenomenon can possibly be explained by saying that the oil particles show greater adherence to the metal than to one another and will therefore tear metal particles from the surface when a rubbing action takes place.

Characterisation of the ability of oil to adhere to metal is, however, also attempted in the coefficient of friction, measured in the region of boundary lubrication, and actually a low frictional coefficient is believed to denote a high capacity for adhesion. If both assumptions are correct there must be a certain relation between the size of the cut and the coefficient of friction. In illustration No. 19 the volumes of the cuts in steel, at 560 revs/min and under a load of 16 Kg. are plotted against the coefficients of friction as obtained with the "Kettenmaschine" at 50°C, using 35 synthetic esters as well as neatsfoot oil and rape oil. From the graph it is seen that the experimental points are scattered over an area ranging from a region of small cuts and high coefficients of friction down to a region of large cuts and low coefficients of friction. It is obvious, therefore, that there is a certain connection. This would perhaps be even more apparent if it were possible to employ a similar pairing of materials in both pieces of apparatus. This relationship, however, which was found in the case of chemically similar materials, does not permit, at the present state of investigation, of any generalisation embracing all types of lubricants. It is altogether questionable whether the purely physical explanation of the phenomenon of metal abrasion, as given above, suffices. It must rather be assumed that chemical actions come into play, perhaps even to the greater extent of the two, an opinion based on various observations. The colouration of the cuts differs very greatly with the various lubricants, particularly when the cylinder is made of light metal or bronze. In some cases, too, it may be seen with the naked eye that the particles ground off, are not always metallic, but may for instance be in the form of metallic sulphide. These events suggest that the chemical attack of oil on metal during the abrasive action is of importance, and it must be borne in mind that at the lubricated portion both oil and material are not only under high pressure but also at high temperature, both of which are factors which greatly speed up any chemical interaction.

In conclusion it may be said that the apparatus described above is a valuable addition to the oil testing machines in existence. Despite its simplicity of construction and ease of handling it yields enlightening information on the mutual action between metal and lubricant. It appears probable that the apparatus will presently be also available for the testing of cutting oils, but a closer investigation into that possibility is still in progress.

Illustration No.	Title
1	Grinding Mechanism.
2) 3)	(Volume of cut, specific surface pressure (and length of chord.
4) 5) 6) 7)	Wearing Tests: disc made of hard metal, against steel 560 revs/min. oil temperature 20°C. Y-axis: vol. of cut X-axis: load
8) 9) 10)	Disc made of hard metal; against steel Load 16 Kg. oil temp. 120°C. Y-axis: vol. of cut; X-axis: total no. of revs.
11	Hard metal disc against steel. Duration of test 10 mins. Y-axis: vol. of cut. X-axis: load.
12	Hard metal disc against cast iron. Duration of test 10 mins. oil temp. 20°C. vol. of cut plotted against load.
13	Hard metal against bearing metal plot: volume against load.

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Illustration No.	Title
14	Hard metal against bronze: 10 mins.: 20°C. cut volume against load.
15	Hard metal against light metal cut volume against load.
16) 17)	Hard metal against steel: 10 mins.: 20°C. cut volume against load.
18	Wear of various metals, using different lubricants: Hard metal against steel.
19	Coefficient of friction and abrasion. X-axis: abrasion of steel 16 Kg. load 10 mins. Y-axis: friction No. from Kettenmaschine at 50°C.