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Wear and Friction Tests.

by.

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Synopses:

Following some tests on metal abrasion it was found that a change in the degree of roughness does not only produce a change in the quantity of abrasion measured, but may also arrange the lubricants in a new order of merit. It is also shown that there is a relation between metal abrasion and seizure: the heavier the abrasion, the smaller the tendency to seizure.

Trials with engine oils containing additives, made it clear that the deductions made from results obtained in testing apparatus have a bearing on actual conditions met with in practice, only if certain definite conditions prevail. Quite apart from the employment of approximately similar materials, one of the fundamental conditions for good agreement appears to be that the temperature should correspond to that met with in practice.

Wear and Friction Tests.

The observations described below have been made during routine tests in the course of the last 8 years. Although it is desirable to carry out systematic trials, the fact is that the testing gear was required for priority investigation of current production problems, thus preventing the adoption of an organised test schedule. In these investigations, some of the phenomena which occurred from time to time were of particular interest to those interested in the problems of lubrication and they are therefore considered worth recording. For instance, in the investigation of cutting oils interesting relations were discovered between abrasion of the metal, and degree of roughness; or when testing motor oils, a relationship could be established between abrasion and seizure. Quite apart from, and in no connection with these tests, an account will be given of trials dealing with the use of lubricating oil addit[illegible] which furthermore permit a critical survey to be made of the various apparatus.

In the development of a cutting oil for light metals, trials were carried out with various lubricants in the "grinding in" apparatus (diag.1.of report No.548). Each test was made with a load of 16 kg for a period of 10 mins, being repeated twice. The usual hard metal discs were employed in conjunction with a light metal, " 124". The surface of the first disc used was not very rough and the results obtained are shown in diag.2.(left hand portion of diag.) proving that the differences in abrasion produced by the four oils tested, are slight. If, however, the disc is replaced by one of similar dimension and material but having a rougher surface, an increase in abrasion will be noticed. This increase does not take place in the same proportion throughout but varies from one lubricant to the next. For oil No.4 for example, the abrasion caused by greater roughness is increased approximately seven times, thus transfering it from second to last place. Oil No.9. with approximately the same viscosity, shows an abrasion only about two-and-one-half times as great, thus moving from fourth to third place. In the case of KW oil "Rotring D" and oil No.3, abrasion effects increase but slightly with a change in degree of roughness. From these tests it may be seen that so far from being replaced by a file-like action, the influence of the lubricant, with increased roughness, does not only hold its own but becomes actually very marked indeed. The viscosity of the oil plays no part in this: whether the different temperatures caused by different degrees of roughness can be held responsible for the violent reshuffling of the results, is a question to be settled by further experiment. One thing, however is certain, viz. that with measurements of this kind, relating to the effect of metals on lubricants, and vice versa, a clear picture is available giving plenty of scope for analysis, from a knowledge of which it may be assumed that there is a certain connection not only with the cutting process but also with the lubricating process.

The theory that abrasion takes place at temperatures far exceeding those existing during normal lubrication, is held to be improbable as temperatures of that kind would be easily observed during the test. In actual fact, no perceptible temperature rise has been recorded either on the disc or the test cylinder, quite in contrast with other instruments, (e.g. the 4-Ball Machine or the Wieland Machine) (Thus, these remarks are apposed to the results published by Prof. Heidebroek.) Tests are in preparation in which the existing temperature changes can be estimated.

Similar experiments, are carried out on our wear-producing apparatus, again with hard and rough contact surfaces (see dia.3. of report No.548). Approximately the same conditions prevail as in the case of the grinding machine and it is again a question of metal abrasion, and the same conclusions as above therefore, apply as regards any similarity to actual practice. In any case, a certain connection between the tests on this apparatus and those on the Almen-Wielands machine permit the conclusion to be drawn that some importance, at least, must be attached to the measured amount of abrasion when estimating the value of an oil as a lubricant.

As already shown for three oils in Report No.548, the corrosion taking place on lubricated metallic surfaces shows a relationship to the abrasion caused in such a manner that increased abrasion points towards a high seizure load. To justify this statement, the results obtained on the Almen-Wieland machine, and the "wear machine", with a number of different lubricants were contrasted: this is illustrated in diag.4. Each point in itself represents a lubricant, its ordinate indicates the amount of abrasion caused by an iron pin in the wear apparatus, at a temperature of 100° C and using hard roughened running surfaces; the abscissa indicates the load at which seizure takes place in the Almen-Wieland apparatus. It is seen that on the whole there is a relationship between seizure load and abrasion. If the hydro-carbon oils and all other lubricants are put into respective classes of their own, it is seen that the esters and poly esters tested, occupy a region all by themselves, in the case of those lubricants relationship mentioned is particularly clear, and the greater the abrasion, the higher the seizure load. The KW oils show a very low seizure load as well as poor abrasive qualities. The addition of acids and esters, produces a considerable re-shuffling of the test results, even when the quantities added are small, and favourably changes the lubricant itself. In this manner it is possible to obtain the high siezure load peculiar to an ester with a KW oil, though coupled with less abrasion, a factor which can gain importance when choosing a lubricant. Preference will always be given to the lubricant which couples little abrasive action with a good performance as regards seizure. The KW oils tested are chiefly commercial products which are not absolutely pure but always contain traces of esters or acids. It appears probable that the results obtained with KW oil can be attributed not so much to the properties of pure KW but rather those of the surface active substances contained in it. Perhaps the investigation into seizure loads with the Almen-Wieland apparatus may be called a rough-and-ready method of doing it, but it is also true that in actual practice a lubricant is estimated to no small extent according to the occurrence or otherwise of seizure. A lubricant like castor oil, for instance, does, after all owe, its excellent reputation to the fact that even under unfavourable conditions it will not produce seizure, or similar effects. Low coefficients of friction or high abrasive powers do not usually count in the eyes of the practical observer. The relationship between abrasion and seizure, thus demonstrated may perhaps be explained as follows:

Seizure of metallic surfaces demands the existence of high temperatures along the rubbing surfaces. As long, however, as the lubricant permits sufficient abrassion to take place, no excessive temperatures even got a chance of occuring along the surfaces of the lubricated parts. Before the metal particles attain a high temperature through friction they have already been removed, so that seizure will only occur when the abrasion caused lags behind the increasing heating action.

These tests therefore, indicate that the results yielded by both the Almen-Wieland apparatus and the wear apparatus are very instructive, proving that the determination of abrasion is not a factor affecting cutting oils alone, but that there are interesting relationships with other factors governing the suitability of an oil which are of significance, in actual practice.

We have, furthermore, carried out experiments on the method of adding a substance manufactured by ".I.G. Werke Leverkusen" to aero engine oils. The purpose of such additions being the smoother running-in of aero engine bearings.

Two substances were found to be particularly suitable in trials carried out in conjunction with other research centres: both were phosphorous compounds, listed as I.G.891 and I.G.1586/80, the latter being obtainable in several varietes. Starting with practical results right away, and as both substances are practically equivalent as regards effect, these results, obtained on the engine, are stated in combined form.

61 engines, type DB 605, using "Rotring D" without addition, and 65 engines using "Rotring D" plus addition of 1586/80 or 891, were run in at the Daimler Benz works. On termination of the running-in period photographs were obtained of free journals, points being awarded in each case according to the condition of the bearing: the award being based on the presence of any traces of wear, points that produced excess pressure, grooves, etc. For every one of the 126 engines an average number of points relating to the whole engine was calculated from a knowledge of the individual awards to all bearings, separated into pedestal bearings and journal bearings: the results are shown in diag.5. (left hand side) They indicate that on the average the point award shows a noticeable trend towards the "credit" side when the substances are added. This is particularly true in the case of pedestal bearings, and somewhat less markedly with journal bearings. There were 14 instances of seizure without addition of the substances, and no cases of seizure when the substances were added, so that their beneficial effect cannot be denied The results are based on a great abundance of testing material and are consequently particularly valuable.

In order to appreciate the time value of the various testing machines, knowledge of such results is of the greatest importance: in what follows, conclusions are, therefore, not drawn from test results to be applied to practical conditions, but rather the other way around, thus enabling a critical view to be taken of the test gear. Apart from the two substances already mentioned, a further material (ref.M.1) will be considered: unfortunately no practical tests have been made with this product, to date.

When testing the substances in the grinding apparatus, a rough hard metal disc was used on copper and "Acterna VL 22", respectively. As expected, the amount of abrasion was greater with an addition of the substances than without it (diag.5, right hand side) both in the case of copper and that of "acterna". However the increase in the amount abraded, due to such additions, is still very small. It is thought that abrasion takes place at an insufficiently high temperature and that a rise in temperature would lay greater stress on the differences obtained. Tests with that object in mind are still in the preparatory stage.

Steel shafts and bearings made of "acterna" VL 22 were employed during tests in the Almen-Wieland machine, the tests starting at room temperature, according to the instructions relating to the test. Hardly any effects attributable to the substance added were noticed either in the course of the test or in the appearance of the test bearings. Only with an increase to 100° C of the temperature of both oil and bearing at the start of the test were there any marked changes (diag.6). Without any additions, the frictional force shows a rapid increase when more than 20 plates are employed (this is indicative of load), whereas on the substances being added, the curves rise steadily within the loading limits of the apparatus. There are differences between the various individual substances, as regards frictional coefficients, 1586/80 being noticeable on account of its low coefficient of friction. Far more important, however is the appearance of the test pieces. "Rotring D" without additive produced deep grooves on shaft and bearing which accounts for the steep rise in the coefficient of friction. On addition of one of the substances mentioned, both the bearing and the shaft are perfectly smooth (diag.7) The results obtained with a method rendered more acute by an increase in temperature are therefore closely akin to conditions prevailing in actual practice: the Almen-Weiland apparatus, then, appears to be a thoroughly useful testing machine; it is only necessary to suit the test conditions to each particular case. In the particular case dealt with above it would be desirable to be able to increase the load still further. In that way it might also be possible to get a better differentiation between the substances added.

As the tests mentioned so far led one to believe that the substances showed their effect only at high temperatures, they were continued in a piece of apparatus in which the test conditions suggest the existence of high temperatures on the rubbing surfaces. The test equipment used here is somewhat similar to that of the Siebel)Kehl apparatus. A smooth circular disc of hardened steel is divided into three single surfaces by countersinking and runs on a smooth copper disc, in oil. The test equipment was installed in the "Four-Ball" machine. Loading starts at zero and is increased slowly and at a steady rate by water filling a container.

The frictional torque is noted on an indicator drum by a lever carrying a pencil, and and both test oil and equipment are heated to a temperature of 80°C, prior to commencing the test. The end of the test was taken to be the rapid rise in the value of the coefficient of friction, indicative of the first stages of seizure.

Diagram 6 (bottom part) shows the results obtained with this apparatus. The conditions met with at the end of the trials with the Almen-Wieland machine are reproduced with a load of 100 kg, approx. "Rotring D" without additive starts failing in both machines, while differentiation between the substances added is hardly possible. Only with a further increase in load in the test gear employing disc friction, does "Rotring D" + 1.2% M.l. fail as well, while failure of the other two substances takes place at roughly twice that load. In that way the agreement with actual practice is clearly established for this instrument, too. How far exactly the agreement applies to M.l. additions will be shown only after the engine test has been carried out.

Further to these trials a few general remarks on the process of running in of bearings and the relation to test equipments are timely when new machinery is being run in , the conditions existing at points of frictional contact are particularly critical because the rubbing parts have not yet adjusted themselves to one another. A few single points exist which bear the main load until even distribution of pressure takes place all over the bearings It is easy to visualise how a bearing not yet properly run in, will function mainly under conditions of hydrodynamic lubrication while at the same time there are single pressure points which penetrate the liquid lubricating film so that here and there conditions of boundary lubrication prevail. Such points are subjected to comparatively high pressure and speed, both of these factors eventually leading to high temperatures on the "crests" of the rough surface. In the construction of test apparatus the opposite path is frequently taken, by adopting very low peripheral speeds it is possible to reduce the load considerably without leaving the region of limiting friction. Those very low frictional speeds and small loads, however, will never lead to a development of temperatures such as are met in practice. On the other hand, since the effectiveness of a lubricant can be very largely dependent on the temperature it is quite imperative to have temperatures comparable with those met in actual practice. Heating of the test equipment and the lubricant in their entirety is possible only to a certain extent as a change in the lubricant must be reckoned with (to say the least) at higher temperatures. The best method, therefore, of producing high temperatures on the "crests" of the running surfaces, is to choose correspondingly high speeds and pressures. The greatest difficulties facing the makers as far as bearings (and particularly motor bearings) are concerned with the problems cropping up during the running-in period rather than during the actual service. It is therefore necessary to become better acquainted with these conditions and to arrange the test equipment accordingly.

Once the additive substances discovered had proved themselves suitable for the running-in of bearings, it still remained to be seen whether they would produce harmful effects with respect to ring-sticking. A number of trials were therefore carried out in which ring-sticking took place, and it was found that M.l. alone produced a reduction in running time. At the same time, in these trials the wear on the piston ring was measured, leading to the surprising discovery that the addition of 891 and 1586/80 reduced the amount of wear quite remarkably. Diag.8, shows the amount of wear on the piston rings, related to the running time and output which was 57 H.P. throughout, the trials being carried out with various cylinders and a new piston ring in each case, Despite the fact that the results are appreciably scattered, the effect of the additions can be clearly observed. This led to the performance of tests whose aim it was to find out to what extent the test instruments are capable of reproducing these effects produced by wear.

With all tests on wear the operator must be quite clear as to whether he is dealing with metal abrasion or with seizure. Presumably, between these two types of wear, there is a "no man's land" in which exact classification becomes difficult. Previous experience shows that abrasion takes place with materials possessing different degrees of hardness where the harder element is at the same time the rougher of the two. On the other hand, wear by seizure takes place especially when the same, or at any rate similar, materials slide on one another. As shown above, the tendency to seizure is smaller as abrasion increases, and as wear by seizure is the considerably more unpleasant form of wear, a large amount of corrosive wear in a test machine must be considered unfavourable and high abrasion favourable, generally speaking. One can therefore not describe a lubricant as being proof against wear without stating which form of wear is implied (translator's note: the marginal note in the manuscript deals with a technicality of expression to the effect that "proof against wear" applies to the bearing material, not the lubricant.)

In an engine, cast iron runs in contact with unhardened steel, and the pairing of materials is such that in case of wear seizure will be the principal result. If now the lubricants are tested for abrasion (say) in the grinding apparatus, an increase in abrasion is expected for "Rotring D" containing 1586/80 and 891, compared with the use of "Rotring D" without additive. But no effects attributable to the additions can be found with cast iron as used in piston rings, or with steel. Evidently the temperature difference between practical case and test gear conditions is here even greater than in the case of the trials on bearings. Here it must again be assumed that an increase of temperature in the grinding machine would yield the result expected. Again, the addition of the substances when a soft iron pin rubs against a hardened and roughened piece of steel in the wearing apparatus yields a positive result in the shape of increased abrasion.

Tests with neat "Rotring D" in the Wieland apparatus on bearings employing steel running on steel, showed that seizure started with a use of 8 plates, while with the mixture the load causing seizure lies above the maximum permissible load of the apparatus (i.e. 25 plates). The agreement between the amount of abrasion in the wear apparatus, and the seizure-producing load in the Almen-Wieland machine, is therefore established again. Both instruments, though in agreement with one another, do not fully agree the actual wear on a piston ring, as found in practice. Moreover, they judge M.l. too favourably, and evidently the conditions they produce are still too moderate.

The temperatures existing between piston ring and cylinder are comparatively high, between approximately 300°-350°.C. An apparatus measuring wear by seizure at high temperatures will therefore resemble actual conditions most closely. The "Four-Ball" machine, using soft steel balls, or cast iron balls, conforms with these requirements: the very high pressures and the comparatively high rubbing speeds produce the correspondingly high temperature. It is thus possible to obtain wear measurements with unhardened steel balls which lie in the same field as the wear measured on piston rings, and lead to almost the same assessment of the lubricants as the engine test (diag.9.bottom). When cast iron balls are used the agreement is even better- in fact, to all intents and purposes, it is complete.

It was thus found that the particularly severe conditions produced by the "Four-Ball" machine corresponded most closely to those of actual practice. From that it can be concluded that these conditions make strong demands both on working materials and lubricants: a conclusion that applies not only to piston ring wear but to the working and especially the running-in , of bearings, as demonstrated above. Conditions of temperature under actual service conditions in particular, and conditions in general, are more severe than is generally believed to be the case, and particularly in the machines mentioned do we see a chance of approaching the severity of these practical conditions, though it is naturally necessary to adjust the test conditions to the individual case. Investigations confirming their scope to the region of non-wear producing lubrication and low surface temperatures, do in our opinion ignore the essentials of the problem because under practical conditions a lubricant is generally looked upon from the point of view of how much wear and other changes on the rubbing surfaces of the engine parts, it permits.

Illustrations.

Diag.No.1. Grinding apparatus (see previous detailed report on this machine)

Diag.No.2. Abrasion and degree of roughness
Y-axis: ground volume
X-axis: small-roughness-great
tests with grinding apparatus:hard metal disc against light metal (marble 24)

Diag.No.3. Wear apparatus
electro motor with transmission gear.

Trommel	drum
Kurbel	crankshaft
Prüföl	test oil
Verschleisstift	pin to produce wear
Schurstange	con. rod
Heizol	heating oil
Elect.Heizung	electric heater
Gewicht	weight.

Diag.No.4. Relation between abrasion and corrosion
Y-axis: reduction in length of wearing pin at 100°.C.
X-axis: corrosion-producing load in Wieland machine

Diag.No.5. Tests with substances added to lubricants.
left: no of engines
no. of points awarded
right volume ground out

Diag.No.6. ditto
top: Y-axis frictional force
X-axis: load (no. of plates)
bottom ditto

Diag.No.7. Photographs of bearings tested in the Almen-Wieland machine.

Diag.No.8. tests with mixtures (as No.7.)
top Y-axis:spec wear on piston ring.
botton Y-axis: volume ground out.

Diag.No.9. ditto
top shortening of pin
bottom diamenter of wear.