A Special Grease for Flexible Shaft Couplings

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Flexible shaft couplings impose unique requirements on the lubricants; mainly, they subject the lubricants to very high and continuous centrifugal forces. Under these forces, grease thickeners are forced toward the periphery of the coupling, displacing the oil from the area where lubrication is needed. Although still full of grease, the couplings tend to wear rapidly.

Two groups of tests were conducted by the author's company: one to find the resistance to centrifugal separation of existing greases, the other to determine which characteristics of a grease have the largest influence on coupling wear. The results of these tests led to the development of two special greases, which will not separate under high centrifugal forces, will significantly reduce the friction between working components, and will reduce the wear rate of coupling parts.

FLEXIBLE COUPLINGS HAVE UNIQUE LUBRICATION REQUIREMENTS

The relative motion inside flexible couplings, whether they are of a gear, chain, or steel grid type, are oscillatory in nature. The frequency of this motion is the same as the rotating speed, and the amplitude of the motion is very small. These conditions make it difficult to generate a hydrodynamic lubricant film. Flexible couplings can operate because the lubricant is forced, and maintained, between the wear surfaces by the large centrifugal forces generated by the rotation of the couplings. Although flexible couplings operate under boundary lubrication conditions, their wear rate can be very small, and their useful life often exceeds 20 years.

Flexible couplings are packed with lubricant at startup, and the lubricant is replaced (or replenished) at scheduled maintenance stops. The interval between relubrication stops depends on the type of coupling and the severity of the application. Although some types of couplings will accept oil lubrication, greases are used almost exclusively in normal industrial applications, mainly because they are easier to seal within the coupling.

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The large centrifugal forces present in the couplings, although beneficial for the lubrication process, have a detrimental effect on greases (*1*). The thickeners, such as metallic soaps, have a greater specific gravity than the oils; hence, centrifugal forces have a larger effect on thickeners. Subjected to centrifugal forces for an extended period of time, the greases will separate, or stratify, into thickeners, additives, and oils.

To be a good coupling lubricant, a grease should:

1. Provide good lubrication even under boundary conditions
2. Resist separation under high centrifugal forces
3. Flow easily, so it can penetrate in the narrow spaces between coupling parts
4. Have a high enough consistency to be easily sealed.

PROBLEMS RELATED TO GREASE SEPARATION

It must be understood that greases are used in flexible couplings because they are easier to seal; from a lubrication point of view, couplings could operate as well, if not better, if only oils were used. It is only natural then that once a grease bleeds off its oil, it looses its only advantage, as the separated oil cannot be properly sealed.

To make the problem worse, under centrifugal forces the heavy components of the grease are forced toward the largest radius of the coupling. As illustrated in Fig. 1, couplings have the torque-carrying elements placed as far from the axis of rotation as possible in order to minimize the forces imposed on them. Once a grease is separated, the heavy thickeners surround the torque-carrying elements (gear teeth in Fig. 1) and prevent the oil from lubricating the surfaces that are in sliding contact. Thus, it is possible (and experience has proven it) that a coupling full of grease can wear out rapidly.

For many years, tests were conducted by various companies in order to find a grease that best resists separation when subjected to high centrifugal forces. Tests on over 200 greases conducted in the research and development

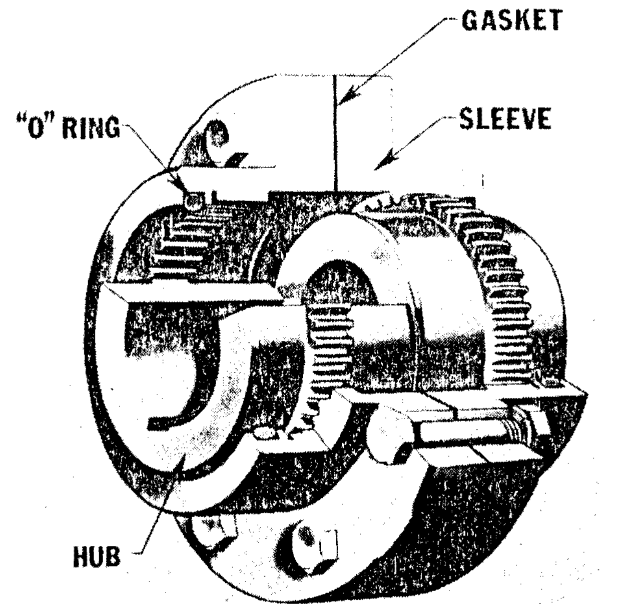

Fig. 1—Gear-type flexible shaft coupling

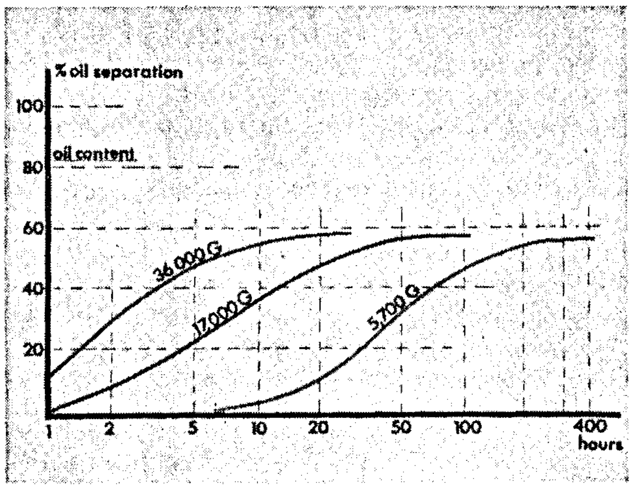

Fig. 2—Grease separation under centrifugal forces

laboratories of the author's company showed that some greases resist separation better than others, but that commercially available greases bleed most of their oil in time. Figure 2 shows that the time required for separation varies with the magnitude of the centrifugal forces, but that the amount of separation that the grease eventually sustains is not a function of the magnitude of centrifugal forces.

The search for good commercial coupling greases was then directed toward finding greases that: (1) will separate slowly, so that there will be little separation at the time the lubricant is changed, and (2) will be blended with as little thickener as possible, so that a minimum surface of torque-carrying elements will be covered by separated thickener.

COUPLING WEAR

The wear rate of a coupling determines its useful life. An extensive study was performed (2) to determine which factors have the most influence on coupling wear rate. It was first decided to measure wear through weight loss. A high-precision balance was purchased, but it was soon found out that measuring weight loss of one milligram is no easy task. Special cleaning and handling procedures were instituted, and still the results were quite erratic. We discovered that our problem was caused by the coupling's breaking-in period, during which time rapid and unpredictable wear occurs. Hence, the test couplings were first broken in. Two couplings were tested under fixed conditions; one coupling was lubricated with the same grease all the time for control, the other was lubricated with various greases. A group of twelve greases was tested, and wear was measured after 144 hours of testing under fixed conditions. The results were analyzed statistically, and plotted against every possible characteristic of the grease. The conclusion we drew was very important: the viscosity of the base oil had, by far, the largest influence on coupling wear; the higher the viscosity of the oil, the lower the coupling wear rate. To verify our results, we conducted a series of tests in which the couplings were lubricated with oils of various viscosities, and the results are in Fig. 3.

A second group of tests was conducted to investigate the interaction between the lubricant viscosity and the operating conditions. For instance, it is known that the larger the misalignment at which a coupling operates, the larger the wear rate. It was found, however, that the rotating speed has a significant influence on wear rate, but opposite of what one might think. The results of our tests are shown in Fig. 4. It can be seen that when a low viscosity oil is used, the wear rate decreases slightly with the increase in speed, but that there is a significant reduction in wear rate when the speed increases and a high-viscosity lubricant is used.

The results of this test are extremely important for high-speed applications. Some coupling manufacturers apply a safety factor to the maximum torque a high-speed coupling lubricated by a continuous flow of low viscosity oil can transmit, a factor which reduces the torque as the speed increases. Based on the results shown in Fig. 4, derating a coupling with speed is not necessary if a high-viscosity oil is used for lubrication.

FRICTION BETWEEN COUPLING COMPONENTS

Practice has shown that wear and friction do not always go hand in hand. In flexible couplings, friction is undesir-

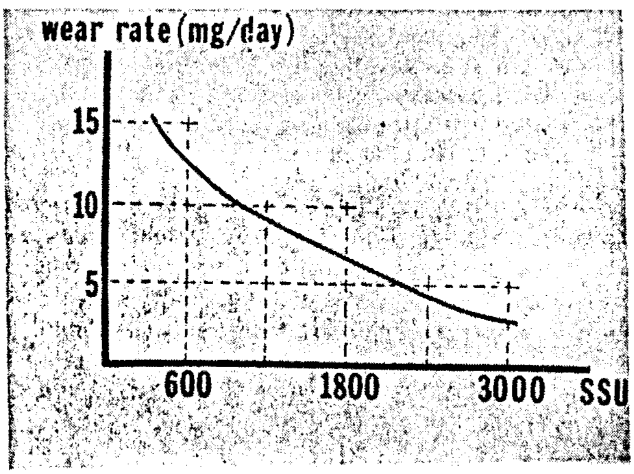

Fig. 3—Coupling wear as a function of oil viscosity

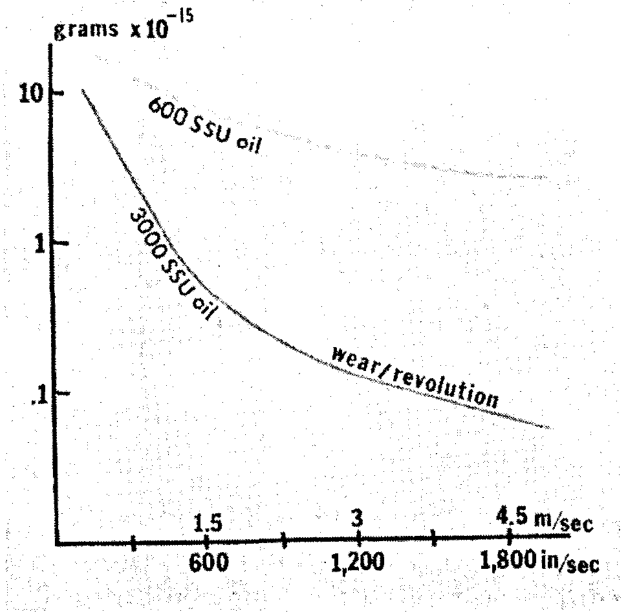

Fig. 4—Coupling wear as a function of pitch line velocity

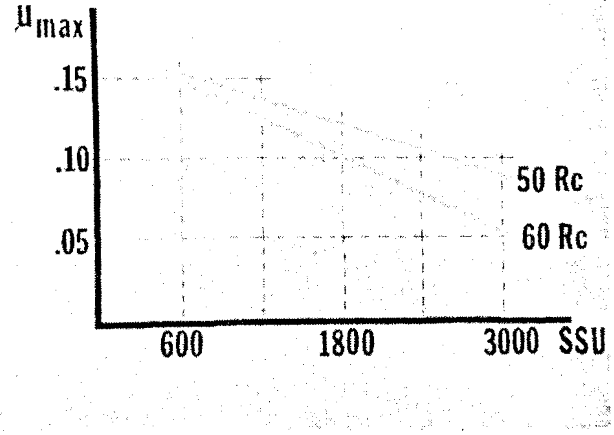

Fig. 5—Friction coefficient as a function of oil viscosity

able because it generates bending stresses and axial forces in the shaft. Many tests were conducted to measure the friction coefficients in couplings, and to find means to reduce them (*4*). As with the wear tests, it was found that the most significant factor influencing the friction coefficient is the oil viscosity. Also, as shown in Fig. 5, it was found that there is a strong interaction between the surface hardness of the coupling parts and the lubrication viscosity.

Again, as it was the case with wear, this is an important finding for high-speed couplings which have hardened parts. While an increase in hardness is not warranted when low-viscosity oils are used, if high-viscosity oils could be used, a significant performance increase could be accomplished through further hardening.

A SPECIAL COUPLING GREASE

As long as a grease is blended with a thickener of higher gravity than the oil, centrifugally induced separation will inevitably occur.

An alternative is the gelling of the oil with the help of a polymer. The biggest disadvantage of greases blended with polymers is their low dropping point, and this is perhaps why so few are commercially available today.

The author's company now markets two "coupling greases" which are blended with high-viscosity oils, and use polyethylene as a thickener. The properties of the two greases are given in Table 1. These greases are similar; the three basic differences between them are the dropping point, the price, and to some extent, the resistance to centrifugal separation.

The centrifugal separation is measured by using Koppers K36 method, which expresses the resistance to separation as the ratio between the maximum amount of oil separated (in percent) and the time necessary to attain this separation

TABLE 1—SPECIFICATIONS OF TWO COUPLING GREASES

	K11P	KSG
THICKENER	LITHIUM & POLYETHYLENE	POLYETHYLENE
BASE OIL	HIGHLY REFINED MINERAL OIL	HIGHLY REFINED MINERAL OIL
Viscosity @ 100°F, SSU	3300	4000
@ 210°F, SSU	163	188
NLGI, Grade (Worked)	1	1
Penetration, Unworked	228	215
Worked, 60 Strokes	335	335
Worked, 10 000 Strokes	433	440
Worked, 100 000 Strokes	473	505
Timken EP OK Load, lbs	50	40
Four ball EP (ASTM D 2596)		
Last non-seizure load, kgf	126	80
Load wear index, kgf	56	46
Weld point, kgf	300	250
Four ball wear, scar, mm (ASTM D 2266)	0.48	0.48
Dropping point, °F	225	190
Oxidation and rust inhibitors	yes	yes
Centrifugal separation (Koppers K36 method)	$K36 = \frac{10}{70} = 0.14$	$K36 = \frac{21.2}{65} = 0.33$
Color	Brown	Blue-Green
Operating range, °F	−40 to +190	−50 to +190

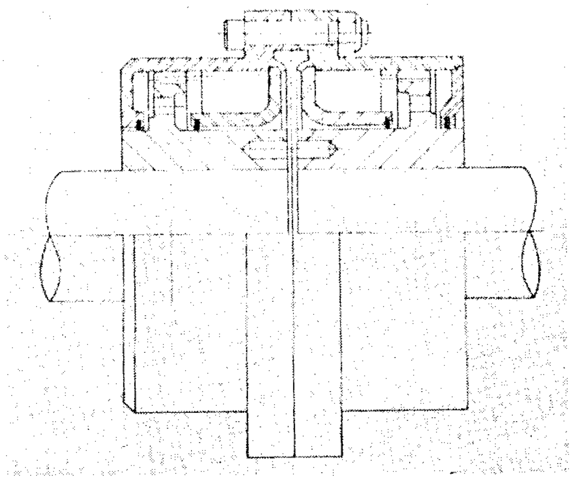

Fig. 6—Experimental sealed coupling

under 36 000 Gs. For instance, the KHP grease has K36 = 10/70 = 0.14, which means that the grease separates no more than 10 percent oil when subjected for 70 hours (or more) to 36 000 Gs. A good typical commercial grease has a K36 value of 75/24 = 3.1.

One of the unique characteristics of the coupling greases is the rapid softening which occurs when the grease is worked. Usually, there is less than 10 percent change between the worked and unworked penetrations of commercial greases. There is a 200 percent change for the coupling greases.

The coupling greases were field tested over many years. Special sealed couplings (Fig. 6) were packed with grease at our plant and installed in various locations around the country. Two of the couplings were removed after five years of continuous use and were found in excellent condition: there was virtually no wear, and the greases were still in as-new condition.

CONCLUSIONS

The main advantage of using greases especially blended for flexible coupling lubrication is a longer useful life for couplings. Hence, coupling users get a better return for their investment because they reduce the yearly expenditures for replacement parts, and because the down time and labor costs are also reduced.

For standard coupling applications (motor speeds and below), an added advantage is the longer period a coupling can operate without maintenance. Sealed couplings were run for over five years without any maintenance, and showed insignificant wear. It is not suggested that all couplings can operate so long without maintenance when using the "coupling grease," but it is possible, for instance, to cut maintenance in half by extending the period between relubrication from the usual one year to two years. Also, the fact that the grease is not blended with a metallic soap makes it possible to merely replenish (*3*) the coupling with grease at the first relubrication, and open and clean the coupling at every other relubrication.

For high-speed applications, the special coupling grease promises even larger benefits. It is known that greases are seldom used in high-speed applications because they separate in a relatively short time and necessitate shutdown of the equipment for the sole purpose of servicing the coupling. This is why continuous oil flow is almost exclusively used. With the advent of the high-speed coupling grease, couplings can now be packed with lubricant, with the following advantages:

— elimination of sludge accumulation,
— prolonged useful life,
— reduced thrust transmission,
— reduced stresses in the shaft,
— increase in torque carrying capacity at high speeds,
— long, maintenance-free operation.

The disadvantages of having to stock another type of grease in the plant is overshadowed by the many advantages that the special coupling greases have.

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(*3*) Calistrat, M. M., "Shaft Coupling Lubrication," *Lubr. Eng.*, **37**, pp 9–15, Jan. (1981).

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DISCUSSION

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The author contributes considerably to our understanding of the lubrication needs of flexible shaft couplings and lubricants that reflect these needs. He points out the metal-to-metal contacts in flexible couplings are low-amplitude sliding motions, oscillating at a frequency equal to the coupling rotating speed. This leads us to the analogy that the contacts resemble those encountered in fretting corrosion and in both situations boundary lubrication conditions prevail. However, oil properties recommended to reduce wear rates differ:

(a) The author concludes higher oil viscosity leads to lower wear and lower friction in flexible couplings.
(b) General experience prefers lower oil viscosity to reduce wear in fretting situations.

These apparently contradictory recommendations are reconcilable if one considers that in each situation the thickness and continuity of the oil film in the contact are the resultant of the rate of oil flow away from the contact (under the pressure gradient due to load) and the rate of oil replenishment into the contact. For couplings, centrifugal forces make oil readily available for replenishment and higher oil viscosity would tend to reduce the rate of oil escape and increase film thickness. For most fretting situations, only surface tension and normal gravity forces are available to bring oil into the contact area and insufficient oil supply results. Lower oil viscosity improves oil replenishment, but also increases the rate of oil loss from the contact area.

If this model is correct, there should be a lower speed limit for couplings below which centrifugal forces are too low to bring enough oil to the contacts, and lower oil viscosity would then become preferable to reduce wear. Is this observed in service? Also, surface roughness and topography of the contacting teeth should be important factors in rate of oil flow away from the contact. Could such differences in surface be responsible for the differences in friction coefficients for a hardened coupling (Fig. 5), rather than hardness per se? The author's comments would be much appreciated.

Wear and friction data reported are for oils only. Some amplification by the author would be helpful. Did these oils contain EP or antiwear additives? Are there comparable wear and friction data for the author's greases to confirm that high oil viscosity in his greases is also important? The low end of the operating ranges for the greases reported (-40 to $+190°F$ and -50 to $+190°F$) seem unusually low for greases with base oil viscosities of 3300 and 4000 SSU at 100°F. The higher ends of these operating ranges seem somewhat high for dropping points of 225 and 190°F. Could the author please tell us the basis of determining the operating ranges reported? Does the rapid and very extensive softening of grease penetration under the mild shear stresses of prolonged working (ASTM D217) play a role in coupling lubrication? What kind of coupling (used in the author's grease field tests) is illustrated in Fig. 6, and how does it relate to Fig. 1? Again, the author's comments would be appreciated to further our understanding.

DISCUSSION

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What is the form of polyethylene filler? Is it spherical or fibrous? If it is fibrous, does it degrade with work?

AUTHOR'S CLOSURE

The wear model suggested by Dr. Raich is quite correct, and it can also be found in Ref. (*2*), in the paragraph "Wear at Low Speeds." A formula is given "$N = 850/\sqrt{2R}$" where N is the rotational speed below which rapid wear can occur, and R is the pitch radius of the coupling (inches). Actually, this formula states that if a high-consistency grease is used, rapid wear can occur when the centrifugal forces fall below 10 Gs. This rapid wear is not a function of the oil viscosity because the amplitude of the motion in couplings is quite larger than the one usually associated with fretting. Dr. Raich also comments on the fact that the data from Fig. 3 is for oils only; a few spot tests conducted with greases using various base oils confirmed the results of Fig. 3. All the tests were conducted with lubricants which included EP additives. No antiwear additives were used as they tend to rapidly separate from the lubricant when high centrifugal forces are present. [Reference (*1*) in the paper.]

A point which the author omitted to mention in the paper was also brought up by Dr. Raich. Greases compounded with polyethylene do not have a dropping point in the meaning of ASTM D566, because contrary to soap-thickened grease, they do have a well-defined melting point. On the other hand, the melting of polyethylene-thickened grease is a completely reversible process. The upper operating ranges of the new greases are, indeed, close to the dropping point; however, the author would like to quote from the D566 standard: "Results of dropping point tests . . . should not be considered as having any direct bearing on service . . ." The new greases can actually operate satisfactorily at temperatures higher than the dropping points, even though the practice is not recommended.

At the opposite end, although the penetration of the greases decreases with a lowering of the temperature, the greases will still perform satisfactorily at -40 and $-50°F$, particularly because the temperatures inside the couplings are higher than the ambient.

Finally, Dr. Raich requested an explanation of the differences between the couplings of Fig. 1 and Fig. 6. While Fig. 1 represents one of the most popular flexible couplings on the market, Fig. 6 represents an experimental coupling which differs mainly through a double-sealing arrangement, and through a very large lubricant reservoir. Only a few such couplings were ever made.

The detailed properties of the polyethylene are considered proprietary at this time.

The author would also like to clarify a point relating to the original wear study (conducted in the late 1960s) when twelve greases were used. At that time, we selected the greases that were most often recommended by coupling and grease manufacturers. The majority of these greases are no longer available; the author mentioned the original study only to show how the first indication of the influence of oil viscosity on wear rate came to light.