M. M. CALISTRAT

Grease Seperation Under Centrifugal Forces

Shaft couplings are used to mechanically connent two shafts, so that power can be transmitted from one to the other. Shaft couplings can be:

1 Rigid: when no relative motion is possible between coupling parts
2 Flexible: when the connected shafts can be slightly misaligned, but the connection is torsionally rigid
3 Resilient: when the flexible coupling permits the two shafts to change relative angular position as a function of torque.

One of the most widely used types of flexible couplings is the gear type. Two configurations of gear couplings are illustrated in Fig. 1.

A gear coupling consists of one or two sets of meshing gears, each mesh having a internal and an external gear, with the same number of teeth. The relative motion between the mating teeth is in the axial direction, is oscillatory, and has a low amplitude and a relatively high frequency. This type of motion is unlikely to help in forming a hydrodynamic film of lubricant. The lubrication of the active surfaces in a gear coupling is insured by the centrifugal forces present in the lubricant.

There are two basic methods for coupling lubrication: batch and continuous flow. In the batch method, the coupling is filled either with grease or with oil; the continuous flow uses only oil, and almost exclusively light turbine oil.

Of the two methods, the batch one is the most popular, and greases are generally used: (a) because they are easier to be retained within the coupling even without a perfect seal, and (b) because the lubricant is not lost when the coupling is opened. Centrifugal forces play an important role in coupling lubrication (1)[1]. Without sufficient centrifugal force, the grease would be expelled from in between the teeth and adhesive wear would occur. The beneficial effect of centrifugal forces on lubrication can also be observed in Fig. 2, where the wear of a coupling was plotted as a function of the tangential velocity at the pitch line. However, when the centrifugal forces are very high, they have also a negative effect: they cause most greases to separate into oils and soaps. Soaps have a higher specific gravity than oils, and when separated they would cost the inside diameter of the coupling's sleeve. The teeth are always placed at the maximum diameter possible, considering that the torque capacity of a gear coupling is directly proportional to its pitch diameter. Because of the high soap concentration in the teeth area, and because soaps are not lubricants, the teeth do not receive as good a lubrication as they would have with a non-separated grease.

The grease-lubricated coupling can be completely starved of lubricant if it is relubricated too often, which at first glance seems a paradox. When a coupling is relubricated without being first opened and cleaned, which is the general case, the additional grease pumped into the coupling brings more soap, and expels part of the oil separated from the previous batch of grease. If this process is repeated often enough, then the coupling ends up filled with a very high soap content grease, and wear out rapidly.

Two questions are likely to come in the readers mind: (a) why not use oil instead of grease, and (b) why not use a coupling that does not require lubrication.

The answer to the first question is that it is more difficult to retain oil inside the coupling; it will leak more readily between the flanges when the coupling is rotating, and under the seal when the coupling is stationary. A notable exception is the coupling illustrated in Fig. 1(a), which was designed for oil lubrication.

There are three answers to the second question:

[1] Numbers in parentheses designate References at end of paper.

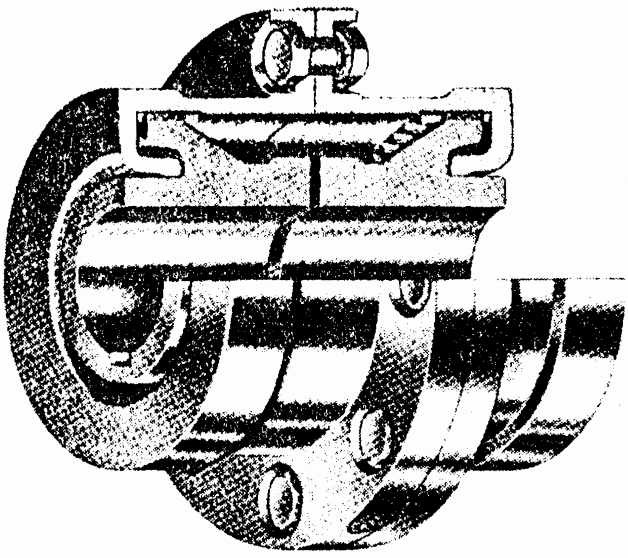

Fig. 1(a) Gear coupling with metal seal

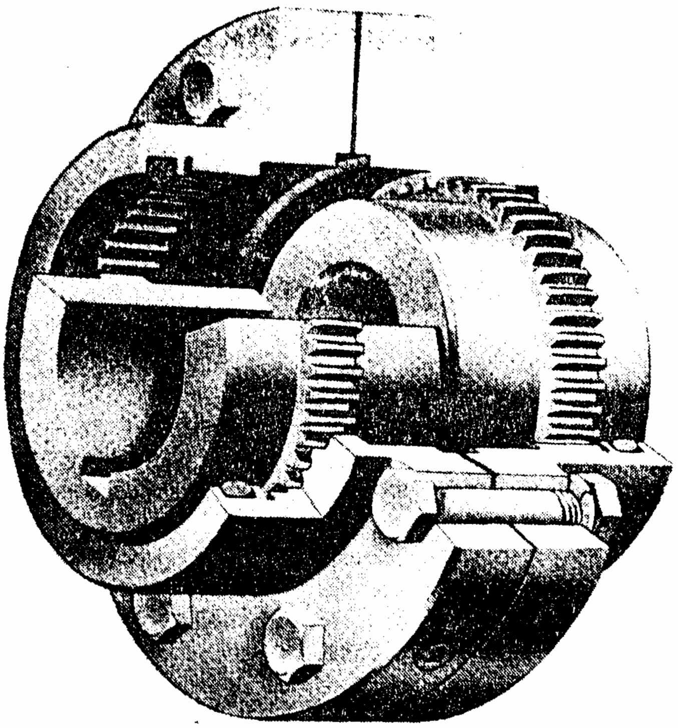

Fig. 1(b) Gear coupling with "O" ring seal

- Gear couplings can transmit more power per pound of steel, or per inch of diameter, than any other coupling.
- Gear couplings are forgiving, they accept errors in installation and mistreatments more readily than other types of couplings.
- Gear couplings are reliable and safe; they do not throw around pieces of metal or rubber even when they fail, and they can work longer in corrosive conditions than most other couplings.

Considering the advantages of grease-lubricated gear couplings, many grease and coupling manufacturers strived over the years to develop or to select greases that have a high resistance to centrifugal separation.

EXISTING TEST METHOD

In a recent presentation on coupling lubrication (2) it was stated:

> ". . .the quality levels established by the specification should be consonant with the particular application and type of service involved. For example, it would be wasteful and unnecessarily restrictive to require all greases for flexible couplings to be capable of withstanding centrifugal forces of 50,000 G's at 300 F when only a fraction of the coulings made would ever operate under such conditions."

This is a logical statement and represents the general approach taken by grease and coupling manufacturers.

Fig. 3 is reproduced from the Exxon Flexible Couplings Data Sheet. It can be seen that some greases are not recommended at G[2] levels above 8000.

In order to establish the greases' separation characteristics, we conducted tests at four G levels and three temperatures. Fig. 4, reproduced from a previous paper (3), represents the relationship between the G levels and the coupling dimensions and rotating speed. The G levels selected for the tests were 5700, 9100, 17,300 and 36,000. The temperatures were 80, 150, and 200 F (the last two only at 5700 G's). Each test lasted one hour and the volume of oil separated was measured and expressed in percentage of the initial grease volume. This is basically the method used by other laboratories (4). The G levels used are 2400, 9400, 27,000, and 60,000 and the duration of the tests is 6 hr. It was reported that at 60,000 G's, the separation has equalized in 2 1/2 hr and that "the greases with low separation characteristics indicated by the 2 1/2-hr runs at 60,000 G's were

[2] G is an adimensional unit for comparing a given acceleration to the earth standard gravity

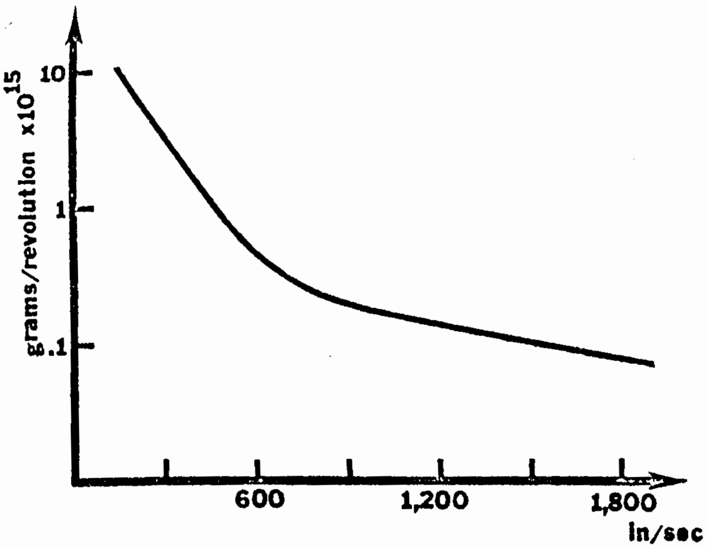

Fig. 2 Effect of pitch line velocity on coupling wear

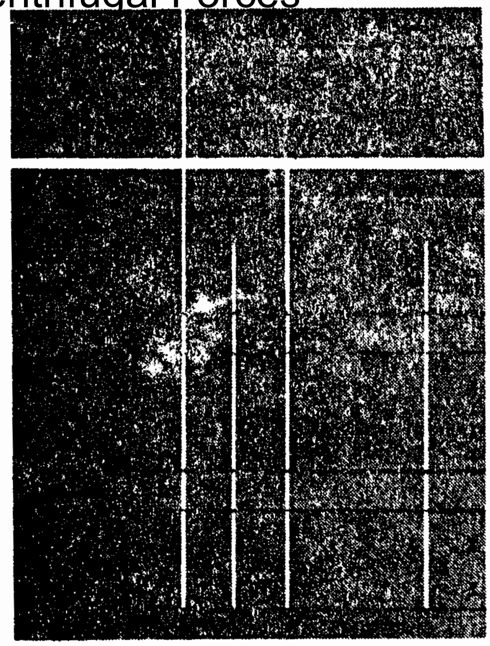

Fig. 3 Typical lubrication data sheet

low at all speeds, and the greases with high separation characteristics at 60,000 G's were also high at all speeds."

Table 1 shows eight of the results obtained through our method, with four high quality greases used in couplings, and with four greases considered unacceptable for couplings.

In analyzing this table, we observe that some greases will separate rapidly at high temperatures, but are very resistant at high G's (such as Grease A); while other greases will separate faster at high G's than at high temperatures (such as Grease F).

In selecting a grease based on its centrifugal separation characteristics, one should be guided by the actual operating conditions of the coupling. For instance, a coupling with a 7-in. pitch diameter operating at 1800 rpm has a G level of 322[3]. The question that comes to one's mind is: why are the E, F, and G greases from Table 1 not acceptable for an application like this? There are three reasons:

1 Why not use a grease that has no separation if all the other conditions are the same?

2 Any oil separation indicates that the grease has a tendency to separate into oils and soaps. If we see 4.1 percent of oil floating on the surface, we can assume that some of the soap lies at the bottom. In other words, under centrifugal separation the grease is being stratified, with high soap concentration at the outer diameter. As shown before, the teeth of a coupling are exactly at the outer diameter of the grease annulus, and the high soap concentration around the teeth deteriorates the lubrication process.

3 When the coupling is serviced, more grease is pumped inside. Every time grease is added, the total quantity of soap within the coupling is increasing.

4 The grease separation is continuing in time, and this is why a new test method is now being suggested.

[3] The formula for G, in this case, is $G = 11.2\ RN^2/10^6$ (R is radius in cm, N is in rpm).

NEW TEST METHOD

It was generally thought that once a grease reaches a given separation, an equilibrium is established between the centrifugal forces and the resistance to separation of the grease; the percentage separation was thought to be a function of the G level. As such, greases were categorized into: not acceptable, acceptable for low speeds, and acceptable for high speeds. The following graphs illustrate what happens with the grease separation if the tests are performed over relatively long periods of time.

Fig. 5 represents the centrifugal separaion of the grease "A" (from Table 1). The temperature was maintained at 120 F. Fig. 6 is for the grease "B". The striking conclusion from these two figures is that the greases attained

Grease Seperation Under Centrifugal Forces

Table 1 Centrifugal Separation After 1 Hour

"G" Level	5,700			9,100	17,300	36,000
Temperature °F	80°	150°	200°	80°		
Acceptable greases						
Grease A - NLGI #1	0	10.7	42.0	0	0	0
Grease B - NLGI #3	0	0	4.7	0	0	.8
Grease C-NLGI #2 HT	0	0	.8	0	0	.8
Grease D-NLGI #2 EP	0	0	0	0	0	.4
Unacceptable Greases						
Grease E-NLGI #1 EP	4.1	42.0	81.0	13.0	30.5	51.0
Grease F-NLGI #1 EP	1.6	22.0	32.0	7.7	15.0	75.0
Grease G-NLGI #0	4.3	38.5	48.0	23.0	42.5	57.5
Grease H	Immediate Total Separation					

their maximum separation, independent of the G level; but that at low G levels, it takes longer to attain the maximum separation. The percentage of separation differs between the two greases: while grease A separated completely into oil and soap, grease B did not reach that level. Both greases, however, reached the maximum separation in roughly the same time (10 hr at 36,000 G's). Not all greases will attain their maximum separation as quickly as A & B. Fig. 7 illustrates the centrifugal separation at 36,000 G's of greases C and D. It can be seen that it took 80 hr for these greases to separate.

The 120 F temperature, at which these tests were conducted, was selected because we considered it to be representative of the operating conditions of most couplings.

CONCLUSIONS

1 When subjected to relatively high centrifugal forces, most greases will separate into oil and a grease with high soap concentration.

2 The percentage of the oil that will separate from the greases varies widely even under constant conditions: for some greases, it can be total (when all the oil is separated), but for other greases, it can be zero.

3 The time required for a grease to attain its maximum separation is a function of the G level; the lower the G level, the longer it takes.

4 A common method could be used for determining the centrifugal separation characteristics of greases. We suggest using a factor (which we named K36) which is expressed as a fraction. The numerator of this fraction repressents the maximum percentage of volumetric oil separation obtained at 36,000 G's, and the denominator represents the number of hours required to attain the maximum separation.

As an example, grease A, from Fig. 5, has the K36 = 82/10, while grease C, from Fig. 7, has the K36 = 53/80.

This K36 factor enables us also to determine, approximately, how long it will take for any grease to attain its maximum separation at a given G level. The formula we use, based on the results of many tests, conducted at G levels of 5000 and the foregoing is:

$$T = \frac{100{,}000}{G} \times D$$

where:

G = level of centrifugal force
D = denominator of the K36 factor
T = time required to attain maximum separation, in hours.

As an example, when grease C is subjected to 5000 G's, its maximum separation (53 percent) will occur after

$$T = \frac{100{,}000}{5{,}000} \times 80 = 1600 \text{ hr}$$

Tests are now being conducted at G levels below 5000, in order to determine a more general formula for T.

REFERENCES

1 Calistrat, M. M., "Some Aspects of Water and Lubrication of Gear Couplings," ASME Design Engineering Technical Conference, Paper No. 75-DET-94.

2 Berg, E. H., "Lubricating Grease Specifications for Flexible Couplings," ASTM-AGMA Symposium on Flexible Coupling Lubrication, 1974.

Grease Seperation Under Centrifugal Forces

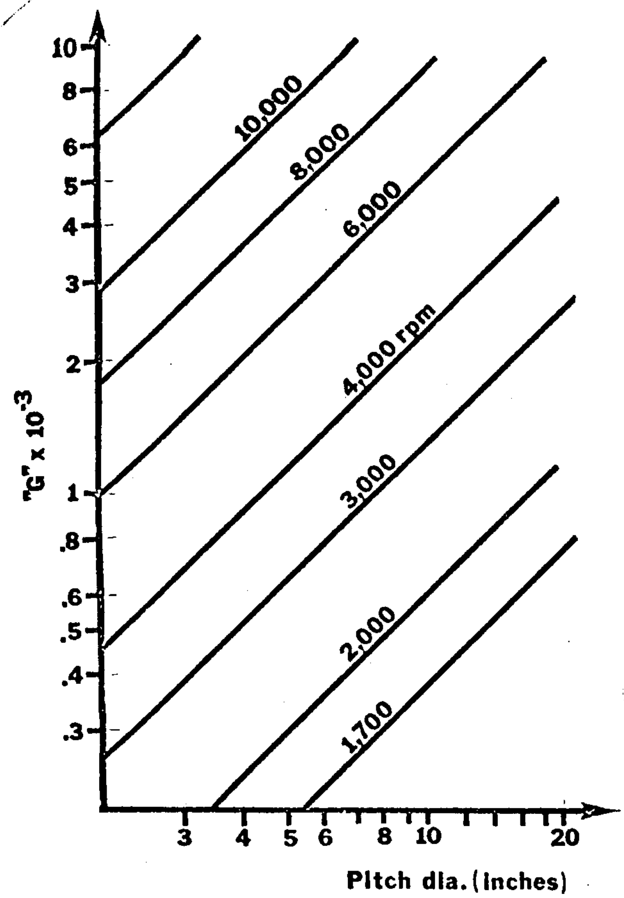

Fig. 4 Centrifugal forces in couplings

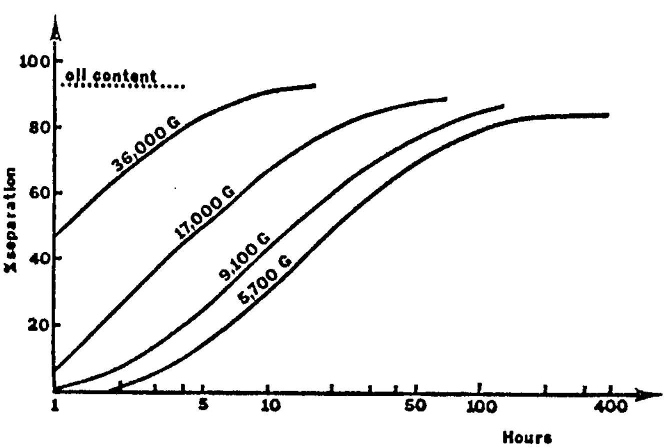

Fig. 5 Centrifugal separation of grease "A"

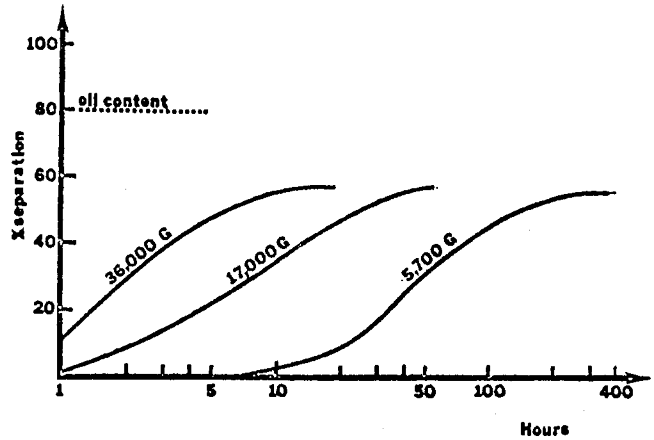

Fig. 6 Centrifugal separation of grease "B"

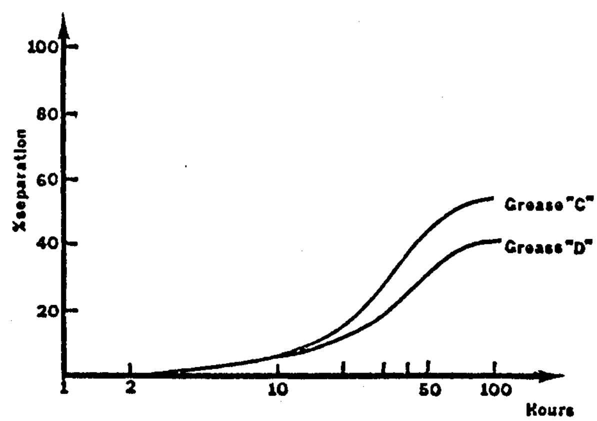

Fig. 7 Centrifugal separation at 36,000 G

3 Calistrat, M. M. and Webb, S. G., "Sludge Accumulation in Continuously Lubricated Couplings," ASME Petroleum Mechanical Engineering Conference, 1972.

4 Clapp, A. M., "Fundamentals of Lubrication Relating to Operation and Maintenance of Turbomachinery," Texas A&M Second Turbomachinery Syposium, 1973.

Grease Seperation Under Centrifugal Forces

ERRATA

Based on tests conducted after the writing of this paper, at 1,100 G's, the following corrections are required on Page 4:

Column 2, Line 7:

The formula we use, based on the results of many tests conducted at G levels higher than 1,100, is:

$$T = D \times \frac{2.4 \times 10^6}{G^{1.41}}$$

Column 2, Line 20:

$$T = 80 \times \frac{2.4 \times 10^6}{5000^{1.41}} = 1{,}170 \text{ hours}$$