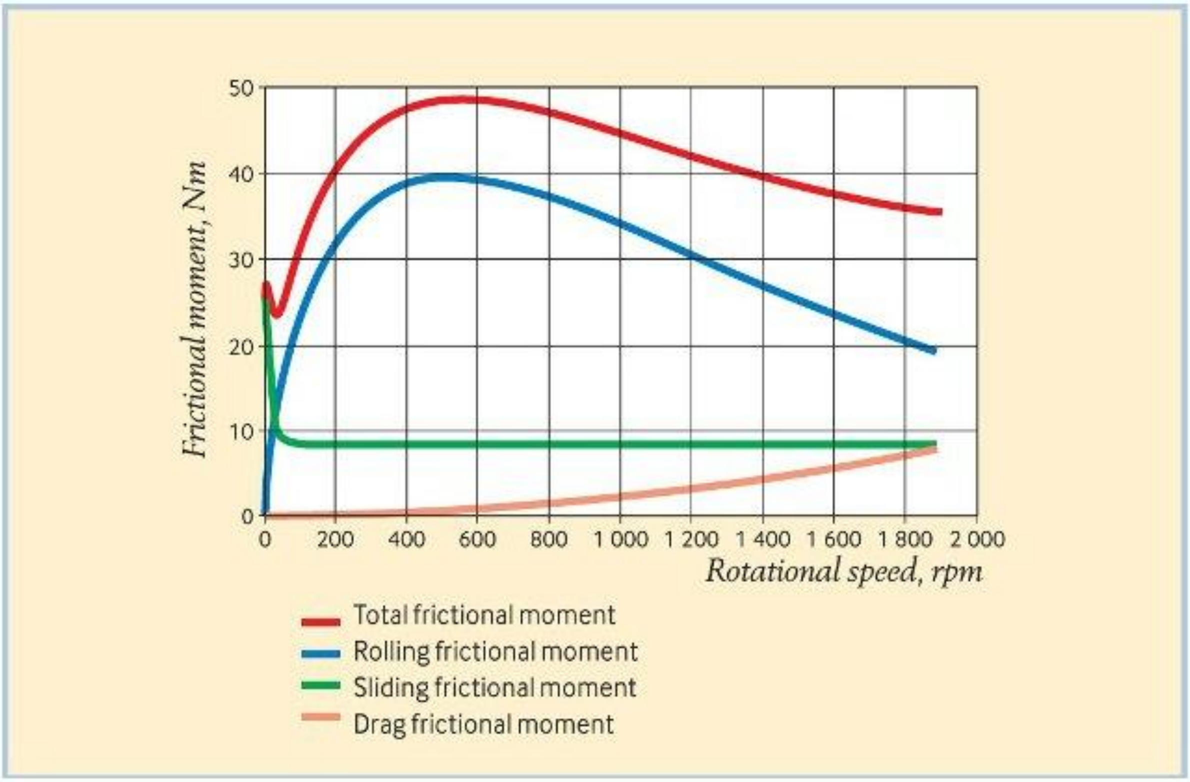
Frictional Losses in Lubricated Bearings

Here are some examples of frictional losses in lubricated rolling element bearings:

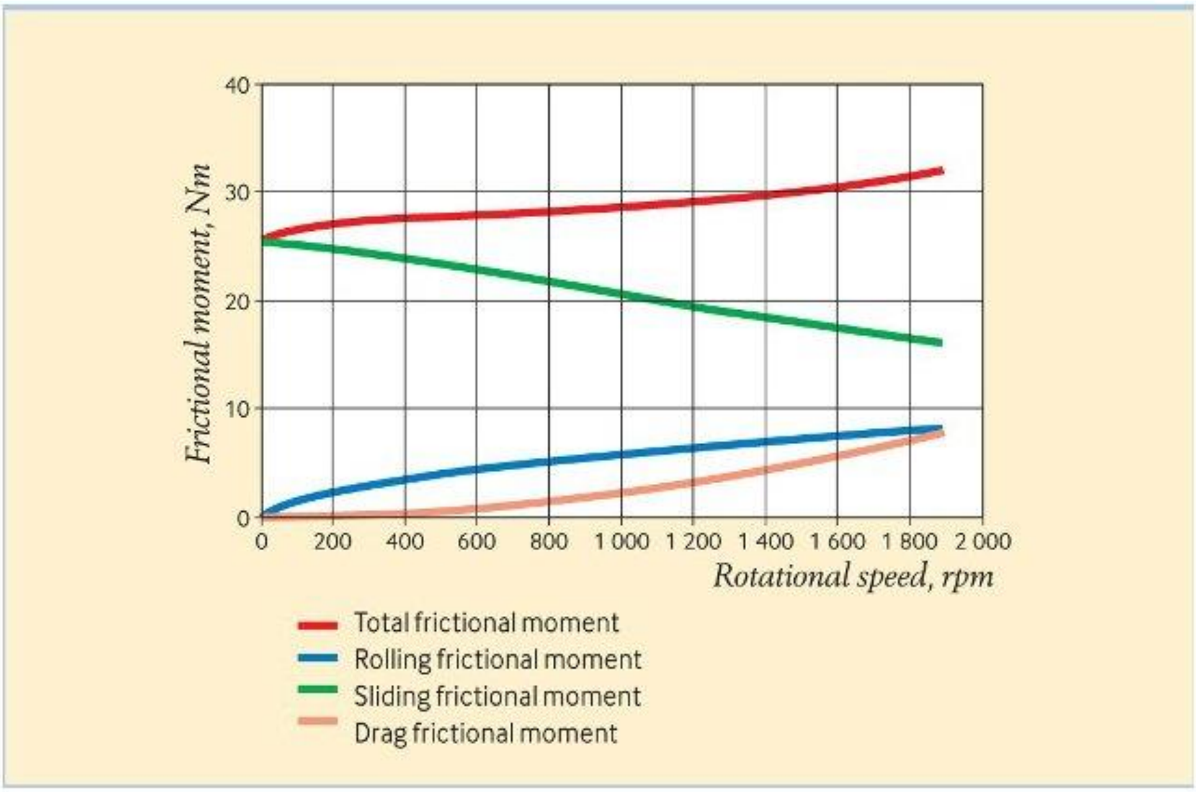


Frictional moment versus rolling speed at constant temperature, plotting the different moment components for an open spherical roller bearing lubricated with oil bath and very high-viscosity oil.

The “Drag” frictional moment is the result of churning of the lubricant, so everything associated with the lubricant being churned in an oil bath or otherwise mechanically centrifuged out of the bearing.

You will note that the contribution of “Drag” to the losses is much smaller than the contribution of “Rolling” friction.

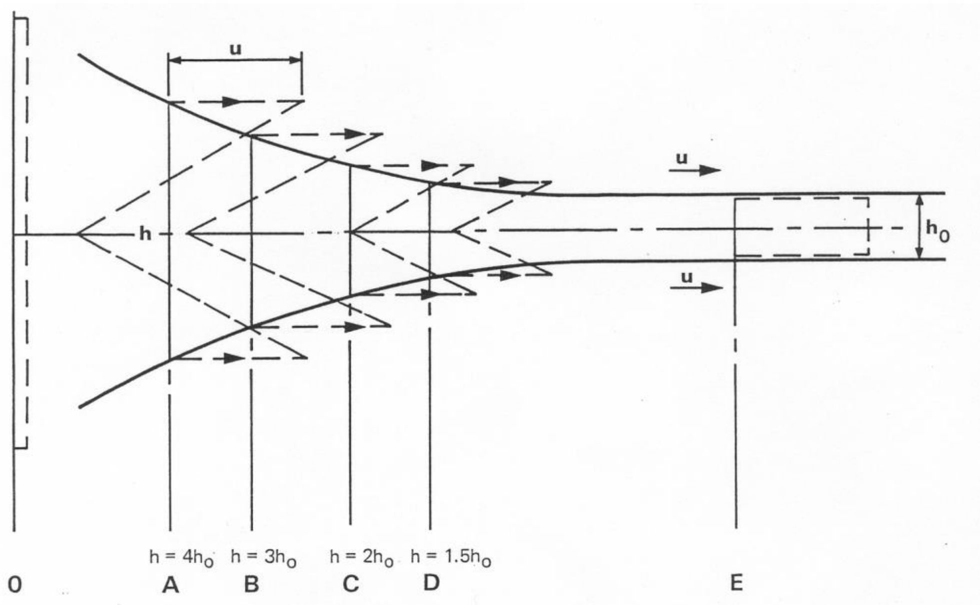
The example above is for a very high viscosity oil.



Frictional moment versus rolling speed at constant temperature, plotting the different moment components for an open spherical roller bearing lubricated with oil bath and very low-viscosity oil.

Here is the same for a very low viscosity oil. You will see that the “Drag” has not changed much, but the “Rolling” friction has. What this is effectively saying is that the frictional losses associated with centrifuging or pumping the oil out of the bearing has not changed much, with a change in viscosity, but the “Rolling” friction has. So we need to think about what causes rolling friction and why it is affected by viscosity.

In a dry contact, rolling friction is assumed to be generated by the requirement to elastically deform the contact. By contrast, in lubricated contacts, the majority of frictional losses are assumed to be as a result of shearing the lubricant at the inlet to the contact.



The rate of shear in the approach to the contact is extremely high, as will be clear from the figure, which shows the velocity profile in a lubricant approaching an EHD contact. The fluid in contact with the moving surfaces necessarily travels with the surface at velocity u. Considerations of continuity suggest successive velocity profiles as the fluid approaches the contact of the form sketched. Remember of course that in our bearing, u will depend on the rotational speed.

The rate of shear reaches a maximum when the distance between the surfaces = 2h where h is the distance between surfaces in the contact zone proper. The maximum shear rate = 3u/2h. It is not difficult to achieve shear rates of 10^6 seconds^{-1} in even a slowly moving contact.

The lubricant entering the contact is first subjected to intense shear, if at only moderate pressure. On its passage into the contact, it is subject to further shear (at a lower rate), but at increasing pressure. Increasing pressure results in increasing effective viscosity, because of the pressure-viscosity effect.

If the response of the lubricant to this combination of shear and pressure is non-Newtonian, that is if shear stress ceases to be proportional to shear rate, it may be expected that its behaviour in the approach region will differ from that of a Newtonian fluid of the same nominal characteristics.

Now, we know that shear force is a function of viscosity, so:

1. the higher the lubricant viscosity, the greater the force required to shear the lubricant at the inlet
2. the higher the shear rate at the inlet to the contact, the higher the "rolling" friction

We also know that

3. the higher the shear rate the greater the shear heating of the lubricant
4. the higher the lubricant temperature, the lower the viscosity
5. the lower the viscosity, the lower the force required to shear the lubricant at the inlet to the contact
6. Etc

So this explains why the rolling friction moment with the high viscosity oil starts by increasing with increasing speed, then, as the speed increases further, begins to go down; the shear heating has increased the temperature of the oil and the viscosity has gone down.

To conclude, the above frictional response only applies if there is sufficient lubricant going into the bearing, in other words, enough oil to ensure that the inlet is fully flooded. If the flow rate is reduced too far, the bearing will end up running under a starved lubrication regime. Under starved lubrication, the bearing will be running under mixed or boundary lubrication, not EHD, so lubricant viscosity gets less and less important and surface interaction at an asperity level becomes progressively more important; the friction model will thus be different.

A G P 22nd May 2021