LUBE-TECH

NO.34

TRIBOLOGY BASICS (continued from LUBE-TECH No.33)

FRICTION

The first article in this short series dealt with the fundamentals of tribology, being briefly described as the branch of science devoted to the study of lubrication, friction and wear. The second article in the series described the basics of lubrication; this third article will now address the subject of friction.

We all appreciate that one of the main reasons for lubrication is to reduce friction, but what exactly is friction and what causes it? Friction can simply be defined as the force resisting the relative motion between two contacting surfaces. The subject was first studied by Leonardo da Vinci, but received more attention from Amonton and others in 1699. Subsequently, his work was almost forgotten until resurrected by Coulomb in 1785, at which time the subject become increasingly important as the industrial revolution developed. The use of mechanisation such as steam power in factories devoted to manufacturing, and an increasing drive to improve production rates and general manufacturing efficiencies, focused attention upon friction and its minimisation. There are a number of conditions, which lead to friction, which may conveniently be summarised as dry friction, rolling friction and lubricated friction.

DRY FRICTION

Dry friction can be further sub-divided into static friction, where there is no relative movement between the two contacting surfaces, and kinetic friction, where there is movement between the two contacting surfaces.

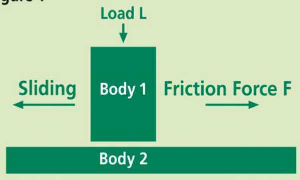
STATIC FRICTION AND KINETIC FRICTION

It was appreciated at an early stage that friction could be divided into two categories, namely adhesive (static) friction and kinetic friction. The difference between the two can be described by the following example (see Fig 1.) Imagine a block of wood resting on top of a level plank. The block remains stationary since there are no forces acting parallel to the plank, which would cause it to move. If a force is then applied to one side of the wood block, any movement will be resisted by friction up to the point where the applied sideways force is sufficient to overcome the frictional force, and the block will move. The sideways force necessary to move the block will depend upon the coefficient of friction (μ) between the block and the plank.

If the normal applied load between one body and another is L, and the resultant friction force required to slide the bodies is F, then:

Friction Coefficient $\mu = F/L$
(μ is dimensionless)

Figure 1



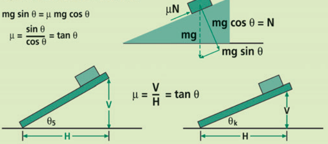
The coefficient of friction can be calculated by a simple experiment (see Fig 2). If one end of the plank is raised slightly, two forces are then brought into play, which govern the potential movement of the wood block. Gravitational forces begin to exert a sideways force on the wood block, which could cause it to slide down the plank. However, it remains in place because of the static friction between the block and the plank. At the same time, the gravitational force, which acts to keep the block in place, is reduced.

Figure 2

If the component of the gravity force down the incline is equal to the frictional force, then

$$mg \sin\theta = \mu\, mg \cos\theta$$

$$\mu = \frac{\sin\theta}{\cos\theta} = \tan\theta$$



Static case: with the block at rest on the incline, raise the incline until the block starts to slide. The tangent of that threshold angle is a measure of the coefficient of static friction.

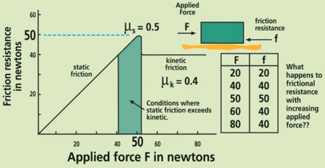
Kinetic case: with the block on the incline, raise the incline in steps and bump the block gently to set it into motion. If it slows to a stop, then friction overcomes gravity. Repeat to find the angle at which it moves down the incline at constant speed. The tangent of that angle is a measure of the coefficient of kinetic friction.

Eventually, as the angle becomes steeper, the block will start to slide down the plank. As explained in the diagram shown in Fig. 2, by measuring the angle of incline of the plank when the block moves at a steady speed which enables the coefficient of kinetic friction to be calculated.

This situation is known as 'dry' (unlubricated) friction. In the static condition, the frictional forces are due to the interlocking of the irregularities of the two surfaces in contact. All surfaces, no matter how finely polished, will consist of a series of peaks and troughs, and it is the interlocking between the asperities (peaks) that prevent the relative movement. For similar materials, rough surfaces will show a greater friction than for polished surfaces due to the more pronounced asperities.

Dry friction can also be reduced by suitably coating the contacting surfaces with e.g. dry lubricants such as e.g. PTFE, MoS_2 or graphite. Besides PTFE, certain other fluorocarbons will provide low friction, but they tend to be softer and less wear resistant.

Figure 3



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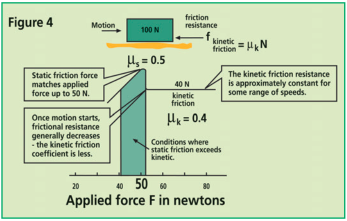
As can be seen in Fig.3, the coefficient of static friction is slightly higher than that of kinetic friction, reflecting the general situation that it is generally easier to maintain the block in motion across a horizontal surface than it is to start it from rest.

Figure 4



If these experiments are carried out with metal surfaces which have been very carefully smoothed and cleaned, the differences between the coefficients of static and kinetic friction become much less, almost disappearing altogether.

When the coefficient of friction for a particular combination of materials is quoted, then it is generally the coefficient of kinetic friction, since this is more reliable, being easier to measure.

ROLLING FRICTION

If one uses the example of a car wheel rolling along a road, then there must be some degree of friction between the tyre and the road surface otherwise the wheel would slide instead of gripping the surface. The amount of grip is determined by the coefficient of static friction between the car tyre and the road surface. If the wheel is locked or sliding, then the amount of grip is dependent upon the coefficient of kinetic friction, which is significantly less than that of static friction.

This can be appreciated when considering why the application of ABS braking systems on cars is so effective. The ABS immediately detects the locking of a wheel, and releases the braking pressure so as to allow the wheel to start rolling again, whereupon it increases the braking pressure to the point of locking the wheel. Since this intermittent locking/rolling happens several times per second, the friction between the wheel and the road surface is mainly in the static friction situation (i.e. where the wheel is rolling) rather than purely kinetic friction, as would be the case if the wheel was locked. As we have seen that the coefficient of static friction is greater than that of kinetic friction, the use of ABS ensures that the overall friction between the tyre and the road surface is greater than in the case of a non-ABS equipped vehicle. This not only results in shorter stopping distances, but also enables the vehicle to be steered at the same time.

Skilled drivers in non-ABS equipped vehicles can however make use of the 'cadence braking' system, where they can artificially increase the friction between the tyre and the road by alternately braking heavily and then releasing the brake pedal at a rapid rate. Since the nose of the car will initially dip under heavy braking, due to movement in the suspension, it follows that on release of the brake pedal; the nose of the car will be pushed up again by the suspension springs. If the braking frequency is timed so as to equate to the natural vibration frequency in the suspension, the nose of the car will bounce with increasingly greater deflection on each successive application of the brakes, so as for each period of braking, as the nose of the car is bouncing downwards, the tyres will be forced onto the road with much greater force than as would be the case under normal continuous braking.

If the wheel is rolling without sliding, then in theory no frictional forces are involved and no energy is being lost. In practice, a rolling wheel will produce some degree of drag due to tyre deformation, friction in the wheel bearings, etc., these frictional forces are collectively known as 'rolling friction'. Figures of between 0.02 and 0.06 have been quoted for rolling friction, as compared with a maximum of ca. 0.8 for the coefficient of static friction between the tyre and the road.

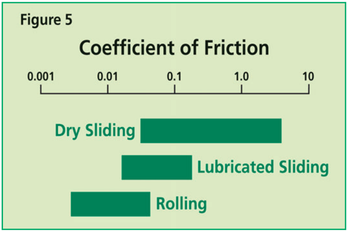
VARIATIONS IN COEFFICIENTS OF FRICTION

Dry sliding friction coefficients vary from 0.05 for PTFE under high loads to as high as 5.0 for metals like gold sliding in vacuum. Typical values for engineering steels are between 0.3 and 0.6.

Lubricated sliding friction coefficients vary from about 0.03 under hydrodynamic conditions (complete separation of the sliding surfaces by the lubricant film) to around 0.15 under boundary conditions (when there is surface contact through the lubricant film).

Rolling friction coefficients (with hard steel balls and raceways) vary from about 0.002 when fully lubricated to about 0.05 when running dry.

Figure 5



LUBRICATED FRICTION

As already mentioned, friction is a result of the interlocking of the irregularities of the two surfaces in contact. If these two surfaces are separated by a fluid film, as in the case of hydrodynamic lubrication (see article in the previous edition of Lube), then the friction is markedly reduced, and the residual frictional forces are governed by the various characteristics, (i.e. viscosity, viscosity index, Newtonian behaviour, etc.) of the separating fluid, also by the relative speed of the sliding surfaces together with the applied load between them.

As would be expected, the higher the viscosity of the separating fluid, then the greater is the friction. At increasing temperatures, the viscosity will decrease, lowering the frictional resistance. The rate of reduction of viscosity of the fluid with increasing temperature is dependent upon the viscosity index. We would normally assume that most lubricants exhibit Newtonian behaviour, i.e. that their viscosity is independent of shear rate. However, non-Newtonian fluids, such as thixotropic fluids, where the viscosity reduces with increasing shear rate, will show reduced frictional levels under conditions of increasing shear.

With the increasing emphasis on fuel economies, most engine oils these days include some form of friction modifier additive. Friction coefficients of fully formulated lubricating oils generally have friction coefficients of 0.12 to 0.18. By using a friction modifier additive, friction coefficients can be reduced to 0.06 to 0.08, which provides measurable benefits in fuel economy. Friction modifier molecules are strongly attracted to metal surfaces, and their structure is such that the frictional characteristics between the metal surfaces coated with layers of the friction modifier additive is less than that between uncoated metal surfaces.

However, there is a contradictory requirement in that some types of machinery call for a certain level of controlled friction in order to operate properly. As an example of a situation requiring controlled lubricated friction, modern motorcycle lubricants are required to lubricate a number of components, all with differing needs. The lubricant formulation therefore needs to be carefully balanced in order to ensure the optimal compromise performance. The major components are:

1. The engine
2. The primary transmission
3. The clutch
4. The centrifugal clutch*
5. The gearbox
6. The back torque limiter
7. The starter system torque limiter/ sprag clutch

Items such as the clutch, the back torque limiter and the starter system all rely on a certain amount of friction in order to operate satisfactorily. The use of friction modifiers in these situations could adversely affect operation.

Again, in the automotive field, a major potential improvement in fuel efficiency utilisation is anticipated by using more sophisticated transmission systems, which enable the engine to operate continuously at its most efficient speed. Current transmission options include manual gearboxes, sequential manual, conventional automatic systems, automated manual transmissions, belt driven continuously variable transmissions (CVTs), and toroidal transmissions (IVTs), each type of system requiring an optimised lubricant. However, much emphasis is now being placed on variable type transmission systems. It was only when fully integrated electronic control system became incorporated into vehicle design that the full potential of these variable drive transmissions for improving fuel economy was realised.

When considering variable transmission systems, although higher torque loadings can be accommodated by toroidal systems compared with belt driven systems, the technology is still in its infancy, and most attention is currently being focused upon improving belt-driven systems. The original expanding pulley CVT, known as the Variomatic, was initially used in DAF cars in the form of a rubber V-belt connecting two split conical pulleys whose effective diameters could be varied to give different drive ratios. The system was improved in the 1970s by substituting a steel belt version, which evolved into the present push belt design. The torque-carrying capacity of the steel belt-driven system is dependent upon the steel-on-steel coefficient of friction between the belt and pulley. Initially, conventional automatic transmission fluids were used in these systems, which limited their use to smaller and low-powered vehicles, since the original purpose of this automatic transmission fluid was to reduce friction and frictional losses, the opposite of what was required. Fluids were then developed which instead maximised the friction between the belt and pulleys, this being achieved by the use of appropriate additive systems. Since lubrication in these units was non-hydrodynamic due to the high pressures involved, surface-active additives were developed which adhered to the respective metal surfaces and increased the friction, i.e. acting like 'molecular glue'. The immediate benefits were the opportunity to transmit much higher torque, or alternatively to use less clamping pressure for lower torque loadings, leading to reduced wear and more efficient power transmission with better fuel economy. This is another example of the need for the OEM and lubricant designer to work together during the design stage of such novel technology.

IVT toroidal drive systems were originally used in the 1930s, and the current system, known as the Torotrak, consists of two tilting rollers running between discs with toroidal profile surfaces. Unlike the CVT, the IVT is capable of providing all ratios from full reverse to high overdrive, and therefore does not need a clutch or torque converter making for simplicity, reduced weight, and lower cost. Again, the properties of the fluid are critical to the success of the drive, and, like the CVT, a high traction coefficient is required.

David Margaroni

END-USERS ADVICE: USING METALWORKING FLUIDS SAFELY

Best practice keeps operatives safe when using metalworking Fluids

METALWORKING FLUID TYPES

There are two main types of Metalworking Fluids (MWFs) - neat cutting oils and water-mix MWF. Neat oils are used for more severe cutting operations or in situations where a particular high surface finish is required. Water-mix MWFs are generally used in less arduous conditions and where the cooling capability of the fluid is paramount. Modern water-mix fluids came about as a result of the need to simultaneously combine the high machining performance and production rates attainable with neat oils with the increased cooling capacity of water.

Water-mix fluids are also known as coolants, not to be confused with car radiator coolants. Both neat cutting oils and water-mix MWFs are used during the machining of metals to provide lubrication and cooling, and to help carry away debris such as swarf and fine metal particles. They can also help to improve machining performance and prolong the life of the cutting tool, as well as provide corrosion protection for the surfaces of work-pieces.

Best Practice Advice

Compared to most other lubricant uses, MWFs need extra care. They require operatives to understand any specific risk(s) associated with MWFs **and to take them seriously**. Current UK regulations: The Control of Substances Hazardous to Health Regulations 2002 require employers to carry out a full evaluation and risk assessment of all aspects of workers interaction with chemicals, including those mentioned on a MWFs safety data sheet.

MWFS CAN ENTER THE BODY

Machinists are at risk from skin contact and oil mist inhalation, as they are generally confined to an environment in which most MWFs are applied by continuous jet, spray or hand dispenser.

Skin Contact

If appropriate precautions are **not** taken, such as the use of mechanical aids, splashguards and adequate ventilation, which prevent contact with the MWF and any associated mist, together with personal protective equipment e.g. gloves, overalls or face shields, contact with the skin, particularly hands and forearms can occur. Skin contact can also occur during the preparation or draining of fluids, handling of workpieces, changing and setting of tools, and during maintenance and cleaning operations. Skin contact risks are also caused by cuts and abrasions or other broken skin or through the mouth if you eat, drink or smoke in work areas or do not wash your hands before eating or smoking.

Oil Mist Inhalation

MWFs can enter the body when operatives inhale the mist, aerosol or vapour generated during machining operations. Exposure depends on the type of machining undertaken and how well the machine is enclosed and ventilated. Exposure is likely to be highest in close proximity to metalworking machines in operations involving high-speed tools or deep cuts, when machines are not enclosed and are used with inadequate ventilation.

METALWORKING FLUIDS CAN AFFECT YOUR HEALTH

Respiratory Health

Workers exposed to high levels of metalworking fluid mist and vapour may observe irritation in the respiratory tract and impairment of lung function. Exposure may also cause irritation to the eyes, nose and throat. Under suitable adverse conditions, bacteria and fungi can grow well in metalworking fluids. Inhalation of these bacteria or toxic by-products can cause irritation of the respiratory tract or flu-like symptoms, as well as making existing asthma symptoms worse.

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Skin disorders

Improper control and use of all types of metalworking fluids can cause irritation of the skin or dermatitis. Regular and prolonged contact with the skin by neat cutting oils can cause irritation of the hair roots. Also, fine microscopic metal particles, which are generated during machining, can damage the skin and make any existing irritation worse. Poor personal hygiene and oily work clothing are key factors that operatives should take action on.

Dermatitis can be caused by: -

- Poor personal hygiene;
- bacteria and their toxic by-products when these are present in the machine sump oil;
- contact with metal sensitising agents such as chromium, nickel and cobalt, which can leach out from cutting tools and grinding wheels into metalworking fluids[1];
- sensitising chemical components within MWFs, refer to the product's COSHH product Safety Data Sheet[2].

Dermatitis usually affects the hands or forearms - the parts of your body most likely to be in contact with metalworking fluids. It can be very painful, but with care most cases can be prevented.

Cancer

In the past, the use of refined mineral oils could lead to skin cancer affecting the exposed skin, often hands and forearms. Also, oil-soaked clothing and oily rags kept in overalls for lengthy time periods has led to cancer of the scrotum. Today, the risks of cancer are likely to be negligible as a result of the use of highly refined oils, the substitution of cancer-causing chemicals in metalworking fluids, improved work practices, regular changes of work clothing and improved personal hygiene.

HEALTH AND SAFETY MEASURES.

Ensure your staff understand the hazards associated with metalworking fluids and carry out the implementation of all recommended health and safety precautions. Staff should follow the instructions and training given by the employer on safe systems of work when working with metalworking fluids. Follow the advice given in the task and control sheets in HSE: *Good practice manual HSG231*[3]. Follow the advice given in the 'Do and Don't' HSE MWF wall chart [4].

Skin protection

Reduce your contact with wet workpieces and surfaces. Don't put your bare hands into fluid sumps or use oily rags to wipe them clean. Wear suitable gloves, overalls, aprons, goggles or face shields if needed (NB: Gloves can be hazardous if worn near rotating machinery or parts.) Take care not to contaminate the inside of your gloves with metalworking fluids when putting them on or taking them off and replace them as often as specified by the glove manufacturer. Pre-work barrier creams can cause skin problems, consult an expert on their use. Use after-work moisturising creams to replace the natural skin oils removed by washing and the metalworking fluids. Cover any cuts and abrasions with a waterproof dressing. Wash regularly with soap and water to remove metalworking fluids from your skin. Avoid using abrasive or powerful solvent cleaners. Wash your hands thoroughly before eating, drinking or smoking. Pay particular attention to washing skin under rings and wristwatch straps.

Control of MWF Mist, Vapour and Aerosol

Use machine splashguards, where provided, to control splashing and misting. Minimise the production of mist and vapour by MWF grade selection and controlling the volume and rate of delivery of the fluid to the cutting edge of the tool. Control any mist or vapour produced by using any enclosures or ventilation provided. Allow a time delay before opening the doors on machine enclosures to ensure that the ventilation has removed all mist and vapour. Report any damaged control equipment and where possible improve natural ventilation in the workroom. Don't use compressed air to remove excess metalworking fluids from machined parts or plant or equipment.

Sump fluid control

Do not discard unwanted cigarette stubs, food, drink, or any other waste and debris into the sump. Operatives should tell their employer or supervisor if they see any layers of scum or large amounts of tramp oil on top of the sump fluid, or if the sump fluid is dirty or smelly. The use of a system cleaner before the sump is re-filled when a complete machine refill is undertaken, especially if the machine has becomes smelly (Monday morning bad-eggs smell) is good practice. System cleaners are used to kill bacteria remaining in a machine after the MWF is emptied and their careful use between refills will usually control bad smells during normal operations. System cleaners have a much stronger action than MWFs and require special handling precautions, refer to the product's COSHH product Safety Data Sheet [2].

REFERENCES

1. **BLF Publication: Exposure to Hardmetals in Metalworking Fluids during Machining Operations.**
2. **COSHH Regulations: Suppliers of all lubricants and chemicals used in the UK, including MWFs and System Cleaners, which have a hazard label classification issue industry product users with a Safety Data Sheet (SDS), which should be referred to when making a statuary risk assessment for the use of the product. See the HSE brief guide to the regulations:** What you need to know about the Control of Substances Hazardous to Health Regulations 1999 **leaflet INDG330 ISBN 0 7176 1827 7**

3 & 4. HSE:

Working Safely with Metalworking Fluids: ***Pack HSE Books ISBN 0 7176 2561 3, prepared by HSE with input from AMICUS-AEEU, BLF, EEF, Envirowise, Energy Institute (was Institute of Petroleum) and MTA (was MTTA), a set of 8 encapsulated task sheets, a Do and Don't wallchart and 10 copies of the leaflet:*** Working Safely with Metalworking Fluids.

BLF METALWORKING FLUIDS PRODUCT STEWARDSHIP INTIATIVE

The current environment within the EU demands that the manufacturers and suppliers of MWFs provide products that are both safe to use and ecologically acceptable. The potential exists for legislation and regulation to significantly affect the formulatory approach to these already complex products in the near future.

As a result of these concerns and in order to positively promote the technological advancements of this sector of the lubricants industry, the **British Lubricants Federation (BLF)** has initiated and supported the formation of a UK based Metalworking Fluids Stewardship Group.

Rod Parker