

Stick-slip

What makes slideways and violins different?



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Introduction

While minimizing friction is a lubricant’s prime target for many applications, this is simply not good enough in machine tool slideways. Smooth and precise slideway operation requires special attention to the friction properties of the lubricant. Loss of frictional control can cause inaccuracies, and in a metal-removal process, these inaccuracies ultimately result in lost machine tool productivity.

Friction fundamentals

Friction is the force that opposes the relative motion of two surfaces in contact. The friction between lubricated surfaces is illustrated by the model plain bearing (Figure 1). While the system is at rest, the shaft and bearing surfaces are in direct contact with each other. Any force applied to turn the shaft must first overcome the interactions between the two surfaces. This is called static or break-away friction. As the shaft begins to rotate, dynamic or kinetic friction comes into play. As a result of the shaft rotation, lubricant is “dragged” into the contact zone, which reduces surface-to-surface interactions and thus causes friction forces to drop.

With increasing speed, the lubricant film in the contact zone also increases and friction drops further. When surfaces are fully separated by the lubricant, friction is reduced to a minimum. If speed continues to increase past this point, friction increases again as the lubricant film grows and generates viscous drag.

The relation between speed and friction in lubricated contacts can be described by the Stribeck Curve (Figure 2). There are three different lubrication regimens:

- **Boundary lubrication:** Friction is dominated by the properties of the surfaces
- **Mixed lubrication:** Both the properties of the lubricant as well as the properties of the surfaces affect friction with a ratio depending on speed
- **Hydrodynamic lubrication:** Friction is governed by the viscosity of the lubricant film

Figure 1

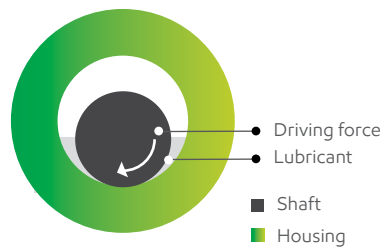
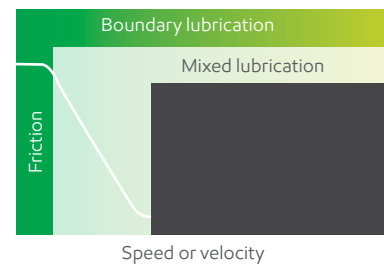


Figure 2



Slideway lubrication

Slideways are sometimes referred to as linear bearings, and the same lubrication principles as described above apply. The differences are that the two surfaces in contact are now flat and the motion is linear instead of rotational. While a plain bearing is designed to operate under hydrodynamic conditions and theoretically could do so forever, slides have to stop when the end of the way is reached, and start moving again in the opposite direction. Therefore, and because slideways typically operate in a stepwise manner, mixed lubrication plays a more important role.

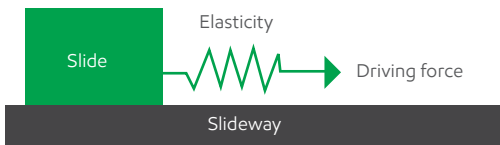
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Most significantly, slideways are far more susceptible to a phenomenon known as stick-slip due to the large amount of time that they operate in a mixed-lubrication regimen.

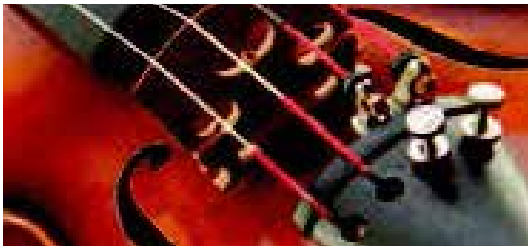
The stick-slip effect

Stick-slip is a phenomenon caused by continuous alternating between static and dynamic friction. It can occur when static friction exceeds dynamic friction, and when there is some elasticity in the system, as illustrated in Figure 3.

Figure 3



When a driving force is applied, high static friction prevents the slide from moving immediately. Instead, the force is loading the spring, by which the driving force exerted on the slide is gradually increased. When the force of the spring exceeds that of the static friction, the slide starts moving. Because of the change from static to dynamic friction, the spring force accelerates the slide while the spring unloads rapidly. Eventually the spring is completely unloaded and starts opposing the slide movement. The slide slows down, while friction following the Stribeck Curve-model for mixed lubrication grows rapidly, until finally the slide comes to a halt and the cycle starts all over again. This jerky movement is what is often referred to as stick-slip.

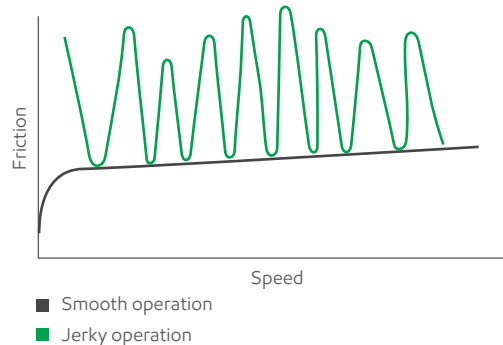


While it may not be visible to the human eye, stick-slip is all around us, producing a range of very audible experiences. Stick-slip renders possible the experience of an enjoyable violin concerto, but also causes the less enjoyable noise of the teacher's chalk on the blackboard or the brakes of a train coming to a halt at the platform. Stick-slip is responsible for the jerky motion of windshield wipers as well as the squeaking sounds of a loose drive belt. Car drivers making their

tires squeal by abruptly changing speed or direction unknowingly make use of the stick-slip effect. And for those who like it big: Stick-slip in seismically active faults is discussed as one potential root cause for earthquakes.

The small list above gives a flavor of how undesirable stick-slip is in most situations. This is especially true for slideways, where stick-slip may cause jerky movements of the slide and the attached workpiece or tool. Such uncontrolled motion can result in inaccurate machining operations, unacceptable finished part quality and lost production (Figure 4). To facilitate smoother operations, special additives called friction modifiers may be added to the lubricant to allow for better friction control. Modern slideway lubricants usually contain a synergistic mix of friction-modifying additives that enable accurate and smooth operation over a range of operating conditions.

Figure 4



Modern slideway lubricants

Modern machine tools and slideway designs demand more of the applied lubricants. Increasing speeds and loads as well as greater expectations for machine accuracy require highly sophisticated slideway lubricants. In addition, there are an increasing number of friction material pairings (e.g., metal-on-plastic) that have different lubrication needs.

Modern slideway lubricants must meet these challenges with a carefully balanced combination of base oils and additives to achieve:

- **Low static friction for easy startup**
- **Continuous transition from rest to movement**
- **Smooth movement even under heavy loads**

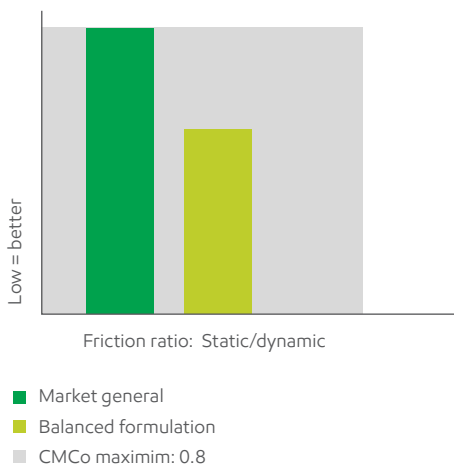
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There are several recognized friction tests to demonstrate frictional properties of slideway lubricants. These tests allow evaluation of static and dynamic friction characteristics of a lubricant and the effect of various slideway materials.

Cincinnati Lamb friction test

In the Cincinnati Lamb friction test (Figure 5), the ratio of static to dynamic friction is determined. To avoid stick-slip, a ratio of 1 must not be exceeded; smaller values enable easy startup and a smooth transition from rest to movement. The Cincinnati Machine Company defines the upper limit of this test to be a ratio of 0.8.

Figure 5



SKC Tribometer

The SKC Tribometer test (Figure 6) determines static friction for steel-on-steel and steel-on-SKC3 (a special plastic material). Lower numbers indicate easier startup and a reduced propensity to cause stick-slip.

Darmstadt rig test

The University of Darmstadt in Germany uses a full-scale machine tool way to simulate real-life machine tool applications. Lubricants can be tested (Figure 7) on various slideway materials and designs under a range of speed and loading conditions and thus unveil significant differences between poor and higher-quality lubricant formulations. Figure 7 shows how a lubricant performs well with steel and steel slides, but very poorly with steel on plastic. A properly

formulated oil will perform well under many different material and speed conditions by reducing friction and thus minimizing occurrence of stick-slip.

So what makes violins and slideways different? Slideway lubricants contain friction modifiers to reduce static friction and thus prevent stick-slip. A violin player applies rosin for the opposite effect: to increase static friction between bow and string to generate stick-slip and produce a sound.

Figure 6

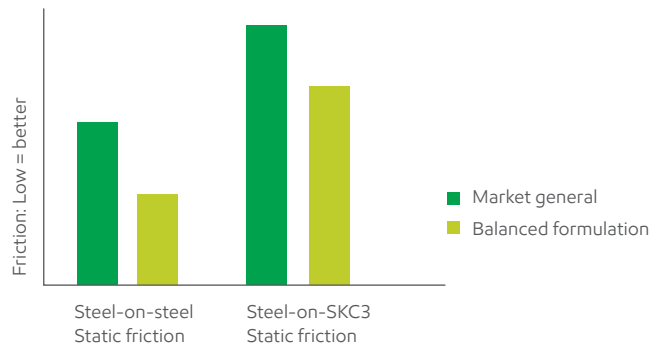
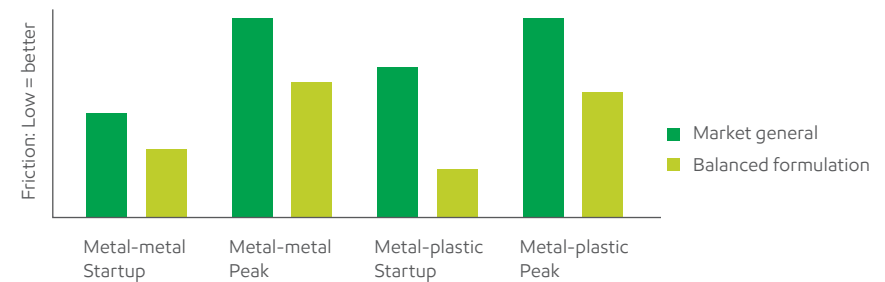


Figure 7



Benefits of reducing stick-slip:

- Greater machining accuracy, no jerky movement
- Improved finished part quality
- Lower wastage/lost productivity
- Increased efficiency over a range of operating conditions
- Easier startup due to lower friction