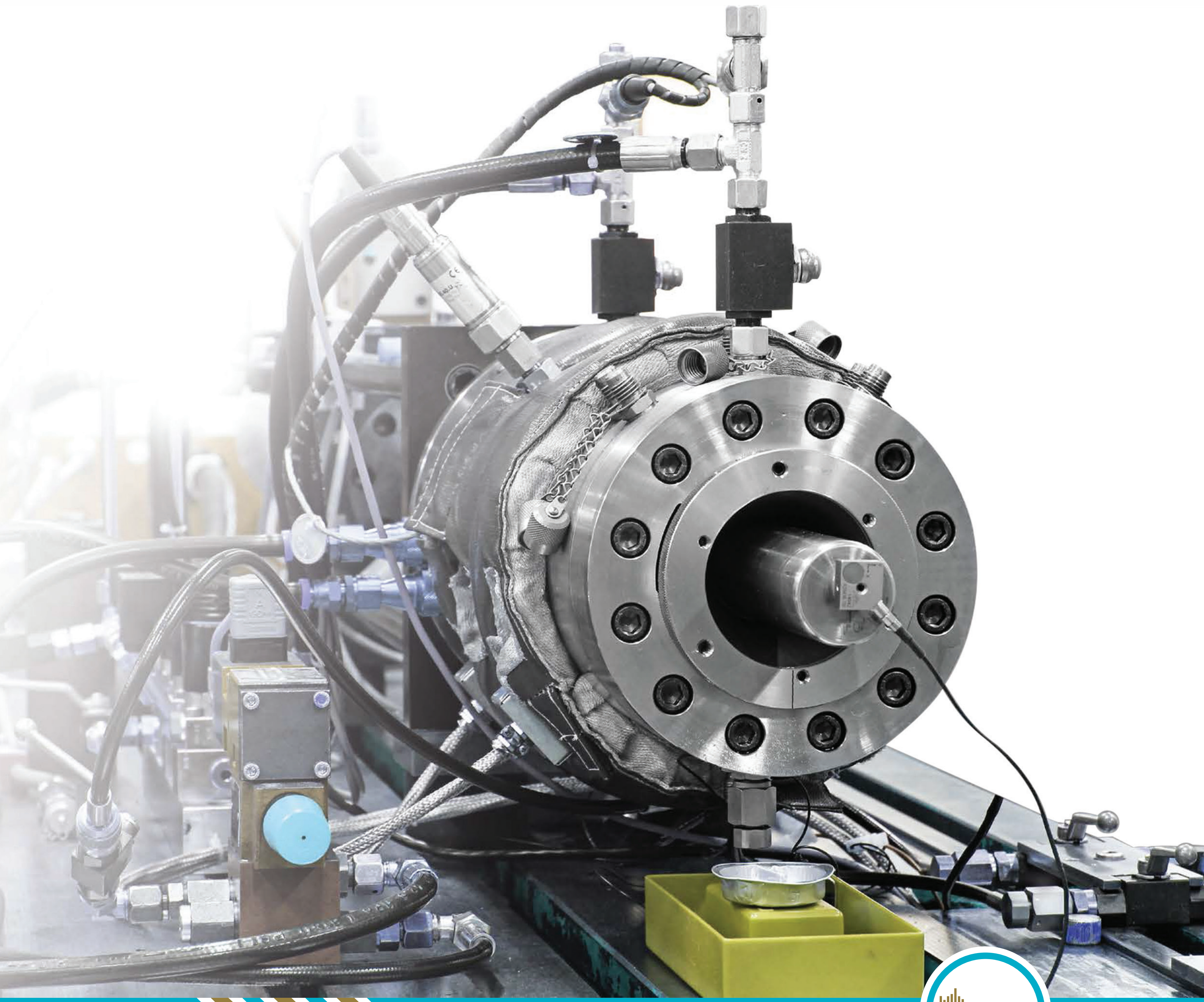
The Stick-Slip Solution

THE IMPORTANCE OF DAMPER INTEGRATION IN DYNAMIC SEALING



Introduction

The force of friction

Friction is a universally important and ever-present force. It makes possible the sound you hear from stringed instruments like the violin. It makes music from the interplay of your finger and a wine glass. It enables communication for insects like grasshoppers, and is the fundamental force active in earthquakes. And, unfortunately for mechanical applications, it can create unnecessary vibration and noise.

Tribology is the art of combating this force of friction; smoothing the interface between mechanical parts and enabling ease of movement. Typically, it's hugely successful in this task – but friction has one more trick up its sleeve. The stick-slip phenomenon: the spontaneous stop-start jerking that can take hold of even the most well-lubricated sealing system. There is, however, a solution to this phenomenon: integrating dampers into machinery to counter the stick-slip effect.

In this whitepaper, we take a closer look at the problem of stick-slip and how dampers can combat or otherwise minimize it. It must be noted that, academically, there exists very little consensus as to the underlying principles of stick-slip – so, this paper will take a practical perspective, addressing how engineers can use dampers to reduce resultant noise and vibration; once again mastering the force of friction.

The Challenge

Understanding the stick-slip phenomenon

Stick-slip has often been observed, sometimes investigated but – academically – rarely agreed upon as to its causes. It would seem to be a characteristic of friction at the atomic level – it could even appear to be a feature of the continuously fluctuating interactions between particles. Either way, it's here to stay; evident in any number of friction-based processes – like the aforementioned violin and wine glass examples. In mechanical sealing and engineering, however, it's a pressing issue, particularly as Jan Zuleeg observes, "Polymers in particular can have a high static friction coefficient and can exhibit stick-slip in tribological contacts."[1] The best we can do therefore is to compensate for it and minimize its effects.

In engineering terms of forces of motion, stick-slip occurs when the static friction coefficient between two surfaces is larger than the kinetic friction coefficient. As another force is applied to overcome the level of static friction, the velocity of one surface will suddenly 'jump', before 'sticking' as the applied force is spent.

In the field of dynamic sealing, this process can be repeated wherever seal interfaces are moving or oscillating against each other, creating harmonic vibration and noise. As Bengisu and Akay note, "At a microscopic level, the true contact area changes as the surfaces move relative to each other. Thus at a macroscopic level, total friction and normal forces are time-dependent phenomena."[2]

In such applications, stick-slip is a 'chattering' behavior that typically occurs at low velocities or whenever there is a large change in friction force relative to a small variation in velocity – as shown below. Thermal fluctuations can also influence the effect – but it all combines to cause sliding surfaces to stick and slip as they pass over each other, resulting in tiny variations that create noise and vibration.

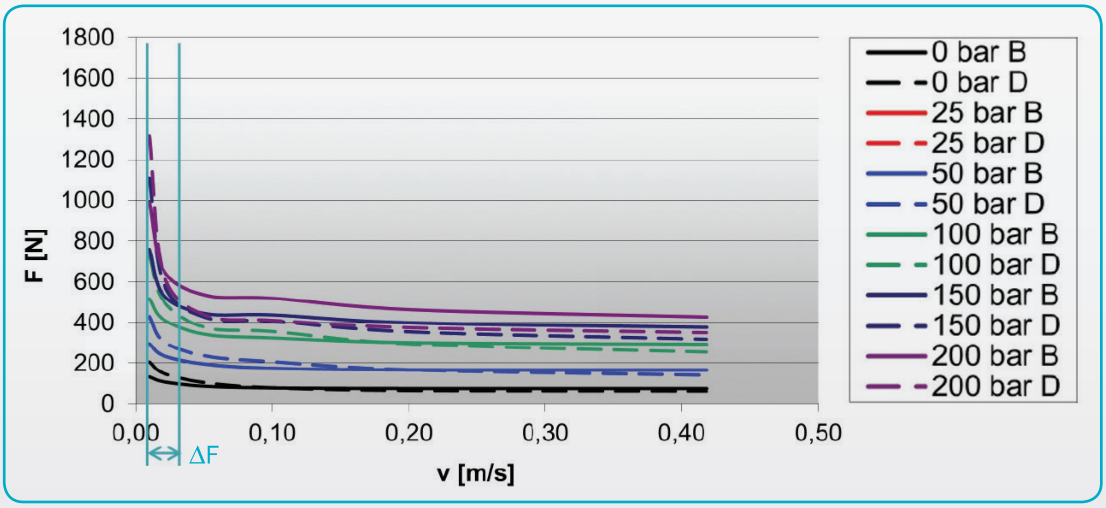


Figure 1: High ΔF leads to the Stick Slip Effect

Further complicating this situation is the fact that the tribological condition in the contact area of a dynamic seal is extremely complex. Boundary conditions, such as the structure of a counter surface in combination with pressure fluid, and the design and material used in the seal itself, have a direct influence on friction – together with pressure, speed and temperature variations.

For example, temperature has a major influence on both oil viscosity and the modulus of the seal material – while, simultaneously, there will be slight variations in the surface roughness values of the contact areas of the seal. Put together, this has a direct impact upon a seal's friction behavior – seen, in this context, in the observation of stick-slip behavior.

The immediate result of this, as has been noted, is increased noise and vibration of the sealing system. However, in the longer term, more worrying consequences could result from this manifestation of friction – such as overshoot and large-amplitude position or force limit cycling in low-velocity applications.[3] In turn, this could cause increased wear on the sealing system, leading to premature failure, cost and downtime. Plus, not to mention the potential dangers to life and wellbeing if the sealing system is used in safety-critical applications and fails due to stick-slip issues. Thankfully, however, there is a clear solution to this issue – as we will learn next...

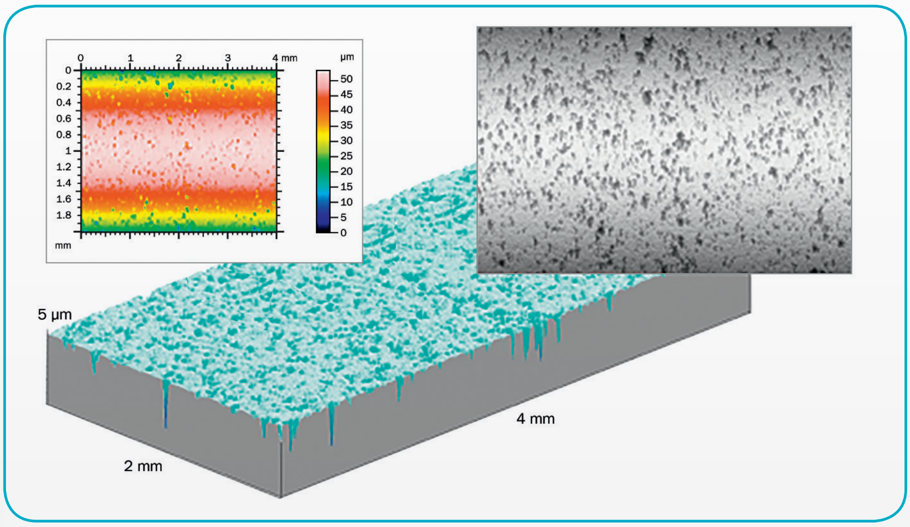


Figure 2: Roughness of counter surface

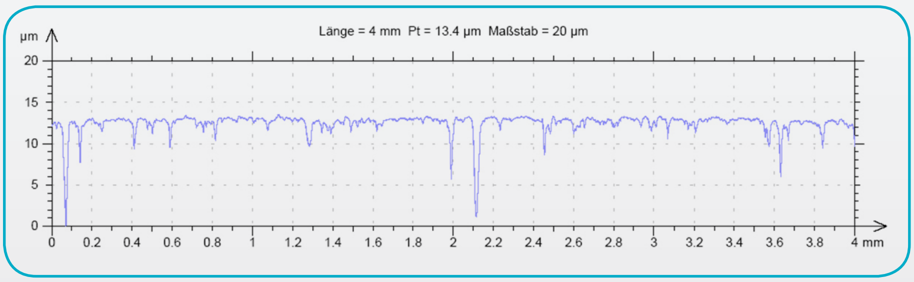


Figure 3: Typical analysis of counter surface that could produce stick-slip effects

The Solution

Damping the situation

Elasticity is key to addressing stick-slip behavior. As you'd expect, many common sealing materials do show elastic behavior – after all, this behavior is exactly why they're used for sealing – and, in the right selection of materials, we can also account for cycling pressures or deflections. However, when devising a sealing system, particularly for low-velocity applications, extra consideration must be given to an elastomeric damping element integrated into the sealing system.

By doing so, the micro-movements created by the stick-slip phenomenon at the sealing contact area can be dampened to eliminate vibration and noise. There is a sound scientific foundation underpinning this fact:
To establish the values of the elastomeric materials (storage modulus E' and loss modulus E'') in hydraulic seal applications the following formula is used:

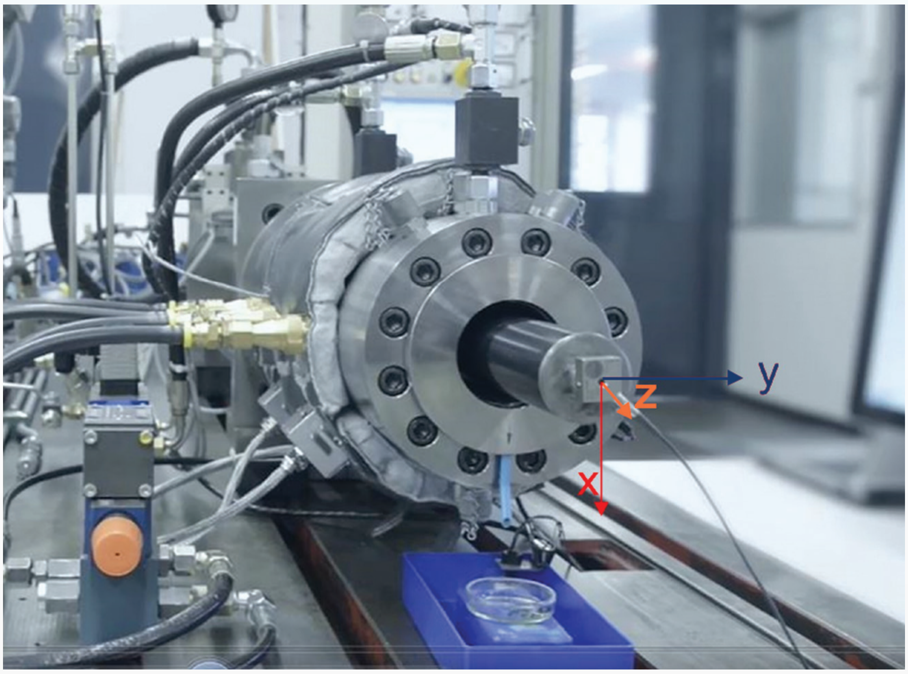
$$E^*(iw,T) = E'(w,T) + E''(iw,T)$$

While to calculate the ratio between the loss and storage modulus, where the loss angle δ describes the phase displacement between elongation and tension:

$$\tan\delta = \frac{E''}{E'}$$

The basis here is that the elasticity of dampers provides a balance of stored energy for recovery and absorbed energy, created by the relative movement of molecular chains. In simpler terms, dampers compensate for variations in movement, ensuring smoother operation.

So, how does this work in a test scenario? To demonstrate, we fitted a rod seal test rig with a three-dimensional acceleration sensor to measure frequencies along the X, Y and Z axes of movement. We also ran the tests on a seal with an O-Ring in pretension, both without and with an axial damping element, to observe the effect on stick-slip behavior.



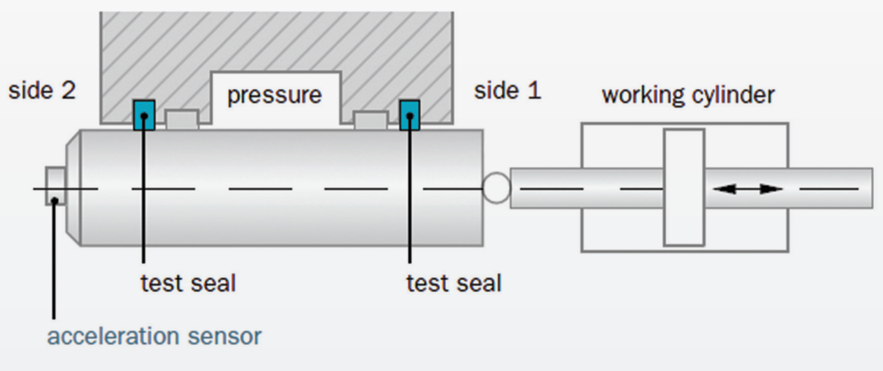


Figure 4: Test rig with acceleration sensor

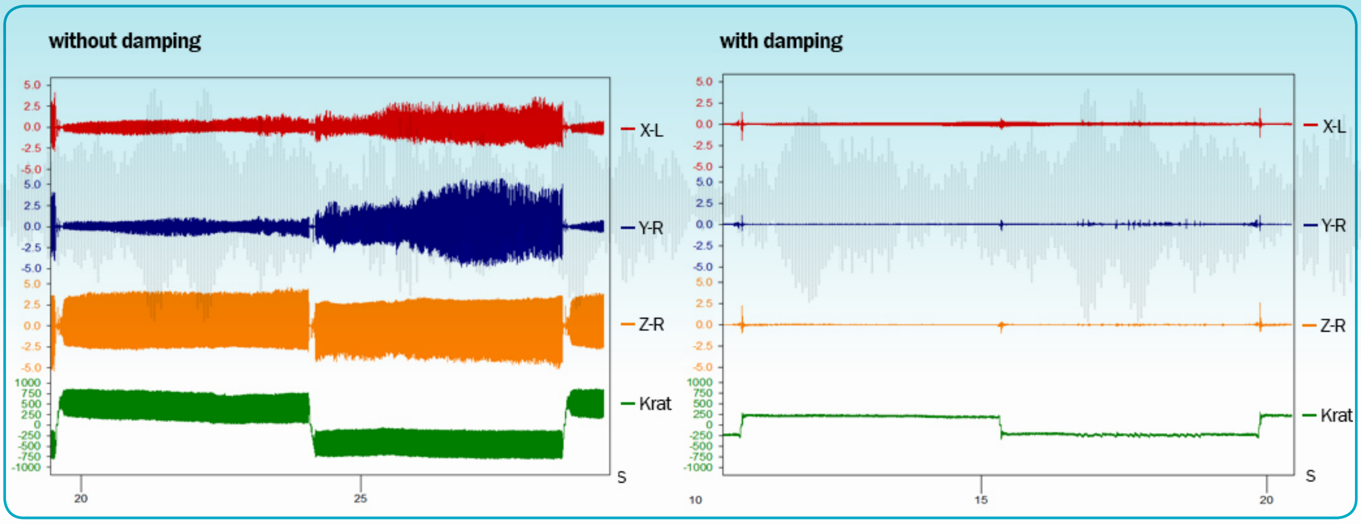


Figure 5: Comparison of vibrations at low speeds with and without damping

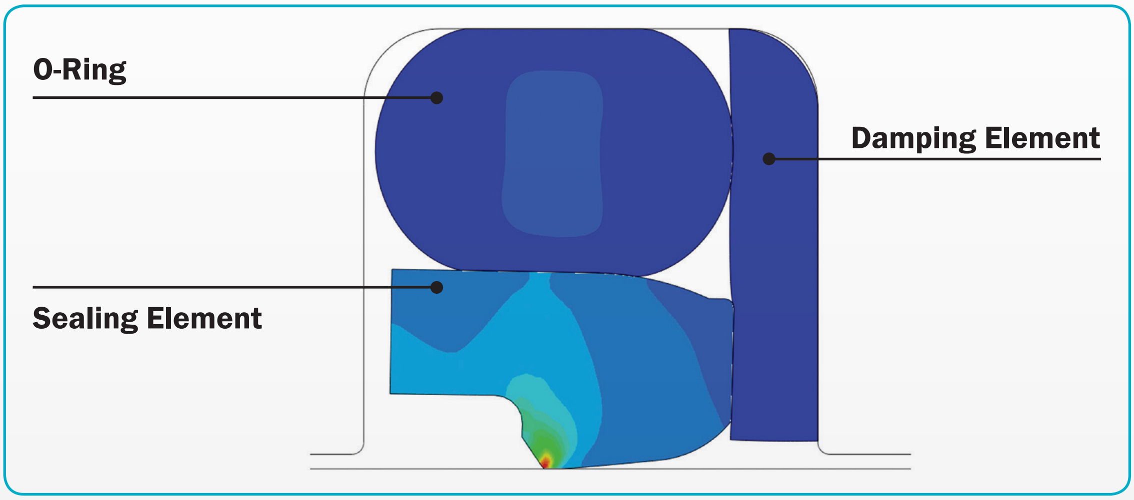


Figure 6: FEA of Turcon® Stepseal 2K including a damping element

The reduction in noise and vibration of the test rig demonstrated how effective damping can improve equipment performance in the real world – from increasing the reliability of agricultural equipment to enhancing repeatability and periodicity in high-volume process industries. It is easy to see how positive damping can account for the natural occurrence of stick-slip in mechanical sealing – and, as technology and materials science advance, this compensation will improve to create optimal sealing systems for ever-quieter, more efficient machines.

Partnerships

Putting it into practice

So, we've seen that damping can effectively counter the occurrence of stick-slip in mechanical seals – but this paper is only intended to scratch the surface of this subject. A brief primer on what stick-slip is and how to minimize its effect. There's much more to the subject than this...

Integrating damping elements into seals is not as simple as it sounds. A whole system approach needs to be taken – and this is an integral part of the modern lubrication management paradigm.

To begin with, planning for the application and environment in which your sealing system will operate is critical – and will inform your choice of sealing materials and damping element. There is a need to gauge the probable causes and severity of stick-slip in your system right at the outset, so for this reason, extensive testing and prototyping will be required. Given how fast industry moves, however, as well as the fact that damping in the sealing system is a highly niche field, it makes sense not to take it all on yourself.

Instead, get advice from an expert in lubrication and tribology. A partner who can 'plug into' your business, training and educating your people in sealing and lubrication, while working closely with you to create long-term, sustainable damping solutions as part of more efficient, effective and reliable sealing systems.

Summary

In closing

The stick-slip effect is, and always will be, a feature of engineering and the wider universe. In fact, it's set to become even more prevalent. As the evolution of technology in hydraulic and mechanical systems continues to gather pace, increasing power and efficiency, we are seeing machinery become lighter in construction, and more flexible in speed capabilities. This lightweight, precision-engineered future will make the issue of stick-slip even more pressing over the coming years.

At the same time, businesses, operators, users and consumers alike demand more from their machinery. They need quieter, smoother running – and certainly not the squeals, whirrs, rattles and clanks of a system suffering from stick-slip, whether it's a machine involved in heavy construction or a piece of precision engineering.

So, damping is a vital consideration in the overall sealing system. The choice of materials, design variations, testing and planning are all essential to overcome the noise, vibration and performance challenges set by stick-slip. From speed and temperature control to pressure fluid viscosity and damping selection, solutions are present. But, as we've seen, the most important ingredient is a long-term, whole-system approach to sealing. An approach rooted in tribology and effective lubrication management. And, given that the stick-slip effect permeates our physical universe even at the atomic level, damping is a critical part of your engineering universe.

References

1) Zuleeg, J., 'Controlling Stick-Slip Noise Generation with Lubricants', http://www.sandv.com/downloads/1606zule.pdf (retrieved January 2017).

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3) Dupont, P.E., 'Avoiding Stick-Slip Through PD Control', http://www.bu.edu/biorobotics/publications/94_Tac_friction.pdf (retrieved January 2017).

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