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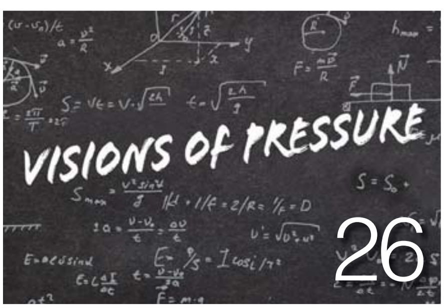

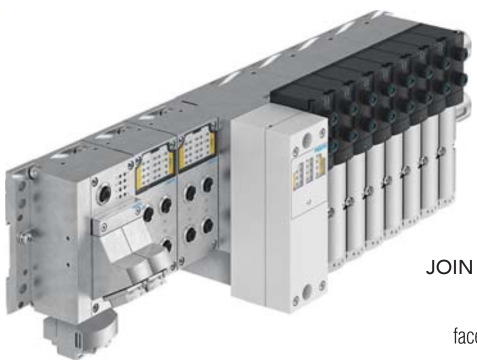

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Finding Your Best Path

AS WE EMERGE FROM 2020, if not from all of the problems that have besieged us, it's useful to ask if we've learned anything this year. As we gaze toward 2021, the answer to that question may define us.

There are some glimmers of light against the darkness of the year. We changed the way we did business, and we did it on the fly. We quickly implemented technology when and where it was needed. It didn't require fighting through levels of corporate wrangling to find and deploy solutions designed to maintain social distancing in our plants, to automate operations to overcome manpower shortages and to provide the protective equipment needed to keep workers as safe as possible.

We asked an enormous amount of our workforce in 2020. Most of those stories were drowned out by the political and social upheaval these measures required, and yet the workers persevered. Our workforce saw the value to themselves and their community. They understood the sacrifices it would take. Manufacturers of all sizes moved forward and helped drive manufacturing back into growth mode by summer.

We also saw the weaknesses in our system. In particular, supply chains were challenged and stretched and recreated, and that work isn't done as of yet. Regrowing the global economy will take a reimagination of how we move from raw materials and parts to finished goods, and from there to delivery to consumers.

Consumers have changed as well. Boxes are delivered to our front stoop. We still are learning the value and dangers of an on-demand economy, and that too will take some reconciliation once the pandemic is better under control.

We have benefitted from our technology improvements and our determination to stay strong despite the pandemic and the struggles it created. Did we learn anything? It's a fair question; we're far from out of the woods, and yet there remains, remarkably, a ray of hope.

But when you're in the middle of the woods and you cannot see the way out, the first thing you need to do is orient yourself. You need to find your direction before you can hope to get out of the woods. Going backwards isn't really an option. Heading off in just any direction keeps you moving, but may not get you any closer to the edge of the woods. The only way to get where you really want to go is to find your best path and keep moving forward. hp

News

High Modulus Plastics for OFF-HIGHWAY EQUIPMENT

The extreme conditions off-highway equipment experiences demand high-performance components.

Exploring the chemical makeup, product types and future uses of these highly durable materials.

Off-highway vehicles operate in conditions that challenge hard-working components and the materials they are made of. Those vehicles and ancillary equipment must withstand summers in the Australian Outback, with its 130°F temperatures, as well as travelling though Siberian snowstorms at –60°F. They can also be found on mining sites where they are exposed to sulfuric acid, which can severely damage polymer-based parts such as guide rings. And maintaining this off-highway equipment in extreme conditions is a challenge. So low-maintenance, long-life parts are a must; they can make the difference between hitting a deadline or paying a late fine.

One group of materials that stands up to such conditions are high-modulus thermoplastics. The elastic modulus (stress/strain) is a mechanical property that measures a material's elasticity; the higher a material's modulus, the more stress, or force, is needed to deform or compress it.

BASE POLYMERS AND FILLERS

Although there are three main groups of high-modulus plastics—amorphous thermoplastics, imidized materials and semi-crystalline thermoplastics—only the third one has affordable materials suitable for processing into guide rings, bearings, back-up rings and structural components.

Within semi-crystalline thermoplastics, several base polymers are commonly used in extruded parts for use in off-highway hydraulic systems:

- Polyamide (PA or nylon)
- Polyphthalamide (PPA)
- Polyetheretherketone (PEEK)
- Polyoxymethyline (POM or acetal)
- Ultra-high-molecular-weight polyethylene (UHMW-PE)

These polymers vary in terms of temperature resistance, tensile strength, flexural modulus (bending stiffness), Izod impact (toughness/resistance to impact) and chemical resistance. For example, PEEK materials are extremely strong and temperature resistant, but UHMW-PE is tough and abrasion resistant.

Several different fillers are used to add strength or modify the tribological effects of these thermoplastics. For example, adding a polytetrafluoroethylene (PTFE) powder to the pellets used in injection molding can reduce friction and improve the wear characteristics of PEEK materials. And adding molybdenum disulfide (moly) to nylon leads to a harder and more wear-resistant surface.

Glass or carbon fibers can be added to thermoplastics to add strength. A common example is adding glass to PA to enhance strength and reduce the amount of water the final product will absorb. Similarly, adding carbon fiber to a PEEK improves wear properties and extend the life of components such as guide rings in high-temperature applications.

Generally speaking, the higher the temperature resistance and strength of one of these thermoplastics, the higher the cost. For example, PEEK materials are extremely strong (operating stress of up to 11,000 PSI) and resist temperatures up to +450°F. However, this performance comes at a cost. For some applications, the additional cost is worth it; for others, it may make sense to instead use a POM (acetal), UHMW or a PA with a filler such as glass.

Components such as guide rings, bearings/bushings, back-up rings and structural parts can be created from high-modulus thermoplastics and will be lighter than their metal counterparts. Individually, the weight difference per part is negligible, but a change from using thermoplastics instead of steel components that are used in several places on a piece of equipment can reduce overall weight significantly. For example, a shoe pad used in four to six locations on a forklift is traditionally made of cast steel. They can be replaced with glass-filled nylon pads that still withstand the same impacts and loads as the steel component but at 1/6th the weight.

Additionally, high-modulus plastic rings can be modified to include internal lubricants, letting them be used in systems that don't require petroleum-based greases and are more environmentally friendly.

Other components that could benefit from being made of high-modulus thermoplastics include:

Guide rings made with these plastics can be designed to absorb side load forces in pistons and rods in hydraulic cylinder while eliminating metal-to-metal contact. They also provide a coefficient of friction, a long service life, good chemical resistance and high load capacity, as well as a lower wear-rate than metal. The guide rings can be purchased with an angled cut for linear motion, a straight cut for rotary motion or a step cut for special applications.

Bearings and bushings of plastic, like guide rings, prevent metal-to-metal contact and reduce friction, extending the life of non-hydraulic systems.

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High-modulus thermoplastic guide rings from Trellborg Sealing Solutions (HiMod Slydrings) offer increased reliability and operating life for off-highway applications.

Back-up rings are installed in grooves to protect and support elastomeric seals and stop them from being pushed into the sealing gap. They are often used in hydraulic cylinders for excavators and agricultural machines.

Structural components made of plastic for off-highway vehicles, such as wear pads and thrust washers, are lighter and often less expensive than those made of metal.

For off-highway parts that need a combination of properties of high-modulus thermoplastics and those of other polymers, co-injection might be the answer. It combines two polymers in single operation to create a multi-functional component. One example would be an elastomeric material that acts as a seal and a scraper combined with a stronger thermoplastic material that could act as a bushing or guide ring. This component would be an ideal molded rod end in a hydraulic cylinder for an excavator bucket on an off-highway vehicle.

Although the technology for these types of co-injection operations exists, it can be challenging for designers to understand how to use it most effectively. To get the expertise, companies should work with a supplier with experience with co-injection molding. ■

TOM ZOZOKOS is a product line director and BETH FIGLIULO is the fluid power segment manager/Americas for Trellborg Sealing Solutions (www.trelleborg.com/en).

ARMORING A VALVE AGAINST MOLTEN SALT

ENGINEERS AT SANDIA NATIONAL LABORATORY are working on designs for next-generation solar plants that capture solar energy by heating and liquifying chloride salt, which then gets stored and transferred to a generating plant where it is used to create electricity. One aspect of the project involves making valves that can safely and reliably control the flow of the corrosive, molten salt, which can reach temperatures in excess of 1,400°F (750°C).

Even though it is extremely corrosive, molten salt is the preferred liquid for delivering and storing liquid energy because it retains its viscosity, as opposed to water, which turns into steam at such high temperatures. Molten salt also maintains a more consistent temperature as it flows throughout the power plant collecting and delivering energy.

Another challenge in building better valves is the continually changing temperatures, pressures and flow rates during operations, not to mention outside temperatures than dip extremely low in the winter. Valves freezing and thawing due to weather makes them expand and contract, which can weaken the valve. The valves must also maintain constant heat transfer and fluid flow, despite changes in outside temperatures and operational tempo.

The overall goal of the project is to have a feasible plant design that will bring solar power down to five cents per kilowatt hour. To do so, the engineers must design the valves to handle much higher temperatures than current molten-salt solar plants. If successful, the redesigned valves could be used for energy transfer in nuclear plants and petrochemical factories.

Current molten salt valves are made of expensive chromium-based materials susceptible to corrosion because more corrosion-resistant, high nickel-based materials are not strong enough at the anticipated temperatures. Sandia engineers will try to develop less expensive base materials for the valve. They plan to clad the valve with a durable, corrosion-resistant composite. This should make it more durable and lower manufacturing costs.

The Sandia team is also adding shapes and trim inside the valve's piping to buffer pressure surges and pulses created as the molten salt passes through; they also dissipate heat to prevent valve damage. The team also reformulated packing materials to create a modular quick-change method for replacing bellow seals, which can be destroyed if activated in the presence of frozen salt.

The new design will potentially be online by 2030, helping to lower the levelized cost of solar-based electricity—the cost of the plant divided by its lifetime energy output—which has become increasingly competitive for developers to win solar projects. ■

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BOB VAVRA | Senior Content Editor

2020 Salary & Career Report

Professionals find rewards, satisfaction beyond the paycheck.

Engineers Remain Optimistic, Even After a Tough Year

Even in a year of upheaval and uncertainty, engineers who participated in the 2020 Hydraulic & Pneumatics annual Salary & Career Survey offered enthusiasm for both their profession and for their outlook on the future.

With the COVID-19 pandemic ravaging the world at the end of the year, respondents to this year's survey said their companies largely are staying the course in anticipation of a recovery in 2021. While this hasn't delivered large pay increases, it also hasn't mean severe cuts.

Look beyond the compensation and you find a group of professionals intensely proud of their work and fundamentally committed to its future.

"It is a very rewarding profession and provides a sense of accomplishment when an idea become a reality and [it] has a profound effect on some one's life or advances technology in some manner," said one respondent.

"Engineering if done consciously makes for a more makes more wholistic person that you were," said another engineer. "It teaches you wholistic thinking, a never-die attitude, problem solving and many more things."

"It is an amazing profession full of discoveries and developments that change and make you study, research, innovate all the time," another respondent added.

Overall, 82% of respondents said their current job was satisfying, with 15% stating they were "extremely satisfied." As another respondent put it, "Engineering is a profession where your knowledge and wisdom are respected. The satisfaction of seeing a person use your engineering output to better their lives is the greatest feeling."

A CHALLENGING YEAR

The challenges of 2020 were unlike any faced in a generation. The impact of COVID-19 changed the way many engineering professionals approached their job and forced other to alter the way they worked.

The pandemic forced 29% of respondents to do more work from home in 2020, and another 8% said they would continue to work from home after the pandemic. Still, more than one-third of respondents said they do not work from home now.

There were layoffs from the pandemic, as 42% of respondents said their company had reduced their workforce and 22% had used furloughs. New hiring also was put on hold by 45% of respondents and 30% saw a cut to engineering department budgets. But almost one-third of respondents said there was no impact on their operations.

The pandemic also changed the way engineers interact with each other and their industry. Three-quarters of all respondents are required to wear masks or other protection at work, while 57% of respondents saw a ban on company travel. This extended to trade events, as 47% were barred from those gatherings. Most trade events have been cancelled or turned into virtual events in the second half of 2020, and those cancellations already have been extended well into 2021.

That has forced engineers to continue

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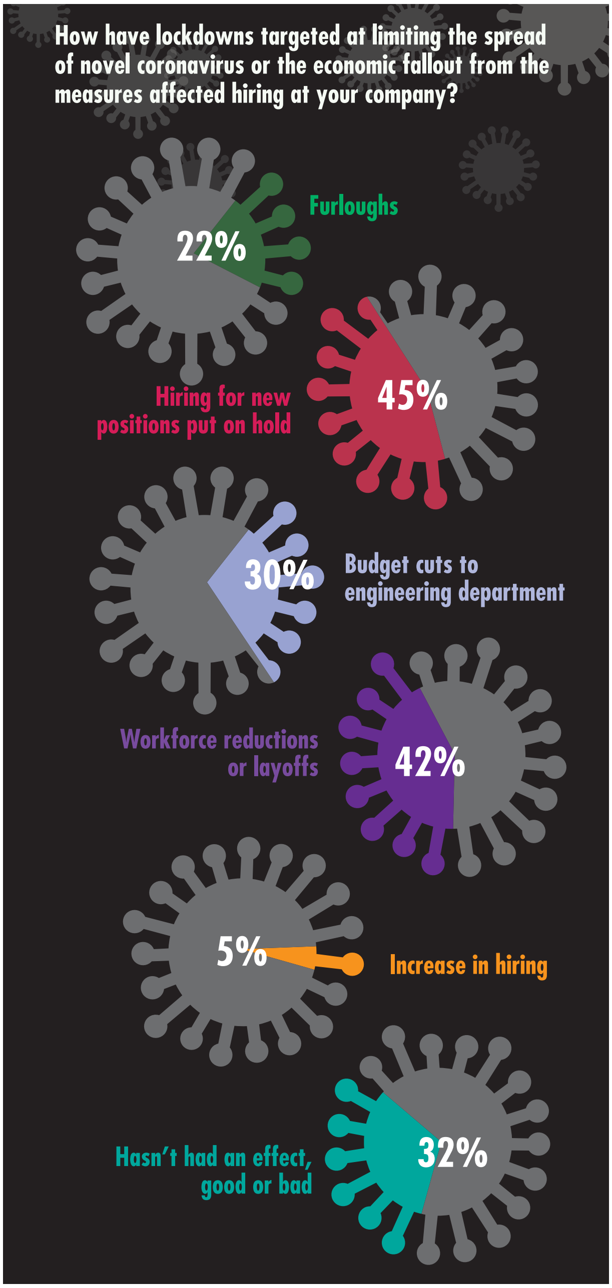
their education using other information channels. Some haven't changed much: More than half use videos or print magazines such as *Hydraulics & Pneumatics*. Webcasts are viewed regularly by 48% of respondents, with publication websites used by 46% and white papers by another 36%.

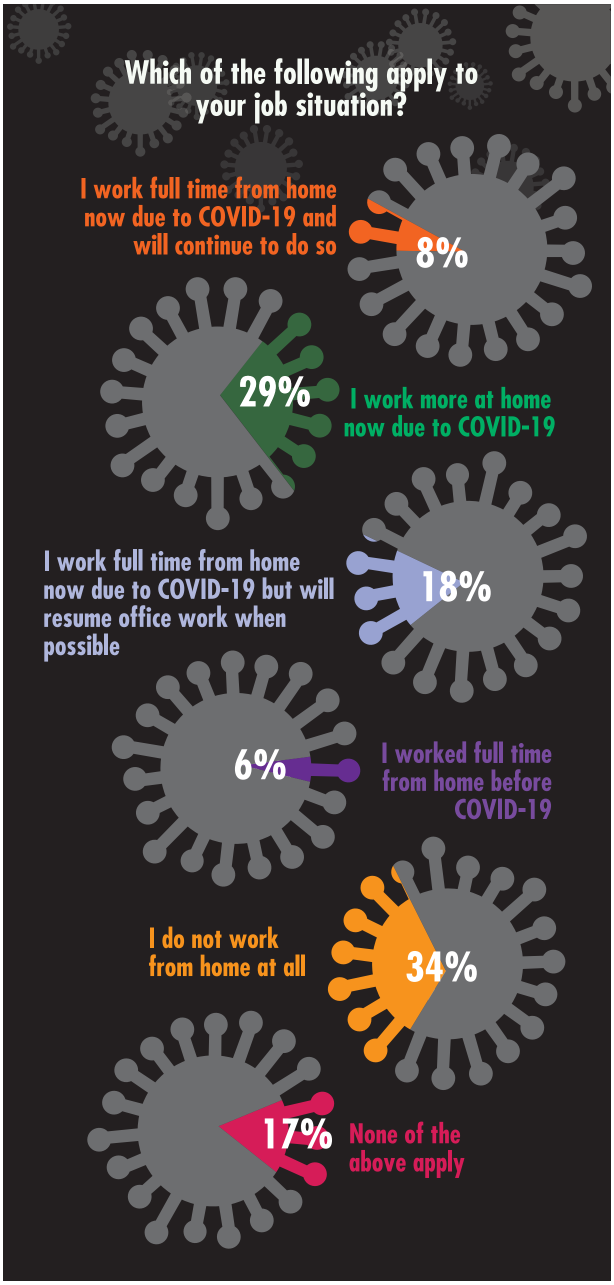
The biggest challenge pneumatic and hydraulics engineers face is the one they've confronted for decades: time. More than any other issue, the lack of time to continue learning about new technologies or simply being able to do their work within the confines of a daily schedule is a continuing barrier. There were 43% of respondents who work more than 40 hours in a week on the job, and 31% said they worked up to 10 hours a week at home on top of their work schedule.

EDUCATION AND SATISFACTION

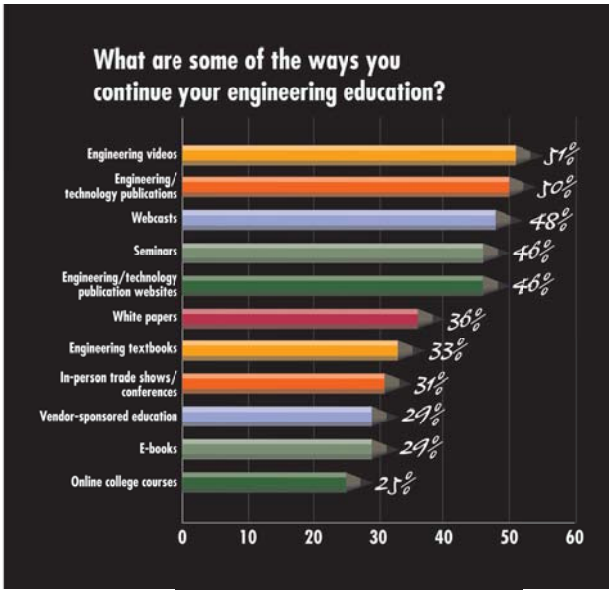
The engineers who participated in this year's Salary & Career Survey are an experienced and educated group: 75% have at least a Bachelor's degree and 25% have earned a Master's or doctoral degree. Their job experience is extensive: 63% have been in engineering more than 20 years and one-third have been in the industry at least 30 years.

While that may suggest there are more engineers ready to leave the profession than





are entering, only 51% of respondents believe there is an engineering shortage today. They also see a strong future for engineering, with two-thirds stating it had the same potential for career growth and advancement as there was five years ago, and 89% would recommend engineering as a career to a young person.



The engineers who participated in this year's Salary & Career Survey are an experienced and educated group: 75% have at least a Bachelor's degree and 25% have earned a Master's or doctoral degree.

Their enthusiasm on this point is great and profound. One respondent wrote, "Engineering will always be in demand. I suggest the study of robotics/automation as the world is moving to replace as much labor with robots/automation as financially practical."

"Not everyone's cut out to be an engineer," another respondent wrote. "It is those few that have the aptitude and interest that will succeed in the profession."

One other survey respondent sees his work as something that benefits the larger world as much as his own career. "You have to engage your brain," he wrote, "and the sense of satisfaction when you bring a project to its conclusion or find a solution for a problem and sometimes what you do can make a difference." hp

THOMAS SCHWARZ, WOLFGANG SWETE, SILVIO SCHREYMAYER, MARTIN WALLNER, EMMANUEL PICHLMAIER AND MICHAEL LIEBMINGER | SKF Seals

Test Results Compare Buffer Seals for Hydraulic Cylinders

Tests check the two most common buffer seals to determine what applications each is best suited for.

AT A GLANCE

- Testing determines which factors affect buffer seal performance.
- The wrong seal in an application can be damaged.
- It is critical that designers check out their applications' operating parameters before selecting a buffer seal.

To examine and compare the two most common types of buffer seals—high-sealability and friction optimized seals—and the parameters that extend their service lives, engineers developed a test rig that covers all application parameters to get an overview on seal performance.

What was learned during these investigations should help engineers understand the seal types and the interactions between seals so they can better specify the most appropriate ones for their applications.

GATHERING DATA

The test-rig consisted of a pressurized test cell, a piston rod, an electrical drive and a hydraulic pressurizer. The hydraulic oil had a viscosity class of 46. An additional pressure sensor was installed between buffer and primary rod seals to investigate possible intermediate pressures.

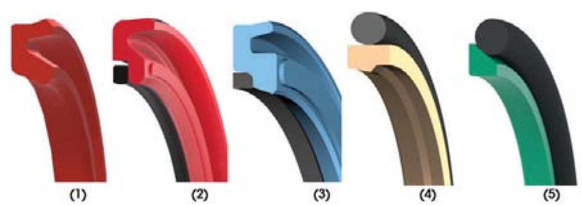
TEST PROTOCOLS

During verification testing, five buffer seals were examined:

1. Lip seal with a round sealing edge and no back-up ring.
2. Lip seal with friction adjusted for heavy duty applications made of polyurethane with a thermoplastic back-up ring.
3. Lip seal made of polyurethane with a thermoplastic back-up ring with high sealability for medium to heavy duty applications.
4. Glide ring seal with an O-ring energizer for light- to medium-duty applications, made of PTFE 40% bronze with an NBR O-ring.
5. Glide ring seal with an O-ring energizer for light- to medium-duty applications, made of hard grade polyurethane and an NBR O-ring.

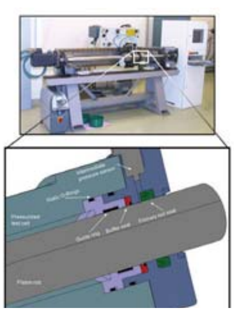
The following performance criteria were considered and analyzed during or after testing:

The seals' friction force levels and bands. The friction level and band should be minimized to improve long-term performance. High friction levels increase temperatures, which shortens seal life. The height of the friction band indicates how well the primary rod seal is lubricated.

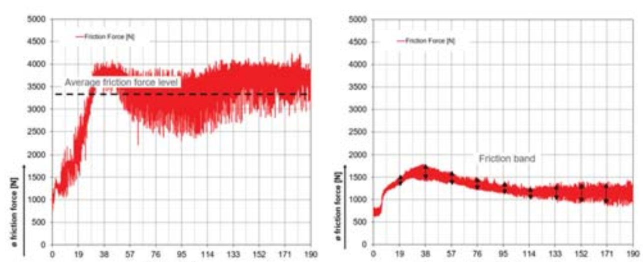


These five buffer seals were tested, and all used the same molded and trimmed U-Cup as the primary rod seal.

Seal type	Buffer	Rod
Seal housing [mm]	Ø50xØ65,5x6,3	Ø50xØ65x10
Seal pressure [bar]	up to 250 (running-in test; pre- and post performance test – push/pull pressurization) up to 400 (long term test – constant pressurization)	
Max. pressure spikes [bar]	400 (only pre- and post performance test)	
Oil temperature [° C]	80	
Speed [m/s]	0,1 – 0,5	
Total Distance [km]	290	
Extrusion gap [mm]	0,25	
Stroke [mm]	1000	
Lubricant (Oil)	Shell Tellus S2 MX 46	
Piston rod type	Hard chromium piston rod	



This schematic shows the hydraulic test rig and main operating parameters. There's also a table of its main operating parameters.



These two traces compare a high sealability seal (left) with a friction optimized buffer seal (right).

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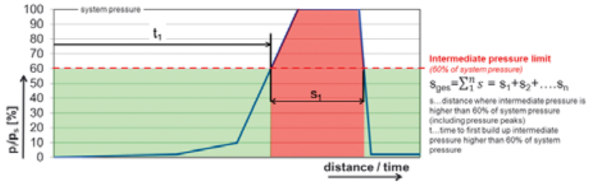


This graph shows the ratio of intermediate pressure to system pressure over distance and time. If the ratio is above 60%, the buffer seal will not absorb pressure spikes.

Intermediate pressure between buffer and primary rod seal. Buffer seals must prevent intermediate pressure build-up to protect the primary rod seal. In heavy-duty applications, pressure spikes can exceed 600 bar and should be handled by the buffer seal. The primary rod seal is often a U-cup made of polyurethane; it handles pressures up to 400 bar. Therefore, the overall distance where intermediate pressure is higher than 60% of the system pressure and the time to build up intermediate pressure were analyzed.

Visual analysis of buffer and primary rod seal before and after testing. Researchers looked at wear and extrusion on the seal, as well as discoloration. The before-and-after comparison provides direct evidence of seal performance. For example, if the buffer seal is not working properly and there's evidence of leaks, the primary rod seal will show high extrusion due to intermediate pressure. And if there's discoloration at the sealing lip of the primary rod seal, the buffer seal was too tight and did not allow enough lubrication to get to the primary rod seal.

Leaks. Generally, oil that escapes from the hydraulic cylinder into the environment must be kept on a minimum level. Recall that the chances for leaks increases as the ratio of outstroke to instroke piston-rod velocities increases. In addition, the primary rod seal needs good back-pumping ability. This is important for the buffer and primary rod seals.

The lubrication level determines the friction level. But the lubrication level also determines the number of leaks. The lubrication level is influenced by instroke and outstroke piston rod velocity, as well as seal design and hydraulic oil used.

The tests were done in four phases:

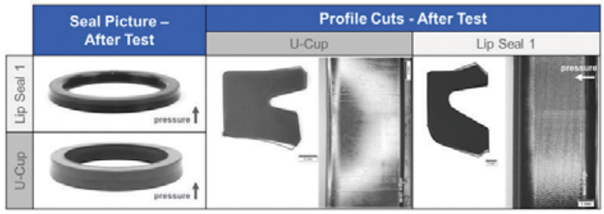
Running-in phase, to set up constant starting conditions for each seal to guarantee correct comparisons.

Pre-performance phase, to evaluate characteristics such as absorbing pressure spikes and time to build up intermediate pressure.

Long-term phase, to evaluate characteristics such as wear and extrusion resistance.

Post-performance phase, to evaluate characteristics as the seals age.

The testing parameters include several different pressure and piston rod velocity cycles, with pressures and piston rod velocities set so that pressure was low when speed was high and vice-versa. This mimics an operating excavator; the high loads are mostly at low operating speeds, and the higher speeds go with low loading.



Visual analysis of Lip seal 1 after an extended pre-performance test.

TEST RESULTS

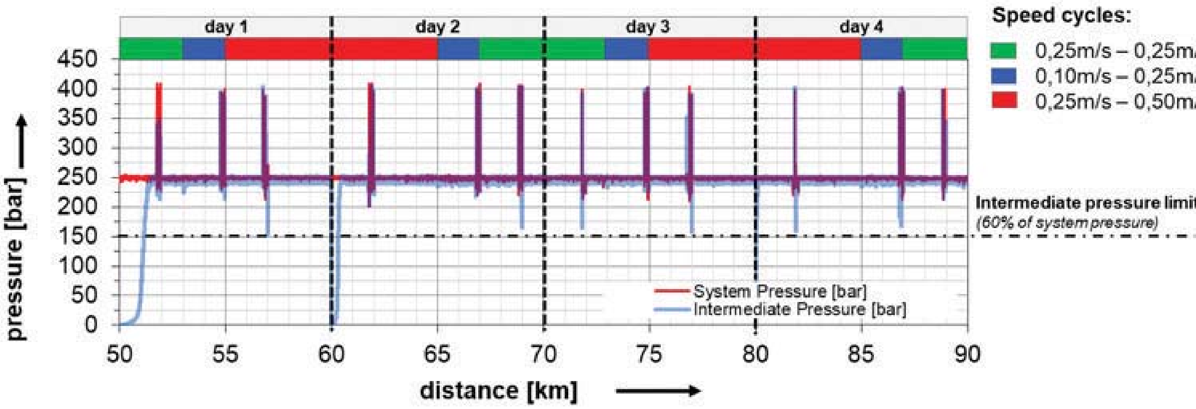
1. Lip seal without back-up ring. The graph on p. 20 shows the system and intermediate pressure curve of seal #11 at the pre-performance test. It is clearly visible that the intermediate pressure increases immediately. Over 96% of the entire testing distance, intermediate pressure equaled the system pressure which means no buffering capability is available.

After the running-in phase, the first day of testing started with constant in- and outstroke piston rod velocity. After about a kilometer of motion, intermediate pressure equals system pressure. After a full system shutdown overnight, the second day started with twice the outstroke piston rod velocity. This caused a quick build-up of intermediate pressure to system pressure, which system pressure and pressure spikes must be handled by the primary rod seal. In this case, the pre-performance test was extended but it was not possible to decrease the intermediate pressure.

> Future evaluations of rod seal packages, including buffer, primary rod seal and wiper, are already underway.

The above images show damage to the seal's profiles. The buffer seal didn't show any major damage. But the primary rod seal already shows some wear and extrusion after a testing distance of 90 km. The seal did no work as expected.

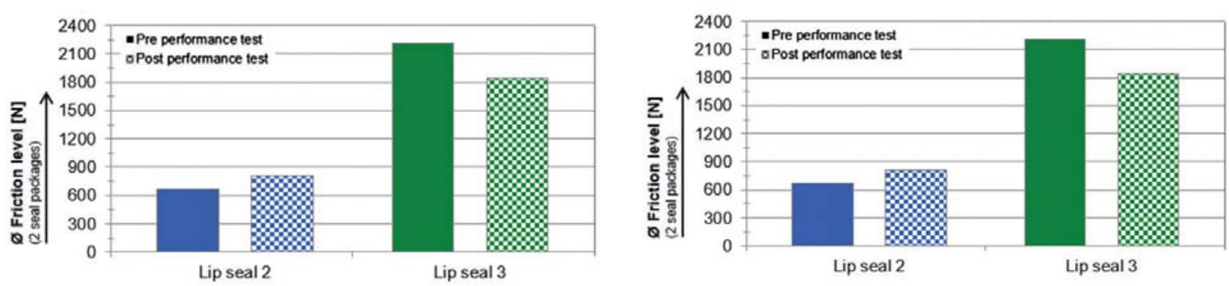
2 and 3. Lip seals with back-up ring. The above images show the friction levels before and after the performance tests, as well as changes to the



seal profile after the entire endurance test of both lip seals with back-up rings. The difference between a "friction optimized" buffer seal (2) and a "high sealability" buffer seal (3) can clearly be seen in the different friction levels. The increased friction of seal lip #3 increased the entire system's temperature and led to higher wear on the back-up ring. Furthermore, the primary rod seal's lip is discolored due to inadequate lubrication.

There is only a slight extrusion tail at the back-up ring of lip seal 2 and nearly no visual damage of the sealing element. The rod seal lip preload was less affected when combined with lip seal 2 due to lower operating temperatures as a consequence of better lubrication.

The friction level for 3 decreased between pre- and post-test measurements. This likely stems from the smaller back-up ring cross section due to wear. Seal 2, on the other hand, had a slight increase in friction after the tests. It can be explained by more contact area on the back-up ring caused by light deformations.



Friction level of pre- and post-performance test and profile cut analysis after the test of both lip seals with back-up.

The charts above show the system and intermediate pressure for seal 2. It has a relatively low intermediate pressure (below 50 bar at 250 bar system pressure), thanks to its design. Deformation of the back-up ring led to better sealability as it ages, lowering the likelihood of building up intermediate pressure and lower levels of lubrication.

Lip seal 3 shows no intermediate pressure during all different system pressure levels. This indicates that 3 has a high sealability at all pressure levels. Both design concepts (lip seal 2 and 3) showed low to no leaks in combination with the primary rod seal.

4 and 5. O-ring energized glide ring seals. The figure on p. 32 (bottom) graphs chart friction level of glide ring seal 4 and 5 at pre- and post-performance test as well as profile cut analysis after the whole verification test.

Seal 4 demonstrates little friction. The PTFE element shows extrusion in both directions because it sealed in both directions and did not vent intermediate pressure as desired. As a consequence, the primary rod seal showed extrusion, which confirms that glide ring seal 4 was ineffective in reducing pressure spikes.

Glide ring seal 5 has slightly more friction than 4, but still an acceptable good level. The decrease in friction after the test is lower compared to glide ring seal 4 because of increased wear and extrusion resistance of the hard grade polyurethane glide ring.

The aforementioned graphs show intermediate pressure at 50-bar of backstroke system pressure during the long-term test for both 4 and 5 glide ring seals. Seal 4 immediately built-up interme-

continued on p. 32

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JEREMY KING | Product Manager for Vacuum and Sensing, Bimba

What's the Difference Between Single-Stage and Multi-Stage Vacuum Pumps?

A single stage-vacuum pump creates enough vacuum to lift four melons.

Several parameters determine which is best, including the size, shape and material of the object being lifted.

Single-stage and multi-stage vacuum pumps have been around for quite some time, but some designers and engineers remain unsure about when to use one versus the other. For example, which pump is best for pick-and-place applications with large objects? Is one a better option for end-of-arm tooling? What about for evacuating tanks, bottles or drums? Or processes such as box-carton folding and handling? How about clamping and holding during bottle-filling operations?

The best choices depend on variables such as dirt tolerance; costs to reduce clogging; actions needed to regain lost suction; and vacuum level, flow and speed requirements. They are also affected by the size, shape and material of the object being lifted, as well as by the application for which the vacuum pump is being used. For example, semiconductor applications, medical industries, material handling in manufacturing processes, manufacturing lines and vacuum pumps used on robots may all have different vacuum pump requirements.

Which pump type is better? Under what circumstances? Let's take a deeper dive into vacuum and see:

VENTURI VACUUM

Vacuum is used to hold things in place or move them from one place to another. When air is removed from an enclosure, the pump creates a pressure differential between the enclosure and the surroundings. This pressure change at the surface of a vacuum cup and workpiece forces the two pieces together. That force is determined by the interface area between the cup, workpiece and vacuum level. In other words, vacuum technology uses the surrounding atmosphere to create force and pull on a workpiece. The vacuum itself exerts no force; the air outside of the container exerts the force.

Venturi vacuum pumps use compressed air to draw the gasses—along with any debris, dirt or dust—out of the chamber. The gas and its particulates are all pulled into the pump.

In the venturi, compressed air passes through a nozzle that accelerates the air. As the air leaves the nozzle, it expands and increases velocity before it diffuses. This movement creates vacuum at the vacuum inlet port between the nozzle and diffuser, letting the nozzle and diffuser combine into a venturi vacuum cartridge.

SINGLE-STAGE VS. MULTI-STAGE

Single-stage venturi vacuum pumps with cartridges:

- Have "straight-through" designs that let dirt, dust and

A typical single-stage pump.

debris pass through without clogging the pump.

• Have no moving parts, so they better resist contamination associated with dirt and debris, thus ensuring a longer operational life.

• Generate higher flow rates and vacuum levels (above 18 in. of Hg), which translate into fewer missed picks for pick-and-place applications.

• Work best for operations that require a larger vacuum flow at higher vacuum levels (above 12 in. of Hg).

The downside of single-stage venturi vacuum pumps is that they require greater financial investments upfront and consume more air when matching evacuation times or flow levels at lower vacuums. Single-stage pumps are therefore recommended for operations where dust and dirt are present as in bakeries or to handle cardboard boxes.

Multi-stage venturi vacuum pumps feature:

• Filters to prevent the pump from clogging.

• Lower upfront costs.

• Greater flow rates with less air consumption at lower vacuum levels less 12 in. of Hg, making them ideal for applications where speed is critical.

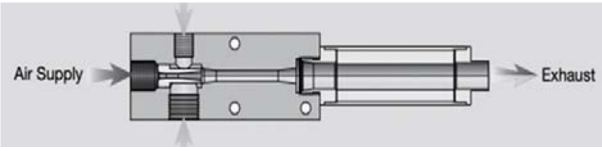
• Higher initial flow rates that let pick-and-place machines move faster to save time.

The downside to multi-stage vacuum pumps is that they are not as effective as single-stage pumps for picking up heavier, porous objects. They are also prone to clogging in contaminated surroundings, so there's more filter- and screen-related maintenance, and this downtime increases as the pump size increases. So, while upfront costs are lower, lifetime costs are higher than those for single-stage pumps due to the extra expenses associated with filters and screens.

Multi-stage vacuum pumps are recommended in clean environments or in applications where speed is critical from the outset, such as medical processes and in making silicon.

Choosing the right pump requires judgment, best practices and knowledge of the application factors such as costs, efficiencies, how much dirt can be tolerated, potential downtime that is acceptable, and the speed and vacuum flow needed.

After reviewing the differences



In this single-stage pump vacuum is created by forcing compressed air through a limiting orifice (nozzle). The aria expands as it leaves the nozzle, increasing in velocity to reach supersonic speeds before entering the diffuser. This creates a vacuum at the vacuum inlet port between the diffuser and nozzle. The nozzle and diffuse together make up a venturi vacuum cartridge.

between single-stage and multi-stage vacuum pumps, designers should also take into consideration the following which might narrow the choices:

- Multi-stage vacuum pumps offer performance advantages over single-stage pumps. At zero to 12 in. of mercury, multi-stage pumps remove air more quickly. With greater vacuum flow rates when matching air consumption, parts can be picked up and moved more quickly. However, this advantage goes away once the pump goes above 12 in. of mercury.
- At this level, single-stage pumps typically provide higher flow rates compared to similarly sized multi-stage pumps.
- If speed is critical and the application only needs lower vacuum because parts are light, a multi-stage pump can handle the job. Similar to flow rates, higher vacuum levels reduce the advantage of multi-stage pumps. As the vacuum level increases, single-stage pumps will surpass multi-stage pumps when it comes to efficiency.
- The weight of the object that must be moved should also be considered. Lightweight robots such as SCARA and Delta styles are designed to be operated with quick cycle times. Lower vacuum levels can handle these applications, so multi-stage pumps are the best choice. If the goal is to move heavy or porous objects, single-stage pumps are the better option. hp

JEREMY KING is product manager for vacuum and sensing at Bimba, part of IMI Precision Engineering. For more information about single-and multi-stage vacuum pumps, please consult www.bimba.com.

Vacuum Pumps Can Be Used For:

Industrial and scientific processes such as:

- Composite plastic molding
- Making electric lamps, vacuum tubes and cathode ray tubes
- Semiconductor processing
- Medical processes that call for suction or uranium enrichment
- Medical applications such as radiotherapy or radiosurgery
- Analytical instruments
- Mass spectrometers
- Milking machines
- Sewage systems

Mechanical devices including:

- Hybrid and diesel engines
- Gasoline engines
- Hydraulic brakes
- Ventilation systems
- Flight instruments

Pick & place operations

End-of-arm tooling/robotics

Vessel emptying (molds, tanks, bottles, drums)

Packaging (bag, box, carton folding and handling)

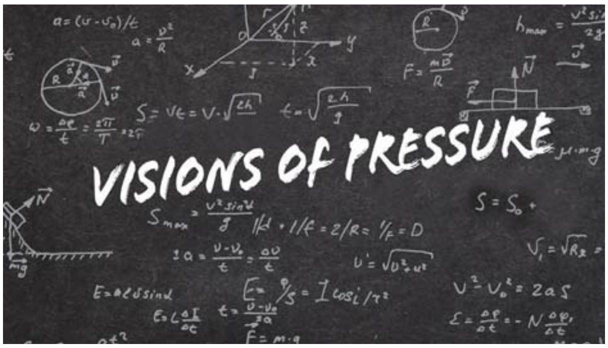
Clamping and holding fixtures and veneers

Bottling

PETER NACHTWEY | President, Delta Computer Systems

Modeling Pressure Changes in HYDRAULIC SYSTEMS

Here's the math behind pressure changes in hydraulics.



Controlling pressure is key to motion and force control, but there is little understanding of how pressure is controlled. A common misconception is that pressure is "resistance to flow," or that pressure is controlled by servo valves using the pressure gain curves. It is time to take a closer look at exactly what happens when a hydraulic system operates.

One of the basic formulas for pressure change is:

$$\frac{\Delta P}{\Delta t} = -\frac{\beta \cdot \frac{\Delta V}{\Delta t}}{V}$$

Where ΔP is the pressure change, B is oil's bulk modulus, ΔV is the change in volume under pressure and V is the total volume under pressure.

So, if the volume under compression decreases, the pressure will increase. This is what happens when a cylinder rod is impacted and the oil on the cap side of the piston is compressed.

The formula above is useful in relatively static situations but in dynamic situations, such as motion or force control, the formula must be modified to include time. Now the formula becomes

$$\frac{\Delta P}{\Delta t} = -\frac{\beta \cdot \frac{\Delta V}{\Delta t}}{V}$$

or

$$\frac{dP}{dt} = -\frac{\beta \cdot \frac{dV}{dt}}{V}$$

Where dP/dt is the instantaneous change in pressure and dV/dt is the instantaneous change in the compressed volume of oil.

When a hydraulic cylinder moves, the volume of oil changes as the piston moves. To keep the pressure constant, dP/dt must equal 0. Therefore, oil must be added or subtracted from the cylinder. The formula for dP/dt must be expanded to include flow.

$$\frac{dP}{dt} = \frac{\beta \cdot \left(-\frac{dV}{dt} + Q(t)\right)}{V}$$

Notice that increasing the volume makes the change in pressure negative. But if the flow as a function of time, Q(t), equals the rate of change in volume under pressure, pressure remains constant.

Next, the volume and change in volume needs to be expanded. The change in volume of oil equals the area of the piston times the velocity of the piston. The volume of oil under compression equals the dead volume plus the distance from the piston to the end of the cylinder. The resulting equation is

$$\frac{dP}{dt} = \frac{\beta \cdot (-A \cdot v(t) + Q(t))}{dv + A \cdot x(t)}$$

Where A is the area of the piston on the cap side in this example, dv is the dead volume of oil between the fully retracted piston and valve, x(t) is the piston position relative to the fully retracted position, and v(t) is the piston velocity as a function of time. It is positive when they cylinder moves away from the fully retracted position. When v(t) is positive, pressure in the cap side of the piston drops unless oil is added.

The piston position and velocity can be measured using a feedback device, which is typically a magnetostrictive transducer rod. The flow is not measured but, rather, is controlled indirectly by a hydraulic motion controller directing a proportional valve. When modeling or simulating, flow can be estimated closely using the manufacturer's specification. First calculate the valve's flow constant (visit www.hydraulicspneumatics.com/technologies/hydraulic-valves/ article/21887929 to learn more about this) using:

$$k_v = \sqrt{\frac{rated\ flow}{rated\ pressure}}$$

Now the flow can be calculated as a function of the pressure and the spool position x(t) using:

$$Q_a(t) = k_v \cdot x_s(t)\sqrt{(P_s - P_a)}$$

The spool's position is controlled by the motion controller's output. Ps is the supply pressure and Pa is the pressure in the cap side of the cylinder. Notice that the pressure change in the cap side of the cylinder depends on many factors, including the pressure in the cap side of the cylinder! This requires a sophisticated calculation.

Sometimes pressure only needs to be controlled, as when testing a container's ability to withstand pressure. In such cases, only a sensor monitoring pressure inside the container is needed.

Usually, the pressure is used to control the force applied to an object. In this case, the pressure on each side of the piston is multiplied by the area of the corresponding piston and the difference is the net force. In this case, the motion controller is closing the loop around the net force. To calculate the net force requires a load cell or pressure sensor mounted so it can measure pressure on each side of the piston.

During motion control, the pressure is also controlled indirectly. However, when simulating net force and motion, there must be a set of equations for each side of the piston because the net force is required. The net force is used to calculate acceleration. Acceleration is then integrated to determine the velocity, and then velocity is integrated to determine position.

Obviously, the equations for calculating pressure changes are complicated and depend on many factors that are constantly changing. Hydraulic simulators use the current state to calculate the next state in small time increments. Usually increments of 100 microseconds are sufficient. The reason for using small time increments is that pressure changes quickly when an obstruction is hit, as in a press. Plus, the smaller the time increments, the better and smoother the simulation will likely be. The tradeoff is the additional calculation time needed and the large amount of data generated.

Back in the early 2000s, I used a spreadsheet to simulate a customers' system which had been designed incorrectly. At that time, my spreadsheet program could only handle 32,768 rows. But at 100 microseconds for each row, I could only simulate 3.2 sec., which fortunately was long enough.

Each column was an equation for calculating position, velocity, acceleration, net force, cap side and rod side pressure. Once the first row was complete, the formulas were copied to the rest of the rows. Pressure changes depend on these values, so they had to be calculated for each row or in 100 microsecond iterations. It worked but was limited by the speed and memory capacity of personal computers back then.

THE NEXT article will show how calculating pressure changes is like calculating interest on savings; calculating interest compounded daily is also an iterative process.

PETER NACHTWEY is president of Delta Computer Systems, Battle Ground, Wash. For more information, call (360) 254-8688, or visit www.deltamotion.com.

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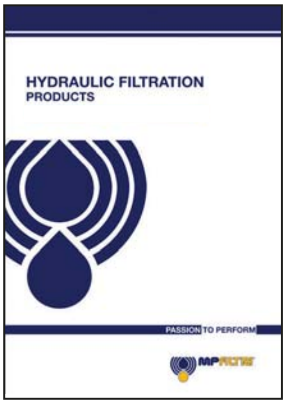

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Technical Brochure

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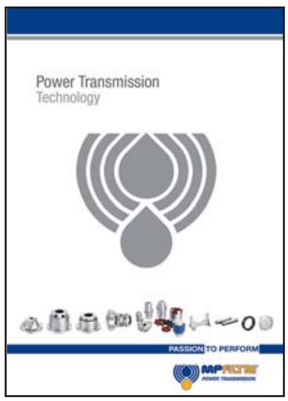

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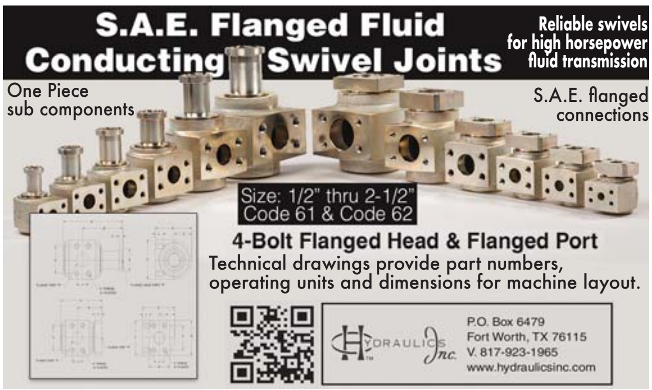

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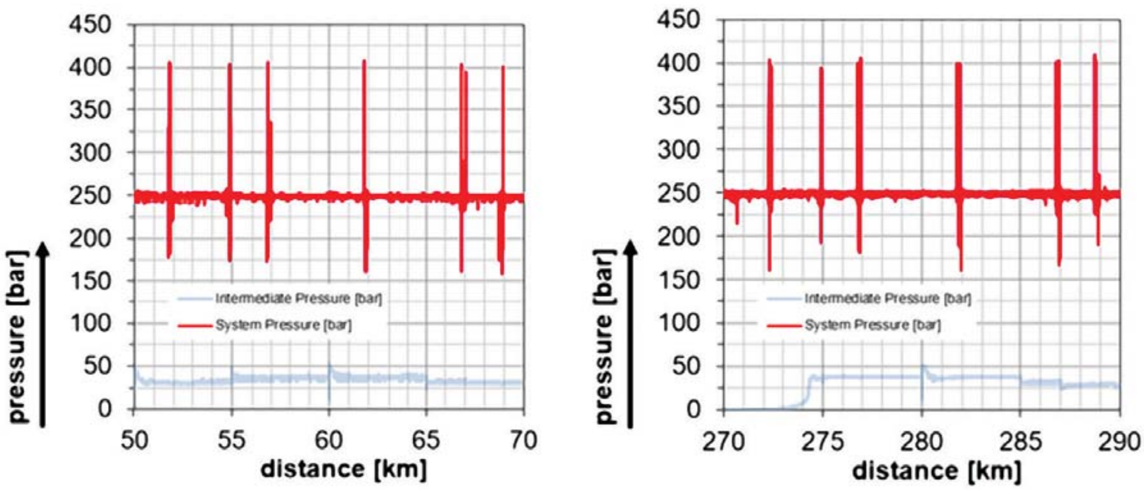
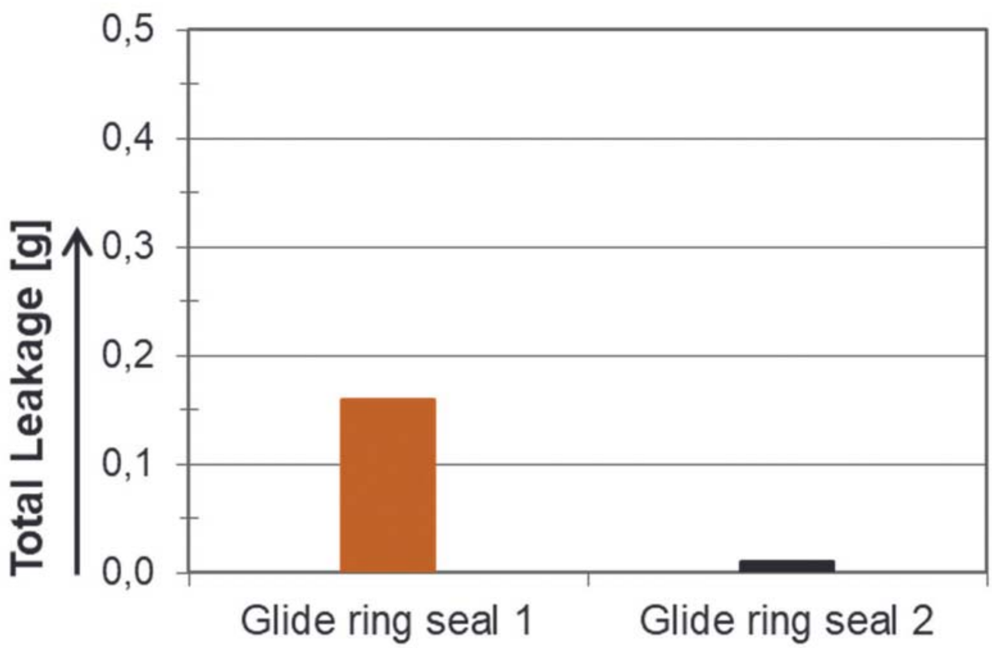
 continued from p. 21



Intermediate pressure during pre- (left) and post- (right) performance test of lip seal 2.



Leakage comparison of glide ring seal packages.

diate pressure to a multiple system pressure level, the result of no venting capability. Seal 5 shows no to low intermediate pressure built-up at several pressure stages between 50 and 400 bar.

In comparing leaks with Seals 4 and 5, the good performance of Seal 5 improves the performance of the entire rod seal package; it had far fewer problems with leaks than Seal 4.

The results clearly demonstrate that it is very important to consider the operating parameters when selecting the buffer seal. Lip-type buffers with thermoplastic back-up rings can handle high pressures, while O-ring energized glide ring seals have limitations in extrusion resistance, hose made of especially Bronze filled PTFE (which showed unacceptable extrusion).

Consequently, these seals should only be used in medium-duty applications. Lip type buffers without back-up rings and round sealing edge didn't work as expected and show no improvement compared to systems without an additional buffer seal.

Future evaluations of rod seal packages, including buffer, primary rod seal and wiper, are already underway. The goal is to find rod seal packages for applications from light- to heavy-duty that guarantee longest service life of the entire sealing system. hp

Thomas Schwarz is manager of testing, materials technologies & research; Wolfgang Swete is manager of product technology and development; Silvio Schreymayer is manager of testing; Martin Wallner is manager of product development; Emmanuel Pichlmaier is a product development engineer; and Michael Liebminger is a testing engineer for SKF Seals (www.skf.com/us).

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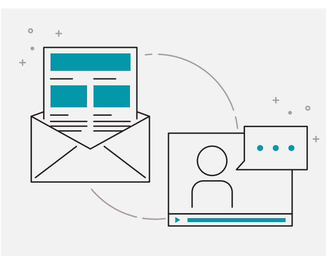

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