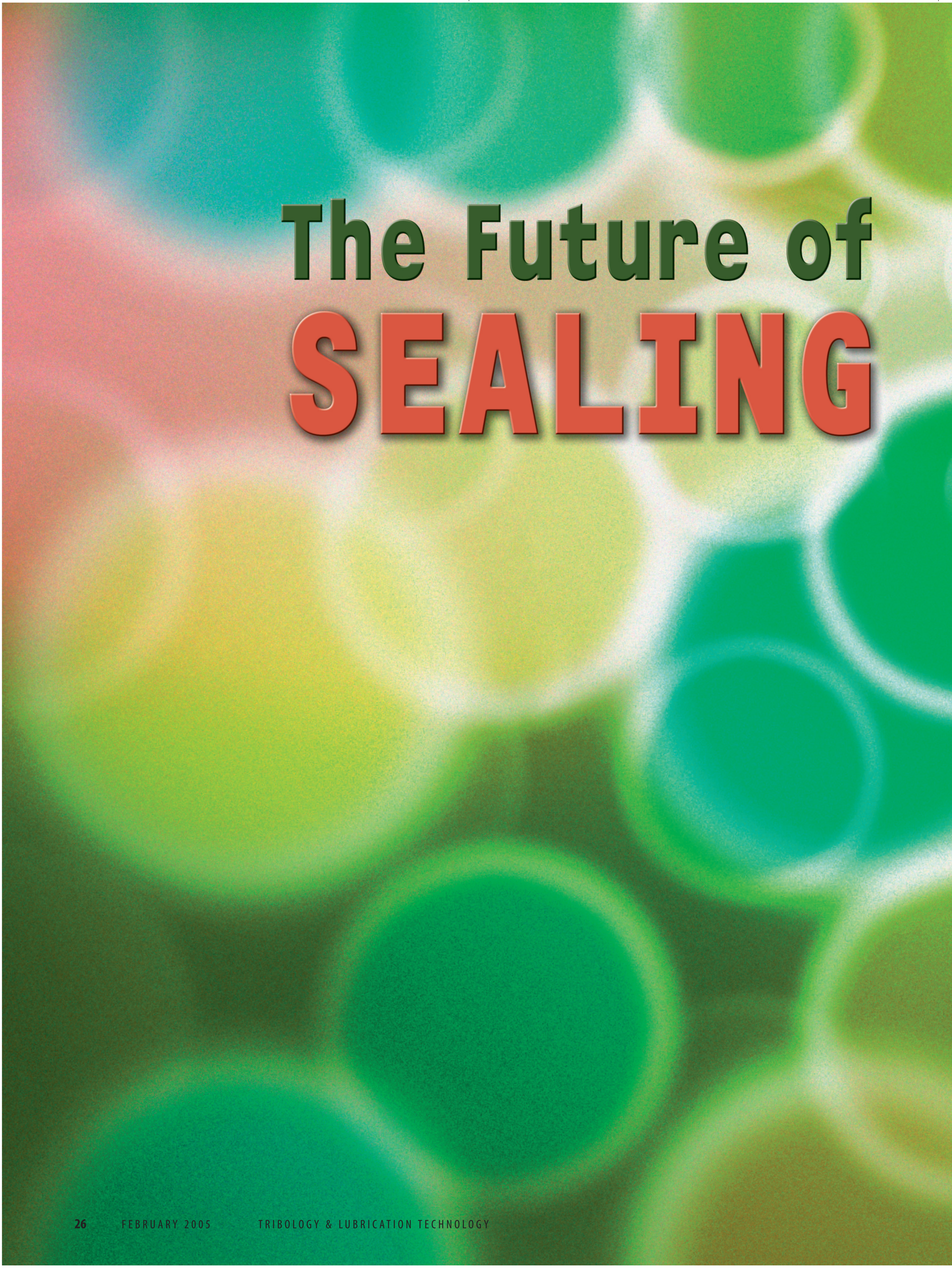

The Future of SEALING

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TECHNOLOGY

Advanced materials, computer-aided design and condition monitoring innovations are just some of the approaches designers are taking to improve the performance of tomorrow's seals.

By Dr. William B. Anderson

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A panel discussion titled "Recent Advances in Sealing Technology" was held at the 2004 STLE Annual Meeting in Toronto last May. The panel of representatives from industry and academia supplied a snapshot of the seal industry today with a view toward future challenges. The topics of discussion, though nominally applied to the seal industry, touched on the challenges faced by every business today and are of interest to the tribology community as a whole.

Seal technology is a very mature field, but seal companies face many of the same challenges faced by other industries, mature and new alike.

Seal technology is a very mature field, but seal companies face many of the same challenges faced by other industries, mature and new alike. These include differentiation from competitors, increased demands on performance and reliability due to more extreme conditions and increased regulatory requirements, and the financial constraints imposed by reduced research and development budgets. These challenges are being met in many ways, from providing complete sealing solutions with packaged services to applying existing technologies to older applications.

DRIVING FORCES

Current trends in sealing technology are driven by conditions in the marketplace. The increased pressure on the process industries to increase production and decrease cost has resulted in smaller maintenance staffs that are less experienced and stretched thinner. Thus, the onus is being placed on equipment manufacturers and, thereby, seals manufacturers to produce more reliable products at a lower cost.

Rob Phillips, manager of product engineering for Flowserve Corp. in Kalamazoo, Mich., summarized this challenge to seal companies: "Rotating equipment reliability is directly related to mechanical seal reliability, as is illustrated by past studies that have shown that as much as 69% of all rotating equipment failures manifest themselves as seal failures.

"In addition, an estimated 59% of all mechanical seal failures are caused by poor system design or improper operation," Phillips says. "Without sufficient staffing at the process plants to ensure the reliability of their rotating equipment and mechanical seals, mechanical seal suppliers are relied upon to ensure that their products meet life and performance expectations."

Henri Azibert, director of engineering for A.W. Chesterton Co. in Groveland, Mass., expresses a more complicated picture. "Applications are not looked at on an individual basis," he maintains. "Products are expected to perform no matter what the application is. Prices are driven down, and the least expensive technology gets specified. As a result, low-cost manufacturing is a primary endeavor, and simplicity in design is a virtue. High-volume manufacturing methods have to be used." Azibert adds that reliability is expected.

An equally important driving force is energy conservation—due to both increased energy costs and legislation requiring reduced energy consumption and emissions. The days of cheap energy and unrestrained consumption are over. Energy efficiency is required across the board, from process industries where mechanical seals are prominent to the auto industry where radial shaft seals are primarily seen. Seal companies must now provide seals that seal better, have fewer frictional losses and run more efficiently.

This puts immense pressure to design and produce quality, robust and energy-efficient products at a low cost with limited research and development budgets. Seal companies are approaching these challenges in several ways that are common to many industries today.

First, new materials that allow for more reliable operation in more extreme conditions are applied to seal design and production. Second, computer-aided design and simulation are applied to predict performance without the cost of expensive experimentation. Bill Marscher, technical director of Mechanical Solutions, Inc., of Parsippany N.J., illustrated how 3-D finite element analysis (FEA) coupled with computational fluid dynamics (CFD) in a "multiphysics" approach can model mechanical seal complexity in a physically realistic manner, useful for design or troubleshooting.

A third approach is to apply today's technology to applications that were developed with inefficient, obsolete or inadequate seal technology or even without seals, thereby opening a new market segment. Finally, faced with the reality of reduced maintenance and increased legislative requirements, many seal companies have assumed the responsibility by offering complete modularized seal packages that often include condition monitoring.

NEW APPLICATIONS & RESEARCH

New materials. One way that seal companies are addressing the challenges is by the introduction and application of new seal materials and pairs. Mechanical seal companies and material suppliers develop new materials that are more durable and self-lubricating, while radial shaft seal companies are introducing more chemically and temperature resilient elastomers and even nonelastomeric materials into their seals.

The advances in materials were illustrated by Joe Boylan, manager-marketing and engineering with Morgan AM&T in St. Marys, Pa.: "The market [end-users] dictates the materials development that occurs, and that communication must be maintained so that materials can keep up with the needs of the industry."

Major trends in seal materials include advances in mechanical carbons, hard-face combinations, engineered coatings and silicon carbide (SiC)/graphite composites. Mechanical carbons are applied due to their self-lubricating properties and the infinite possibilities to create unique mechanical carbons for specific applications. However, mechanical carbons have a relatively low modulus and lack abrasion resistance, which limit their use.

The more severe applications that are seen in industry today have created a trend toward greater use of more hard-face combinations of materials (e.g., SiC on SiC), whose advantages were underscored by Dr. Tom Lai, principal engineer with John Crane Inc. in Morton Grove, Ill. The abrasion and high-pressure distortion resistance of the hard-face combinations allow the seals to operate under more severe conditions.

In addition, the problem of carbon blistering that is encountered in viscous oil applications is not seen with these material pairings since there is no carbon in the seal. Unlike combinations with graphite materials, the hard-face combinations are not self-lubricating and do not run in contact without lubrication for more than a very brief period.

Engineered coatings such as diamond-like carbon (DLC) have become more popu-

Figure 1: Comparison of model to actual seal face wear.

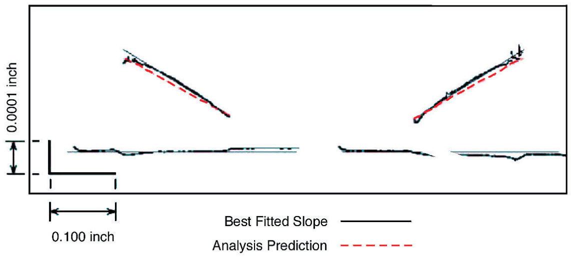

Illustration courtesy of Dr. Tom Lai, John Crane Inc.

Figure 2: 3-D "multiphysics" combined finite element analysis (FEA) and computational Fluid dynamics (CFD) model of a mechanical seal system, including seal components, shaft box, and sealed fluid.

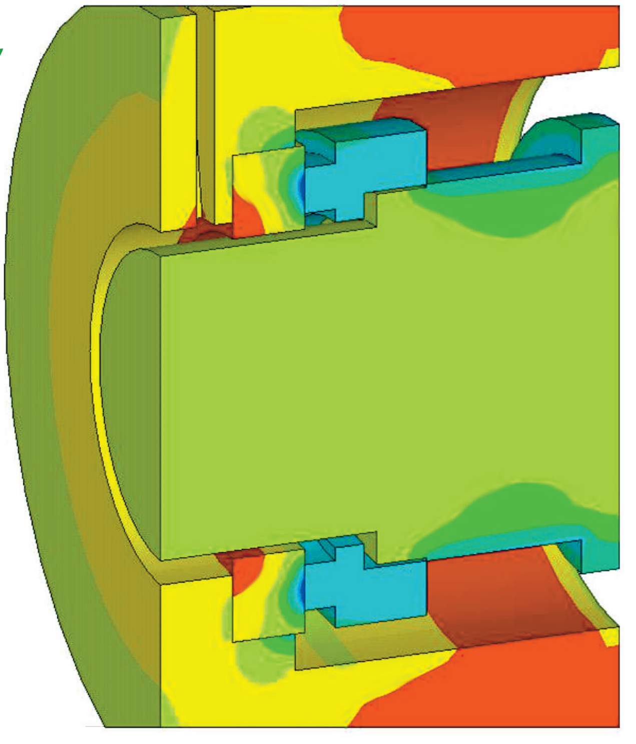

Illustration courtesy of Bill Marscher, Mechanical Solutions, Inc.

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lar but do not currently have the adhesion to make them practical in contacting applications. Further research into this promising technology is warranted.

Other materials that are gaining in usage are the SiC/graphite composites and graphite-loaded SiC, which is an attempt to gain the advantages of each of the common constituent materials. Both Boylan and Lai noted the advantages of this material. The high modulus and abrasion resistance of the SiC combines with the self-lubricating capability of the graphite to produce a material that is more robust but can operate with marginal lubrication. The full limits of these composite materials are currently unknown, but the demonstrated effectiveness will ensure that they see more use in the future.

Figure 3 :
Modern seal technology applied to older equipment

Photos courtesy of Henri Azibert, A.W. Chesterton Co.

New material selection is also a concern in the radial lip seal industry, as presented by Alex Paykin, director of product design and finite element analysis with Chicago Rawhide (CR) in Elgin, Ill. Companies such as CR supply primarily the automotive and heavy-duty truck industry. Like the process industry that mechanical seal companies supply, the automotive industry constantly increases the severity of operating conditions and demands on the seal performance. The greater temperature extremes and more aggressive fluids seen by elastomeric seals have forced seal companies to formulate and apply materials that are more robust. These include base-resistant fluoroelastomers (BRE), hydrogenated nitriles (HNBR) and even non-elastomeric materials such as PTFE.

Computer-aided design. The use of computers to design and simulate new technologies is a reality in the seal industry, as it is in virtually all engineering applications today. Seal companies have invested in computer design and analysis tools. Software and hardware are of such quality that engineers can create a design and evaluate it under almost any imaginable condition and make changes without resorting to expensive testing. Such analysis software predicts pressure and temperature distributions and face deformations and even wear, as seen in Figure 1. Significant research money has been supplied to academic and research institutions to perform the research and analyses that are the backbone of these computer simulations. Bill Marscher showed how his firm had applied 3-D multiphysics FEA and CFD to model an entire seal and its stuffing box cavities, both in steady state and during transients such as machinery start-up. These modern non-proprietary analysis methods can be applied to seals of any manufacturer and for any given process fluid, such as the mechanical seal FEA/ CFD analysis shown in Figure 2.

Lai illustrated some of the gray areas of current mechanical seal modeling and computer design: leakage prediction with a finite gap and frictional hysteresis effect on seal face distortion. Models predict leakage in mechanical seals in all cases where there is a gap. However, there are often cases when there is no measurable leakage, which can sometimes be explained by fluid vaporization. Marscher agreed that the sliding interface was the area where modeling assumptions were most uncertain, and where numerical methods experienced the greatest difficulty converging to an accurate solution.

The disconnect is pronounced enough to warrant further study and refinement of computer models. Significant effort has been undertaken in both modeling and testing to investigate the frictional hysteresis in pump seals as they go through pressure and temperature transients in nuclear power plant pumps. However, similar efforts are required to validate its role in other general industrial pump applications, which use contacting face seals rather than full-fluid film seals.

New applications. Technology is always moving forward, and sealing technology is no exception. New challenges require creativity and engineering experience. Among those faced by the seal industry are those already mentioned, as well as developing technologies such as fuel cells and drive-by-wire applications. However, sometimes new technology can be utilized in old applications such as very large, old equipment.

Many large pieces of equipment (e.g., steam turbines) that are currently in operation were put into service before the appropriate mechanical seal technology was developed. These pieces of equipment can now be updated with modern seal technology. Figure 3 shows an example of modern split-seal technology. Note the date of manufacture is 1910. This is just a reminder that not all applications need to be new.

CONDITION MONITORING

One trend in the seal industry that was stressed by nearly every panel expert was the emergence and maturation of condition monitoring. Many seal companies have identified condition monitoring of the seal system as a viable answer to the dual challenges of reduced maintenance budgets and increased demands on reliability and efficiency. Marscher demonstrated how condition monitoring can consist of either a permanently installed sensor set and associated behavior indication, or could involve mobile instrumentation such as handheld vibration monitors or a thermography camera.

Maintenance philosophies are shown in Table 1. Reactive maintenance requires little up-front investment but produces significant downtime and repair costs when practiced. Proactive approaches are on the other extreme—they require a large initial investment but result in little down time or repair costs. In the past, plant maintenance tended to be reactive, although progressive plant managers practiced preventive maintenance. In his paper, "Integrating Information to Achieve Plant-Wide Asset Health," published in the March 2001 issue of *Control Solutions*, Glenn Schulz documented that current maintenance practices in process plants rely on about 65% reactive approaches and only 1% proactive.

Table 1: Maintenance Philosophies.

Maintenance Philosophy	Operating Mode	Maintenance Process Maturity	Required Action
Proactive	Maintenance on condition	Performance optimized	Identify start of failure and provide corrective action.
Predictive	Maintenance on condition	Performance measured and analyzed	Identify start of failure and plan for failure.
Preventative	Maintenance on schedule	Stable process, repeatable level of performance	Apply best available technology.
Reactive	Maintenance on need	Ad hoc, chaotic, unpredictable	Wait till it breaks, replace with same.

Table courtesy of Rob Phillips, Flowserve Corp.

It is common knowledge in the seal industry that one of the primary causes of rotating equipment failure is mechanical seal failure. Bearing failures are a close second, but in fact studies indicate that most bearing failures actually have seal failure as their root cause. In each case, the failure is usually due to improper installation or application. To combat this problem, seal suppliers no longer just specify a seal for the operating conditions but evaluate and optimize for the effects from the entire system. They have also introduced condition monitors as part of packaged sealing systems. The reduced maintenance budgets and staffs in today's process plants have enabled seal companies to couple expertise in process equipment and monitoring systems and provide condition-based maintenance solutions for their customers. The packaged systems approach reduces maintenance and energy costs for the plants while allowing the seal companies to expand into new areas.

Condition monitoring of seal systems is also a reality in the radial lip seal industry, as seen in Figure 4. Although elastomeric seals tend to be far less expensive than mechanical seals, they are used in applications that

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Current trends in sealing technology are driven by conditions in the marketplace. The increased pressure on the process industries to increase production and decrease cost has resulted in smaller maintenance staffs that are less experienced and stretched thinner.

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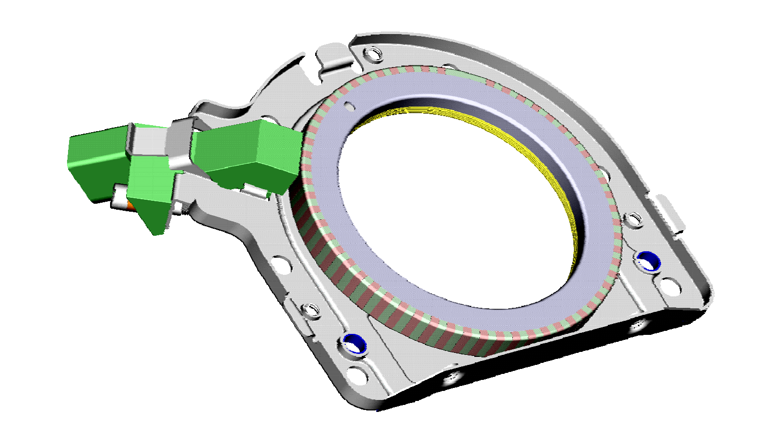
Figure 4: Modular lip seal with sensor.



(Illustration courtesy of Alex Paykin, Chicago Rawhide)

require high reliability. The initial thrust for condition monitoring in lip seal started in heavy-duty diesel engine applications, where reliability is not only expected but is absolutely critical. As in the process industry, the failure of a seal leads to losses due to down time and equipment repairs. Also, new safety and environmental legislation has made condition monitoring a necessity in future generations of cars and trucks.

THE FUTURE

Current mechanical seals and condition monitoring systems are passive in nature—the system is monitored and action is taken when an alarm threshold is reached. Itzhak Green, professor of mechanical engineering at Georgia Institute of Technology in Atlanta, presented a glimpse at a possible future of seal system condition monitoring. The monitor employs eddy-current proximity probes to provide feedback to an active control loop such that the system is monitored and its performance actively controlled. The work presented by Green had two areas of focus: a mechanical seal monitor and crack detection in the seal drive shaft. The two prongs apply the same monitor and control system, thereby providing the opportunity for a complete system condition monitor.

The mechanical seal monitoring system shown in Figure 5 consists of three eddy current proximity probes and a universal controller board connected to a personal computer. The relative angular misalignment and clearance of the seal faces are measured, allowing for detection of contact. Contact of the seal faces is indicated as higher-harmonic oscillations.

The control system monitors the orbit plots of the seal and uses signal processing to determine contact. An active control strategy is employed to adjust the seal clearance in order to eliminate contact. Adjustment of the clearance via a pneumatic pressure change in the rotor chamber changes the stiffness and damping of the fluid film between the seal faces. The rotordynamics of the seal faces changes with the change in clearance.

The crack detection system employs the same probes and control system. A crack in the drive shaft produces changes in its rotordynamic response. The theoretical model used to develop the system focuses on the induced 2X component in the system response. The theory predicts that the 2X-resonance shaft speed should decrease with increasing crack depth and that the magnitude of the 2X component at resonance should increase with increasing crack depth. These are the first and second indicators of a shaft crack, respectively.

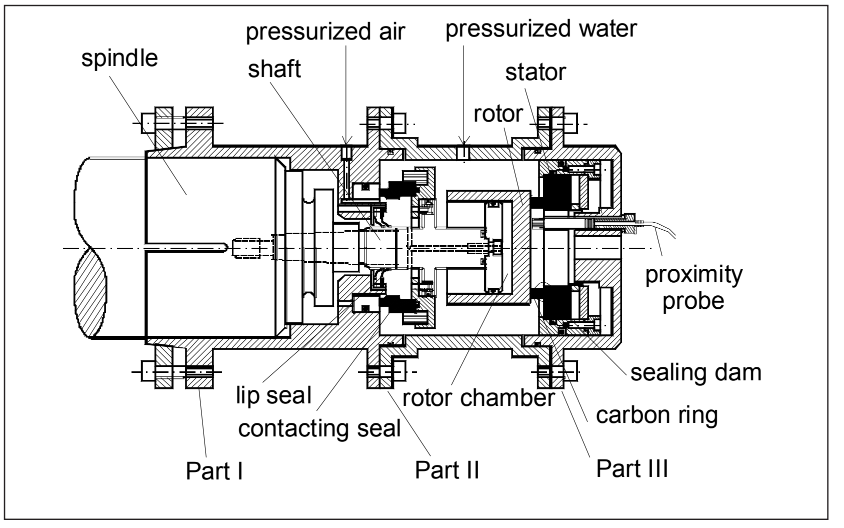
The cracked shaft theory has been tested with the above monitoring system. A slender (flexible) shaft was used in the system. The experimental determination of the 2X response of the shaft in cracked and varying degrees of cracked conditions gives one the relative changes in system responses. By coupling the experimental results with the theory, it was confirmed that such a monitor can be applied to detect shaft cracks.

A monitor that can detect multiple possible failure modes in a system and even correct for precursors to failure (e.g., seal contact) is the type of technology that is the future for the seal industry. Marscher pointed out how this need can be met in part through signal processing that evaluates the signal in the time and frequency domains simultaneously. In addition, sensors monitoring several variables and perhaps different locations would be beneficial. Larger numbers of such sensors may be possible in the near future as technologies mature for Micro Electro-Mechanical Systems (MEMS) and wireless sensors (communicating, for example, by WiFi or Bluetooth), which promise to be unobtrusive and very cost effective. It is no longer sufficient to consider only the single component or to merely watch and wait; a proactive approach to the entire system is necessary to remain competitive.

SUMMARY

Today, the seal industry is highly competitive, as are all industries. There are unique challenges faced by individual companies. But many of the challenges faced by seal companies are most familiar outside the industry: competitive differentiation, stricter demands on reliability due to reduced customer maintenance, more extreme operating environments and smaller R&D budgets. Imagination, innovation and sound engineering judgement are needed in order to meet these challenges. New materials, computer-aided design and finding new applications are examples.

Figure 5: Active seal monitor and control system.



(Illustration courtesy of Dr. Itzhak Green, Georgia Institute of Technology)

Many seal companies have taken on the challenges and applied an entire-system approach to provide their customers with modular components and condition monitoring systems. This approach provides a win-win situation for the seal companies and their customers. The system approach may in the future manifest itself as a complete monitor and control system for the seal, shaft and other components. <<

Major trends in seal materials include advances in mechanical carbons, hard-face combinations, engineered coatings and silicon carbide (SiC)/ graphite composites.

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