APRIL 2022
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PUMPS&SYSTEMS

The Leading Resource for Pump Users Worldwide

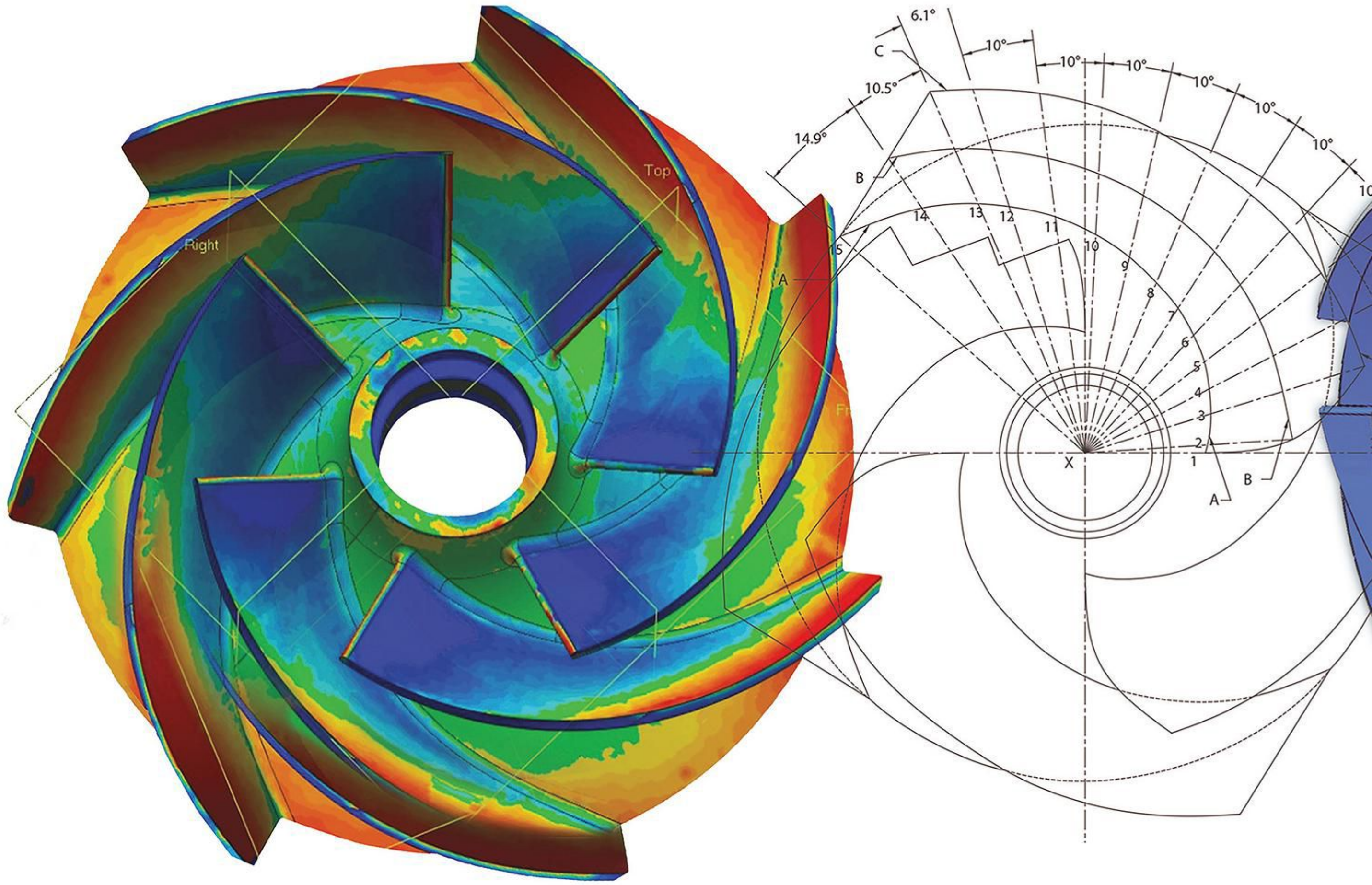
ENSURING RELIABLE WATER SERVICE TO REFINERIES

Texas pump station undergoes rehab and replacement.

SEALS & BEARINGS SPECIAL SECTION

THE IMPORTANCE OF CRITICAL SPEED

WHY DOES CALIBRATION MATTER?



Parts Solutions

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Hydro’s engineers use state-of-the-art equipment and software to help pump users with difficult-to-source cast parts, such as impellers, diffusers, discharge heads, casings, bowls and suction bells without the long lead time.

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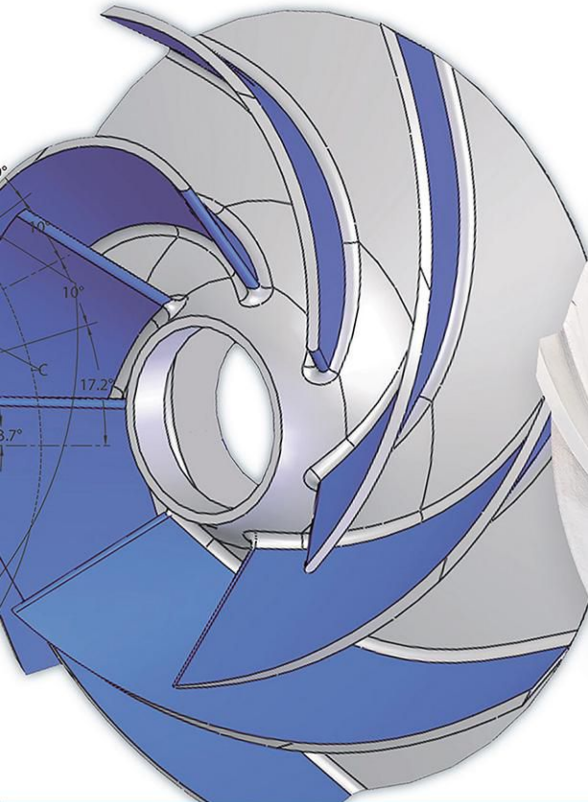

Hydro provides independent, unbiased engineering expertise and support to pump users around the world for better performance and longer life.

THE HYDRO PARTS PROCESS

Laser Measuring and Reverse Engineering
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Engineering Review and Analysis
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Casting and Mold Package Design
Solidification Simulation
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Testing to Verify Required Performance

HYDRAULIC INSTITUTE PROUD MEMBER

Check 101 on index.

Worldwide Service Centers I 800.223.7867 I hydroinc.com

Hydro®

It's a tumultuous time, with the ongoing pandemic, the conflict between Ukraine and Russia, gas prices hitting highs we haven't seen since 2008 and more. The team at Pumps & Systems is watching it all closely, and we'll be reporting on how these events are affecting our industry. You can read about how the industry is responding as these events unfold on page 80 in the April Wall Street Pump & Valve Industry Watch. To stay up to date with the latest news, visit pumpsandsystems.com/news and follow us on social media on Facebook, LinkedIn, Twitter and Instagram.

Gas prices rose to a near record high in March. Check out how much on page 14.

This month's cover series features a topic that is on everyone's mind—oil and gas. While our featured stories won't tell you what prices to expect at the gas pump (you can find that on page 14), the articles starting on page 38 cover many parts of the industry, including supplying reliable water service to refineries, automation in oil and gas, transporting corrosive liquids, valve selection and more.

In this month's Back to Basics (page 68), find out the answer to "How often should I check the calibration of my pressure gauge?" Getting this one wrong can lead to downtime and equipment damage.

One thing we don't feature often in the world of Pumps & Systems? Star Trek! Find out how the sci-fi franchise relates to centrifugal pumps in our latest column from Jim Elsey on page 16. We also have guest columns from Amin Almasi (page 20) and Heinz Bloch (page 22).

Finally, we at Pumps & Systems would like to extend our sympathy to the family of George Harris and all of those he worked with through the years at Hydro, Inc. Harris was a respected member of the pump industry and a friend to our team. He will be greatly missed. To read more about Harris and the legacy he leaves behind, turn to page 8.

As always, thanks for reading.

Amy Hyde

Amy Hyde, Production Manager
ahyde@cahabamedia.com

Pumps & Systems
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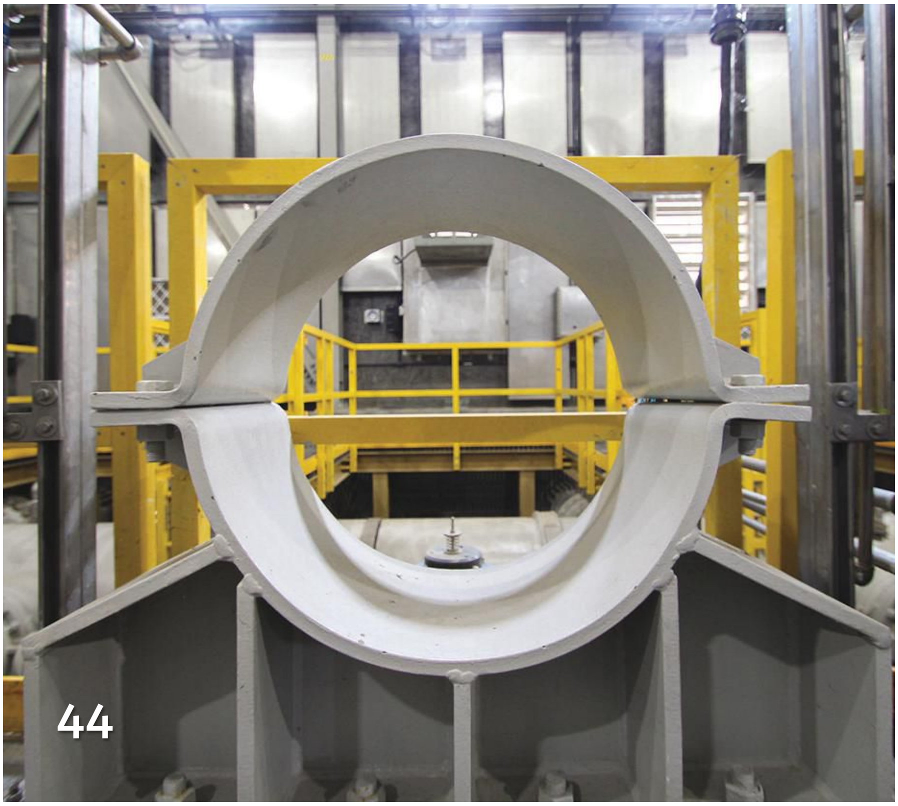


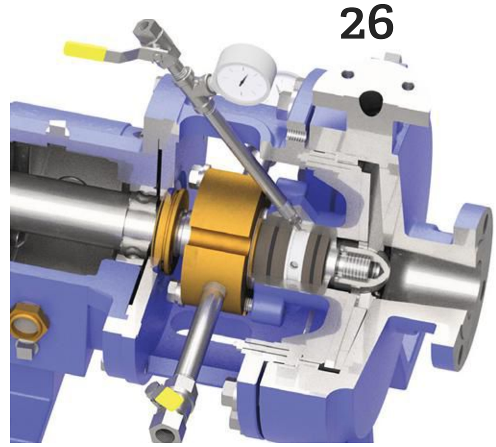
COVER SERIES: OIL & GAS

COLUMNS

EVERY ISSUE

ON THE COVER
Image courtesy of Lockwood, Andrews & Newnam

SPECIAL SECTION: SEALS & BEARINGS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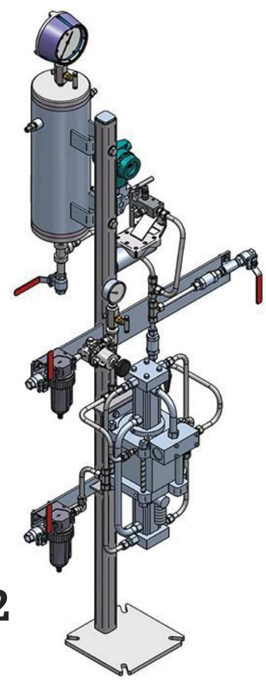
+ PLUS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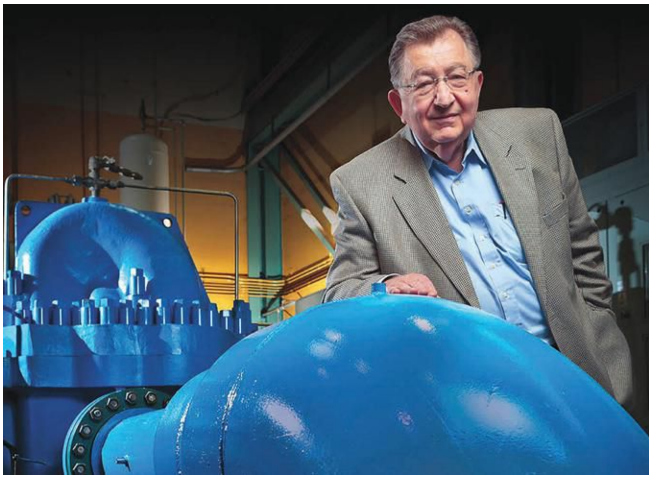
DEPARTMENTS

OBITUARY

Remembering Hydro President & Founder George F. Harris

Hydro, Inc., announced that Harris passed away on Dec. 20, 2021.



Born in Chicago in 1941, George F. Harris came from humble beginnings, working as a waiter and a taxi driver. He attended the University of Illinois at Champaign and graduated with a Bachelor of Science in engineering. After graduation, he worked at several major pump companies as an application engineer and regional manager.

In 1969, Harris was one of the four engineers who founded Hydro, Inc. with the mission of providing engineering services to the pump aftermarket industry. From the beginning, Harris believed in improving the reliability and performance of pumps and encouraging innovation. He was later appointed president of Hydro.

Hydro began with a single shop in Chicago; under Harris' leadership and vision, Hydro became one of the largest independent aftermarket pump companies in the world. Today, Hydro has 15 service centers in nine countries.

Harris was instrumental in defining the culture of Hydro: unbiased, engineering- and innovation-focused, and dedicated to the user. He helped develop programs for customer education in pump processes, believing that the knowledge of how to safely maintain and operate pumps was something that should be shared with everyone. He spearheaded many innovations in the way pumps are serviced, using state-of-the-art technology to re-engineer pumps for maximum efficiency.

Harris is survived by his wife of 56 years, Rita, whom he met at the University of Illinois. She later became vice president of Hydro. Their leadership was characterized by a special commitment to their employees, whom they treated like family. They encouraged all service centers to honor Hydro's workers with monthly employee celebrations and an annual Employee Appreciation Week. As he once said, "Hydro became the company it did because of the commitment of our people—machinists, mechanics, engineers, administrative and sales staff—who all share a pivotal role in serving our customers."

The culture of care and loyalty nurtured by George and Rita Harris inspired admiration and esteem in Hydro's employees, many of whom have worked there for more than 20 years. Harris was well respected by his peers within the pump industry. In 2014, he was elected as president of the Hydraulic Institute, the largest association of pump industry manufacturers in North America. In 2015, Europump awarded him its President's Silver Award in recognition of his valuable contributions to the pump industry.

"I started with HydroAire in 1976 and quickly learned that George Harris was the consummate protagonist who always expected more than people were willing to provide," said Bob Jennings, HydroAire. "As an employee, I learned that half-hearted measures were unacceptable and an attitude of 'good enough' was never tolerated. He took a rag-tag group of five street-wise salesmen and turned the company into a global organization with 19 facilities worldwide—it is an amazing accomplishment. It took hard work, long hours, a 'never say never' mindset and teamwork to grow the company. He wanted to be the best, he wanted the company to be the best, and he wanted each of his employees to be their best.

"George was a gifted individual who had the uncanny ability to 'see over the horizon' and could glimpse the future needs of the industry long before others had digested last week's changes," Jennings continued.

"There was also a side of George that most people never had the opportunity to see: As tenacious a businessman as he was, he was equally generous and caring to those in the 'Hydro Family.' George and Rita always treated their employees as 'adopted sons and daughters,' and they personally bore the burden of knowing that their business decisions not only affected the company but the well-being and security of their employees and their families as well.

"George will be deeply missed but his legacy will live on. He hired who he considered the 'best of breed,' and those that shared his vision will continue to grow the company well into the future." ■

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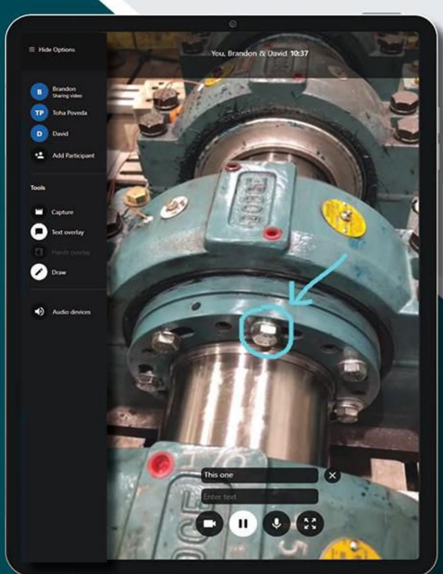

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- Share a real-time video of the issue or problem area

Check 103 on index.

TONY NAJJAR

CIRCOR

BURLINGTON, Mass. – CIRCOR announced that Tony Najjar accepted the role of chief operating officer and was named interim president and chief executive officer in January.

Najjar joined CIRCOR in 2015 as vice president of sales and marketing for the Aerospace & Defense (A&D) group. Since 2018, he has served as the A&D group president. Before that, he served as vice president and general manager of the Aerospace & Defense business.

He has spent more than 35 years in the Aerospace & Defense industry, serving in engineering, sales and general management roles. ■

circor.com

HP NANDA

GRUNDFOS

BJERRINGBRO, Denmark – HP Nanda, a seasoned industrial executive with 23 years of experience, joined Grundfos as executive vice president and CEO, water utility. Nanda comes to Grundfos from a role as the vice president and general manager of the global DuPont Water Solutions Business.

Nanda has a Bachelor of Technology in mechanical engineering from Sambalpur University in India and an MBA in marketing and finance from Xavier Institute of Management. Nanda is based in Houston, Texas. ■

grundfos.com

DAVID GILBERT

DODGE INDUSTRIAL

GREENVILLE, S.C. – Dodge Industrial, Inc.—an RBC Bearings company—announced that it has named David Gilbert as its new president, effective immediately.

Gilbert joined Dodge in 1998 as an engineering supervisor and has held numerous leadership positions, most recently serving as vice president of operations and manufacturing.

Gilbert earned his Bachelor of Science in industrial engineering from North Carolina State University. ■

dodgeindustrial.com

JIM FELKER

SJE

DETROIT LAKES, Minn. – Jim Felker has joined SJE as its newest regional sales manager. Felker will be working out of Oxford, Michigan, covering the northeast territory for SJE Rhombus and CSI Controls.

Felker has been in the water and wastewater industry for over 20 years. He started his career in outside sales selling water well supplies to contractors. ■

sjeinc.com

YATIN TAYALIA

XYLEM

RYE BROOK, N.Y. – Xylem Inc. announced the appointment of Yatin Tayalia as managing director of Xylem in India. Current Managing Director Nitin Bhate will be taking on a new role as the global director and general manager of Xylem Custom Pumps.

Tayalia recently served as senior vice president and business leader for South Asia at SUEZ Water Technologies and Solutions. He has over 25 years of experience in water, chemicals and computational analysis industries across Asia. Tayalia has an integrated Bachelor and Master of Technology degrees in chemical engineering from the Indian Institute of Technology, Mumbai. ■

xylem.com

SCOTT CLARK, JOSH CLARK, NOAH HUDGEONS, KELLYE TURNER

BRANDON & CLARK

LUBBOCK, Texas – Scott Clark has been elected to serve as president of Brandon & Clark.

Clark, a graduate of Texas Tech University with a doctoral degree in electrical engineering, a master's degree from Johns Hopkins University in electrical and computer engineering and bachelor's degrees from Texas Tech, has worked for the company for 20 years.

Josh Clark and Noah Hudgeons have been promoted to senior vice presidents. Josh Clark, a graduate of Texas Tech University, has worked for the company for 26 years. Hudgeons, a graduate of Ashford University, has worked for the company for 19 years. Kellye Turner has been elected to serve as secretary and manager of marketing. Turner, a graduate of Lubbock Christian University, has worked for the company for 19 years. ■

brandonclark.com

STEVEN NESBITT, JOAN MANUEL DIAZ & ROBERT PAIVA

AQUESTIA USA

TULSA, Okla. – Joining the OCV control valve fueling division of the Aquestia USA team is Steven Nesbitt, director of fueling. Nesbitt is a U.S. Marine veteran with 20-plus years of experience in Aviation GSE/Fueling maintenance in both the commercial and military sectors.

Aquestia USA also welcomed Joan Manuel Diaz to both control valves brands (OCV & Dorot) and ARI air valves brands within the industrial, oil and gas and mining sectors. Robert Paiva has been named Tulsa site manager at the headquarters of Aquestia USA in Tulsa, Oklahoma. ■

aquestia.com

BRETT HANSON

PUMPMAN

SADDLE BROOK, New Jersey – PumpMan welcomed Brett Hanson as its new general manager of pump systems. Hanson will be responsible for growing the Federal Pump and Alyan Pump brands with operations in Brooklyn, New York, and Folcroft, Pennsylvania. ■

pumpman.com

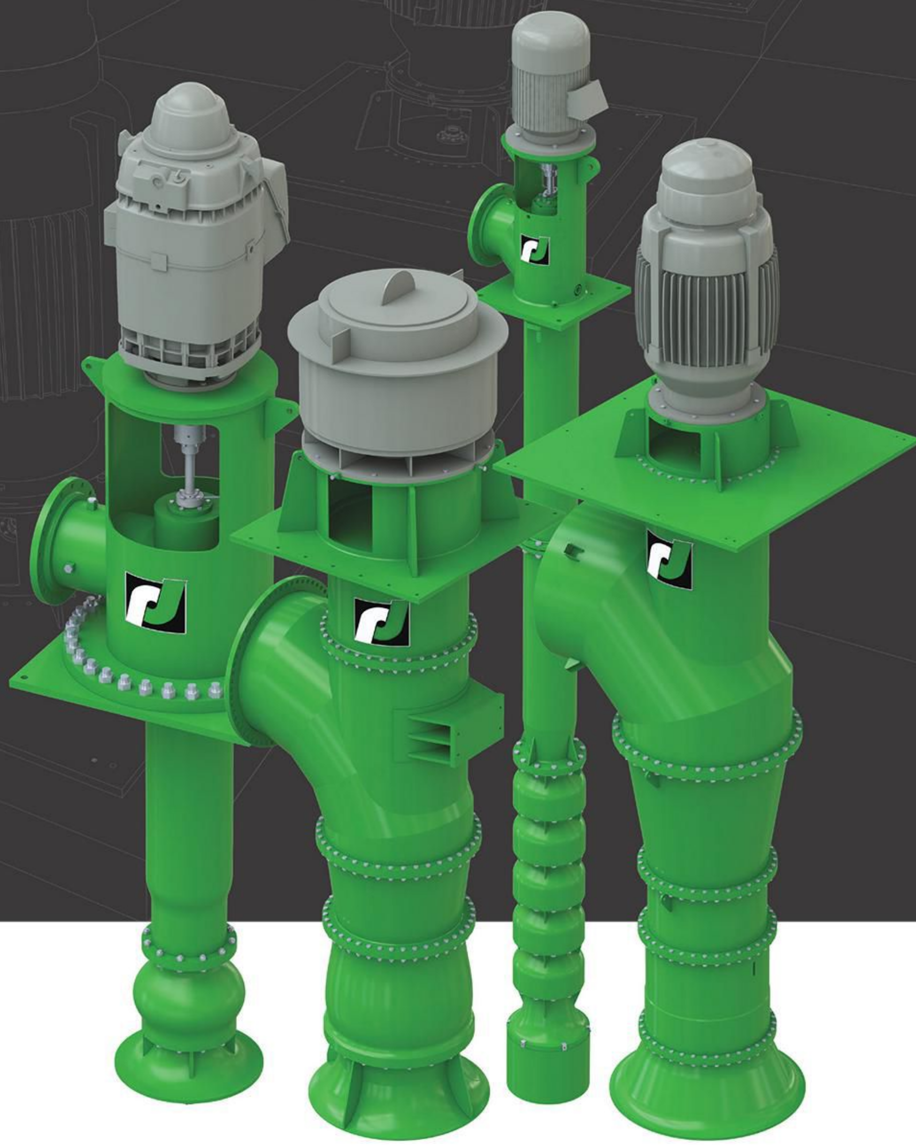
Mergers & Acquisitions

AxFlow A/S Denmark Acquires Pumpegruppen
March 1, 2022

Atlas Copco Acquires Pumpenfabrik Wangen GmbH
Feb. 21, 2022

Wajax Acquires Process Flow Solutions
Feb. 8, 2022

Water is Life Group Acquires Orlando Watertechnology
Feb. 7, 2022



Upcoming Events

OTC
May 2-5
NRG Park
Houston, Texas
2022.otcnet.org

POWER GEN
May 23-25
Kay Bailey Hutchison
Convention Center
Dallas, Texas
powergen.com

NFPA
June 6-9
Boston Convention
& Exhibition Center
Boston, Massachusetts
nfpa.org/conference

AWWA/ACE
June 12-15
Henry B. Gonzalez
Convention Center
San Antonio, Texas
awwa.org/ace

EASA
June 26-28
America's Center
St. Louis, Missouri
easa.com/convention

ACHEMA
Aug. 22-26
Frankfurt am Main, Germany
Frankfurt, Germany
achema.de/en

Turbomachinery & Pump Symposia
Sept. 13-15
George R. Brown
Convention Center
Houston, Texas
tps.tamu.edu

WEFTEC
Oct. 8-12
Morial Convention Center
New Orleans, Louisiana
weftec.org

AROUND THE INDUSTRY

Grundfos Pauses Business Activity in Russia

BJERRINGBRO, Denmark – Following Russia's recent invasion of Ukraine, Grundfos announced on March 2 that it will halt business activities in Russia for the time being.

"We remain deeply concerned about the continued military actions instigated in Ukraine. We are assessing and following the situation and need to have a full overview of the sanctions. However, we can already see the impacts on our operational integrity. This means we need to adapt to an evolving situation with increased and escalating complexity.

"Grundfos will therefore pause its business activities in Russia.

"This decision means we pause all activities at our production facility and in our sales offices across Russia. No products will be delivered, and no new orders will be accepted for the time being.

"Our focus is now on our employees in Russia and Ukraine and supporting them in the best way. We will also do things right toward our stakeholders and we will keep maintaining our offices and our factory to be ready to open again when the situation allows us to do so." ■

grundfos.com

Turbo Lab Moving Forward With Asia TPS 2022

COLLEGE STATION, Texas – The National Recovery Council of Malaysia recently announced recommendations for Malaysia to fully reopen its borders on March 1, 2022.

With this welcomed news, the Turbomachinery Laboratory at Texas A&M University is moving forward with plans to hold the Asia Turbomachinery and Pump Symposium (ATPS) in Kuala Lumpur, Malaysia, May 23-26, 2022.

The biennial Asia Turbomachinery and Pump Symposium is a sister event to the annual, internationally recognized Turbomachinery and Pump Symposium (TPS) in Houston, Texas. TPS just celebrated its 50th anniversary of supporting the industry in professional workforce development.

Both symposia aim to develop new areas of research, bring awareness to training and professional education programs, and offer networking opportunities for a variety of industries. TPS sees more than 350 exhibiting companies and more than 5,000 attendees each year. ■

tps.tamu.edu

TRADE SHOW PREVIEW

OTC
May 2-5

NRG Park
Houston, Texas

Exhibition Hours

Monday, May 2 • 9 a.m.–5:30 p.m.

Tuesday, May 3 • 9 a.m.–5:30 p.m.

Wednesday, May 4 • 9 a.m.–5:30 p.m.

Thursday, May 5 • 9 a.m.–2 p.m.

OTC is a global event that connects offshore energy professionals from more than 130 countries to collaborate and discuss the challenges, solutions and changing energy landscape of the offshore energy sector. Across four days, industry thought leaders, investors, buyers and entrepreneurs will meet in Houston to develop business partnerships and learn about the latest advances, challenges and opportunities.

OTC gives users access to leading-edge technical information, the industry's largest equipment exhibition, and valuable new professional contacts from around the world. Its large international participation provides excellent opportunities for global sharing of technology, expertise, products and best practices. ■ *2022.otcnet.org*

DUE TO THE CONFLICT BETWEEN RUSSIA AND UKRAINE, THE PRICE OF BRENT CRUDE OIL HIT **$139.13 PER BARREL** IN EARLY MARCH—**THE HIGHEST PRICE SINCE 2008.**

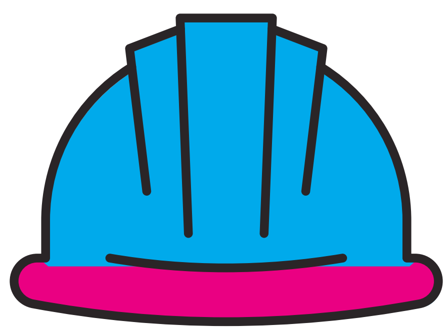
The U.S.'s average gas price also rose to $4.25 a gallon in early March, passing the record high of $4.11 from July 2008.

U.S. Energy Information Administration

Large energy users, including manufacturers, can improve energy efficiency & bolster competitiveness by deploying renewably supplied district energy systems & integrating smart manufacturing technologies.

—Office of Energy Efficiency and Renewable Energy @eeregov

WOMEN **MEN**



According to the U.S. Bureau of Labor Statistics, only 15.7% of workers in architecture and engineering jobs in 2019 were women.

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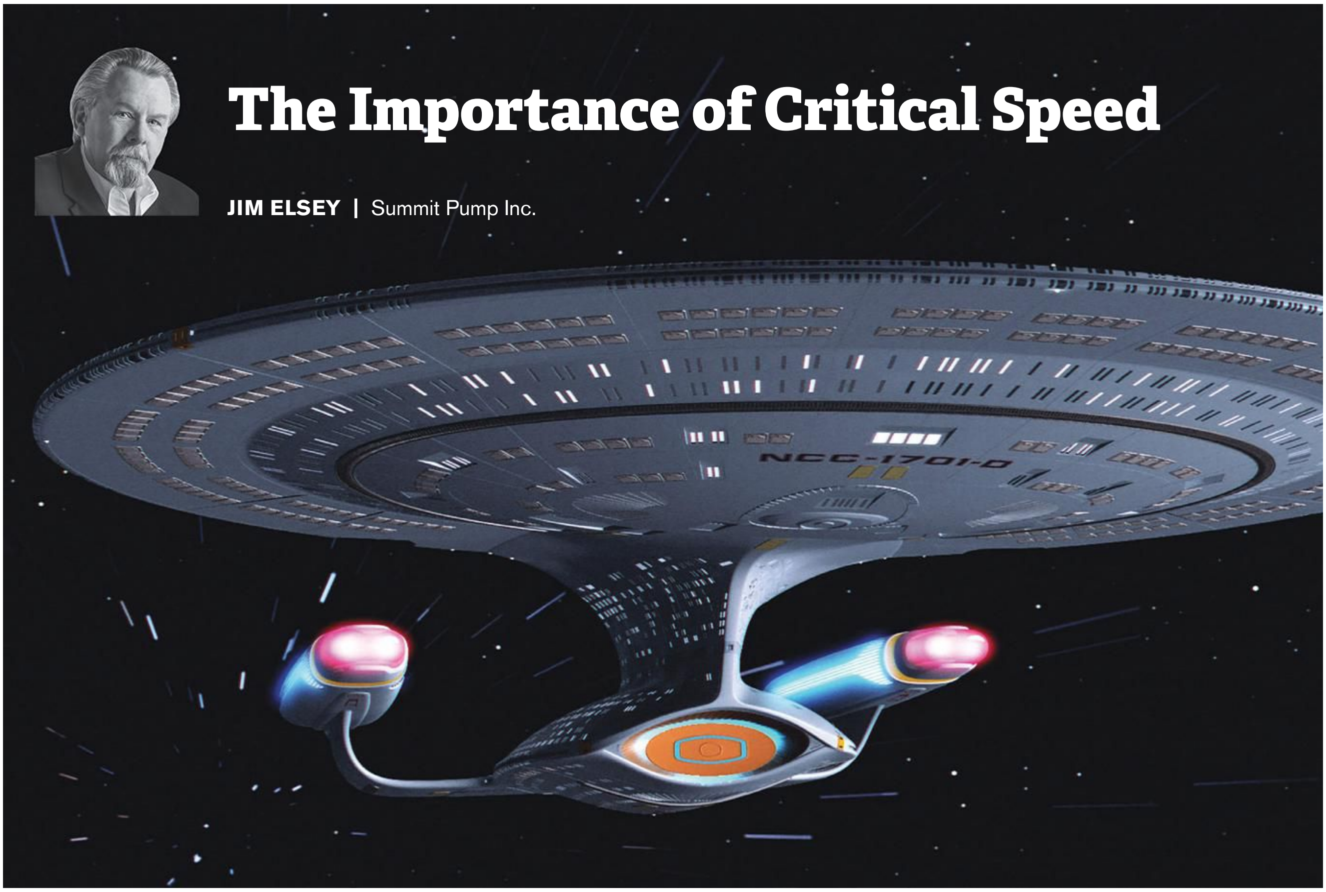
Check 108 on index.

The Importance of Critical Speed

JIM ELSEY | Summit Pump Inc.



The first time I heard the term "critical speed" was in a college mechanics class. I initially assumed it had something to do with the Starship Enterprise or the safe speed range that exists above the posted speed limit but is lower than state trooper ticket speed. I was wrong on both counts.

If you operate high-energy equipment in a power plant or refinery, you are aware of critical speed because of the many multistage pumps and other high-energy equipment such as turbines and compressors.

For the everyday pump operator or technician, you don't need to worry about critical speed because someone else has already figured it out. However, I recommend that you at least be aware of the term and have a fundamental understanding of the concept. The purpose of this column is to initiate discussion of the critical speed concept on a general level and explain why it is important for safe and reliable equipment operation. If you don't know the critical speed of your pump, ask the manufacturer.

> Critical speed is the natural vibration level of the rotating element due to its structure and imperfections.

Critical Speed

Any structure made from an elastic material has a natural resonance frequency. In our example, the structure is a pump rotor. The fact that metal is elastic may be hard to understand at first, and while it takes some noticeable amount of force, metal will deflect, bend and vibrate. If you still have issues thinking of metal as an elastic material, refresh your materials science background with a fast review of Young's modulus of elasticity and remember that most metal choices for pump shafts share a small range of elastic modulus around 29x106 pounds per square inch (psi).

Critical speed is the speed where the natural vibration (resonance) occurs. Resonance is when the unit has high vibration from a disproportionate (small) stimulus. From a different perspective, an example you may remember is old TV commercials or other visceral instances using voice or instrumental resonance to shatter a wine glass.

Rotor Dynamics

All rotating equipment has a critical speed (fans, blowers, generators, motors, turbines,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Proximity Sensors	AutomationDirect Price/Part Number
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12 mm two-wire DC flush prox with 2 m cable	$24.00 AM1-A0-2A
18 mm flush AC prox with 2 m cable	$34.50 VK1-A0-1B

Q/D = quick disconnect

*All prices are U.S. published prices. AutomationDirect prices as of 11/17/2021 Allen-Bradley
11/5/2020. Prices may vary by dealer. Many other part numbers are a

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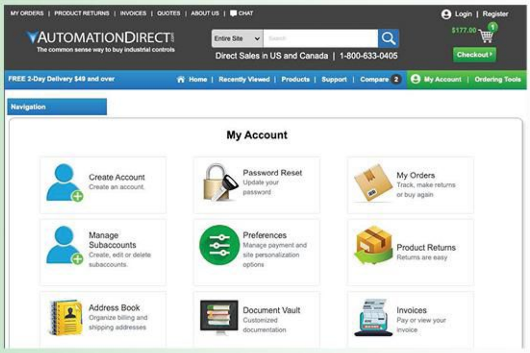

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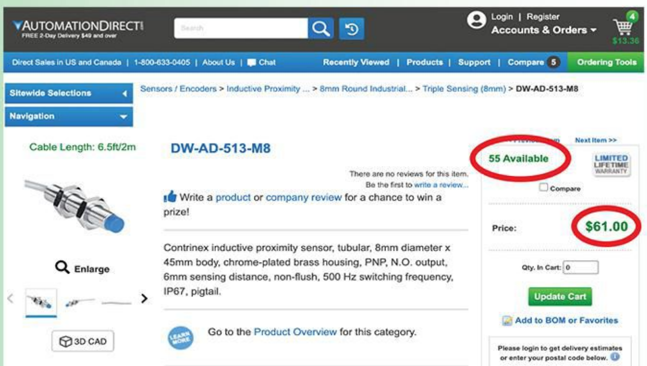

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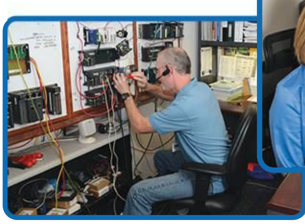

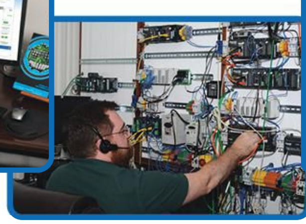

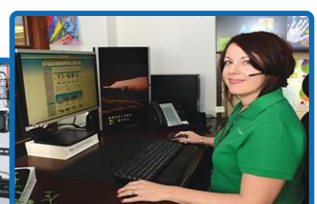

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expanders and compressors). For this column, we will focus only on centrifugal pumps. For the average single-stage pump, the critical speed will be much higher than the operating speed, and so it is of little to no concern. For example, with few exceptions, American National Standards Institute (ANSI) (OH-1) pumps in the S, M and L frame sizes have a first critical speed over 10,000 rotations per minute (rpm), which is well above any allowable operating speed. In lieu of critical speed on OH-1 pumps, it would be more important to pay attention to a related parameter, the pump shaft rigidity factor also known as "L-over-D ratio," or more accurately the L^3/D^4 ratio. L-over-D ratio is derived from the beam deflection formula utilized in statics and is a parameter that will aid in the prediction of magnitude for shaft deflection for a given and applied hydraulic radial force.

Of course, shaft deflection in a pump is not a desired reaction because it leads to failure of the mechanical seal, bearings and shafts. When considering the L-over-D ratio, it is important to understand that a lower ratio is better. L-over-D ratios are of little to no concern when dealing with multistage pumps.

Critical speed is the natural vibration level of the rotating element due to its structure and imperfections. At some speeds (rpm), the rotor will start to exhibit a pronounced vibration due to the natural resonance. For example, imagine a system startup where you are bringing a large pump up to speed on a variable speed drive (VSD) or a turbine. In our example, the pump would run smoothly as we proceeded from 0 to 2,000 rpm, but it would then vibrate profusely somewhere near 2,050 rpm (critical speed). When we continue to increase the speed above 2,050 rpm, the vibration would dissipate. Please note the speeds mentioned here are only for example purposes.

Again, realize that it is that angular velocity (think speed) that excites the natural frequency of the rotor. Critical speed can also be considered as that rotational speed where the dynamic forces cause the rotor to vibrate at its natural frequency. The natural frequency of a pump is a function of the rotor stiffness (k) and its mass (m). One method to express this natural frequency is seen in Equation 1. Critical speed (expressed in radians per second) is equal to the square root of the stiffness divided by the mass.

$$\omega_n = \sqrt{\frac{k}{m}}$$

Equation 1

Bump/Impact Testing

All rotors have a natural frequency that you can determine by conducting a test that is known as the "bump method" (aka "impact test" or "bump testing"). It is not my intent to delve into the details of these methods. You can find plenty of information from various companies that specialize in vibration monitoring/analysis and/or the Vibration Institute (vi-institute.org).

The short explanation is if you bump (strike) a structure or rotor with an instrument, it will resonate at its natural frequency. You will need proper instruments to detect and measure the vibration levels and corresponding frequency. The measurement is typically conducted in a minimum of two planes/directions. The test is normally conducted on idle units, but some instrument systems will allow you to conduct the test while the unit is operating, which is a major benefit. The design of some pump units and systems will also allow for the test to be conducted during coast down.

Striking the unit could potentially cause damage, so be careful where you hit the unit. Use soft face hammers or blocks of wood. Most of the time, you don't need to bump the unit very hard. Many detection systems include a calibrated strike hammer.

Critical Speed Will Vary

No pump rotor is perfectly manufactured—there is always some imbalance or minute imperfection, especially if castings are involved and those flaws become magnified over multiple stages. It is important to note that the "rotor imperfection" can also be due to hydraulic radial force deflection from operating the pump away from the preferred operating range. The deflection due to rotor eccentricity can exceed the elastic restoration limits of the rotor at certain speeds, which will cause the rotor to vibrate as if it was unbalanced.

Critical speed will vary with fluid properties, pump wear (ring fits), shaft length, shaft diameter, bearing types/placement and coupling type.

Critical Speed—There Is More Than One

Critical speed episodes occur more than once for a given rotor. Normally we are only concerned about the first critical speed and its relation and margin to the operating speed. Second and third critical speeds are almost always far above operating speeds.

Speed, RPM & Angular Velocity

Critical speed is a phenomenon that all rotating equipment shares. It is a speed normally expressed in rpm at which the unit will exhibit the highest level of vibration due to the inherent natural frequency of the rotating element. Another way to express rpm would be angular velocity, which is simply the speed of the unit but because it is traveling in a circle (hopefully) rather than a straight line.

To be technically correct, rotational speed is normally expressed in units of rpm while angular velocity is expressed in radians per second (or other units of time). We could also express that velocity as degrees per second (or other units of time).

Lomakin Effect

Critical speed for a pump is difficult to calculate because of the many factors involved. One main reason is that pump shafts have many different diameters over their length. Another major factor is impellers with close ring fits where the liquid is "caught" in the clearance and acts like a dampening bearing (aka Lomakin effect), and so the dampening effect works to mitigate the critical speed vibration by stiffening the rotor. The Lomakin effect has a strong influence on critical speed and the higher the effect, the higher the critical speed will be.

The Lomakin dampening effect can also be created by packing, bushings and

Velocity vs. Speed

Some people erroneously interchange the terms of velocity and speed. We are all guilty of this in some casual conversations. Velocity is the rate of change in position over some period in some direction (vector). Linear velocity is simply in a straight line, while angular velocity relates to the speed of rotation. The difference between speed and velocity is that velocity has a defined direction. Speed is a scalar while velocity is a vector. For example, you can state that your yacht is traveling at 30 knots, which is the speed, but if you state the yacht is traveling at 30 knots on a southerly course at 180 degrees, that is velocity.

other close clearance components. Note that as the pump operates over time, and the clearance opens up due to wear, the dampening effect diminishes and critical speed will decrease.

This decrease in critical speed due to wear is an excellent reason not to ignore maintenance on high-energy multistage pumps. While not likely, it is possible to lower the critical speed into the operating range of the unit and cause severe damage. Large blowers, turbines and compressors do not benefit from this Lomakin dampening effect because the air/gases in the close clearances are compressible.

Stiff Rotor vs. Flexible Rotor & Static vs. Dynamic

A rotor with its first critical speed above the operating speed is referred to as a "stiff rotor." Stiff rotor does not mean little to no radial deflection (during operation) and/or rotor sag when the pump is static/idle.

Caution: I have witnessed operators make costly mistakes because they believed that a stiff rotor meant the rotor did not sag and, consequently, the impeller rings would not be touching the casing rings when the pump was at idle and in a static condition. Because of the sag on multistage rotors at rest, you should never rotate them without liquid in the pump (do not rotate even by hand). Without liquid in the pump, the rings will gall.

For details about this subject of pump shafts—rigid and flexible—I recommend a technical paper from the 10th Pump Users Symposium by Ulrich Bolleter and Arno Frei.

Notes & Comments

1. Operating at critical speed is something to avoid by a wide margin due to the potential for damage caused by the amplification of excessive vibration. The pump is more sensitive to any residual imbalance at critical speed.
2. Critical speed phenomena occur at the natural frequency of the rotor, also referred to as the intrinsic frequency and sometimes the excitation speed.
3. The critical speed of a rotor is the same whether it is vertical or horizontal.
4. Critical speed calculation is fairly straightforward for gas/air turbines, compressors, fans and blower units, but is much more difficult for units that involve liquids.
5. Critical speed calculations for air and gas units are normally correct within a few percent.
6. Large multistage pumps incorporate long shafts simply to accommodate the required number of impellers. The pump designer could design the shaft with a larger diameter to preclude the rotor from sagging when the pump is at rest. However, with larger diameter shafts, the eye area of the impeller is reduced. Reduction of the impeller eye area increases the net positive suction head required (NPSHr) for the pump and it also reduces the pump efficiency.
7. If your pump still utilizes oil rings for lubrication (older designs), know that the oil rings normally rotate at a speed close to 50% of the rotor speed. On multistage pumps, it is common for the first critical speed to be below the operating speed. It is then possible for the ring and/or the oil velocity in the fluid film bearing to be at the critical speed of the rotor. This condition is, of course, undesirable and will cause the rotor to vibrate excessively. Also note that the rotor critical speed and the lubricating oil velocity can occur in bearings without oil rings. This phenomenon is known as whirling or oil whirl instability.
8. Critical speed can be calculated and subsequently expressed as either wet or dry. Dry speed is also referred to as air speed. Normally if there is no added description for a pump's critical speed you can assume it is the wet critical speed. For pump applications, I suggest that you disregard critical speed calculations based on dry values as you can be assured the presence of liquid will change the value and you will not be operating the pump in a dry condition. Some engineers will calculate the dry value as a point of interest and curiosity. Dry speed calculations may be appropriate for some disaster scenario calculations conducted for nuclear and military applications.
9. If the pump speed is variable either by electric VSD engine or turbine, be aware and cautious of the units' first critical speed and take steps to avoid this speed zone.
10. The calculated critical speed of a pump can change simply by placement into the piping system. The system will change both the mass and the stiffness values of the unit. Another reason to evaluate piping and foundation designs with the pump as a total system.

The first critical speed for the Starship Enterprise NCC 1701-D is well above warp 9.9, which is approximately 4 billion miles per hour or 21.5 times the speed of light. The sweet spot for avoiding speeding tickets remains elusive. ■

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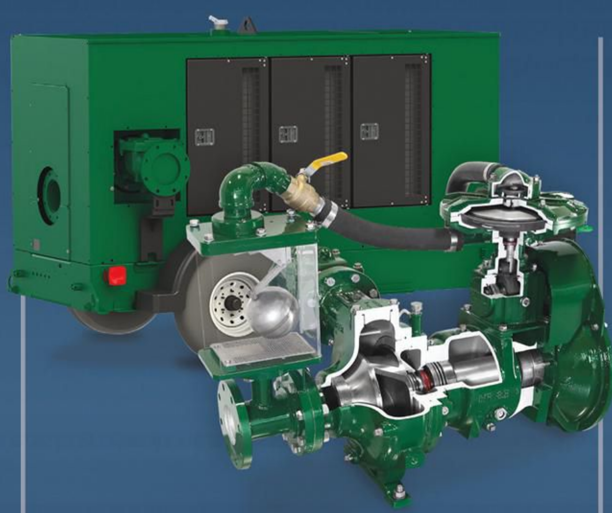

Practical Guidelines for Centrifugal Pumps at Oil, Gas, Petroleum & Petrochemical Plants

AMIN ALMASI | Principal Machinery/Mechanical Consultant

More attention should be paid to optimum selection of pumps, manufacturer's experiences, application details and the specific requirements for each service in oil, gas, petroleum and petrochemical plants. The selection, configuration, packaging, installation, commissioning and operation of pumps needs far more care than what is usually exercised. Here are practical guidelines and useful recommendations for centrifugal pumps in different oil, gas, petroleum and petrochemical services.

Centrifugal Pumps

The most common pump type used across industries is the centrifugal pump. This is because of their flexibility, reliability, favored head-flow rate relations, reasonable prices and well-developed technologies. They are usually driven by electric motors, although steam turbine-driven centrifugal pumps have been used in certain applications. Horizontal pumps can be seen as more desirable, but in some applications, conditions and specific requirements might call for the selection of vertical pumps.

Policy

In many facilities, there has been a policy of "let's see how it unravels" for all stages of projects from design, pump selection, pump location, pump piping to operation and maintenance. This policy is not suitable nor productive. Such a policy is not applicable for oil, gas, petroleum and petrochemical plants. All stages and steps—pump sizing, pump selection, pump order/purchase, inspection, installation, operation and maintenance—should be based on accurate technical evaluations, expert knowledge/experience and recent successful operating references.

Many pumps in key oil and gas services have been installed in a 1+1 (one operation and one standby) configuration, as the shutdown of a pump should not stop production. Shutting down the plant or facility due to a pump trip is simply not an option due to financial damages and other concerns. However, there should also be more attention to key areas related to increasing reliability and availability. Seals and bearings are a key focus in this regard.

Operating Temperatures

The operating temperature is a key parameter for pumps and their systems. Pumps for high temperature or low temperature services need great care. As an indication, for operating temperatures below 5 F (-15 C) and above 266 F (130 C), robust design and manufacturing guidelines should be used for pumps. This usually translates to the use of American Petroleum Institute (API) 610 pumps or an equivalent. There have been different features and provisions for high or low operating temperatures.

For instance, pump casings should be centerline supported to reduce the effects of temperature differences. Usually special materials and sealing systems, compatible with operating temperatures, should be employed. The top discharge, centerline supported pump configuration provides stability when subjected to extreme temperatures and associated (produced) piping loads on pump nozzles.

Speed

Pump speed should usually be chosen at an early stage of the sizing/selection process. Selection of the highest practical speed is often desirable because it yields the smallest size and, usually, the lowest cost and easiest containment of system pressure. The efficiency is usually improved with greater speed. However, higher speeds might reduce the lifetime of components, such as seals or bearings and overall reliability. Therefore, optimization is necessary to find the optimum speed for each pump. Code guidelines (such as API 610) and previously successful references should also be checked.

Mechanical Seals

Today, mechanical seals are specified for nearly any pump. Of course, there are sealless pumps, such as magnetic drive pumps, that do not need seals. Cartridge-type mechanical seals are most often preferred. Almost all seals utilize a small amount of the pumped liquid or an alternative liquid to flush the seal faces.

Mechanical seals need special attention for their selection, assembly, installation and commissioning. Seals should be checked for leakage particularly during the first hours of operation. A minor leak through the seal typically reduces to negligible after a short time, but if it continues there could be an issue. If there is something wrong with the seal installation, the seal could fail in the first hours (or first day) of operation. Otherwise, it might be concluded that the seal installation has been done properly.

The mechanical seal has been responsible for many unscheduled shutdowns of process/major pumps. The overall cost for seal replacement and seal maintenance through a pump's life cycle is one of the most expensive costs associated with pump operation and maintenance. As a rough estimate, approximately $3,000 to $20,000 (on average) can be spent for pump mechanical seal replacement. Some pumps may require pump mechanical seal replacement every one to three years. Although in the case of a mistake in the seal selection or persistent operational issues, a seal failure could be experienced every few months. This is not acceptable, nor cost-effective, and the root cause of the problem should be found and eliminated.

Shop Tests

A shop performance test is an important test for nearly any pump. Pump curves for head versus flow rate, net positive suction head (NPSH), efficiency, power, etc. were theoretical predictions or were based on data of similar pumps. These curves should preferably be verified for each pump at the manufacturer's shop before the pump is delivered to the jobsite. Ideally, a pump manufacturer should operate each pump in the shop for a sufficient period and measure all required parameters in different operating points to verify the performance and trouble-free operation.

There have been many procedures for pump performance tests. The number of points and the definitions are usually subject to negotiation between different parties, but the following are rough guidelines. Ideally, more than eight operating points should be considered and complete test data—including head, capacity, efficiency and power—for these points should be measured and recorded. These points are usually:

- shutoff
- minimum continuous stable flow
- midway between minimum and rated flows
- 80% of rated flow
- 90% of rated flow
- rated flow, typically around the best efficiency point (BEP)
- 115% of rated flow and a point at far-right side

This last point near the end of the curve could be 125% or 130% of rated flow or even more if the theoretical curve extends beyond.

Establishment of NPSH required (NPSHr) usually presents far greater difficulty for a pump manufacturer than other performance parameters. Consequently, more care should be taken when NPSH available (NPSHa) is too close to NPSHr (low NPSH margin).

For critical pumps, low NPSH margins, and others, an NPSHr testing should be specified. As another rough indication, NPSH margin that is less than 1.5 meters (or sometimes 2 meters) may lead to NPSHr testing. ■

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Opinion: When Old Standards No Longer Represent Best Practices

HEINZ P. BLOCH | Process Machinery Consulting

What course of action should managers pursue when a clause in an industry standard no longer reflects best available technology or practices? The answer is: Go with best available technology and, if appropriate, place relevant illustrations, documentation and thought processes in the company's files.

Although relatively infrequent, there are instances where technical clauses are outdated and best practices should prevail. The sealing of firewater pumps is a case in point but other examples exist. This article discusses an incident in 2015 when a large overseas oil refinery suffered great losses by having a firewater pump out of service on the day of a major fire.

By the early to mid-1950s, some knowledgeable multinational corporations with refineries and chemical plants around the world developed supplements to industry standards. These corporations then superimposed and attached their applicable "best practices addenda" to almost every industry standard they invoked or referenced when purchasing equipment. At least one corporation realized that among the items and details that needed to be amended were then-existing stipulations relating to firewater pumps. While these stipulations were well intended when first issued, they were outdated by 1965. One of the old clauses in the industry standard required braided packing in firewater pump stuffing boxes. However, in the mid-1960s, corporations with best practices addenda fitted these pumps with mechanical seals because braided packing risked more frequent failures and unanticipated outages.

There is a trail of documents about the topic of upgrading firewater pump sealing, among them articles advising that modern mechanical seals required less maintenance labor, were leaking orders of less magnitude, and reduced frictional power losses by 50% compared to braided packing. In total, modern mechanical seals are more reliable than packing in firewater service. Starting around 1965, single-spring mechanical seals had become the best available technology for firewater pumps. In some instances, these mechanical seals were to be backed up by a floating throttle bushing and a deflector guard. Because reliability professionals must advocate "designing out" maintenance, they are also encouraged to read about the feasibility and desirability of securely installing an advanced rotating labyrinth-style bearing housing protector seal. Such protector seals should take the place of the deflector guards used decades ago. Moreover, these protector seals should incorporate axially or diagonally moving O-rings. Radially moving O-rings near sharp-edged components were disallowed by knowledgeable users.

Three Layers of Defense

If a facility still uses packing, maintenance and reliability managers would do well to reconsider. Leaking packing jeopardizes pump bearings. Because good managers strive to instill the habit of learning from the mistakes of others and demand fact-based solutions, they may insist on follow-up by their staff. In their quest to make informed decisions, managers might ask reliability groups to research what happened at the above-mentioned refinery in 2015. Requesting to be briefed on the calamity-experiencing major refinery's total economic losses would be a good start. The primary firewater pump at that refinery was out of service because a packing leak had compromised its bearings. On the day when water was desperately needed to fight a major fire, the pump was unavailable. It is a sobering fact that upgrades implemented elsewhere 50 years earlier had not been pursued by the overseas facility prior to mid-2015.

Of interest is the thinking that led many leading oil refineries to opt for single-spring mechanical seals instead of braided packing in firewater pumps as early as 1965. In the 1960s, accurate statistics were kept (for insurance purposes) by a major multinational oil company well known to the author. The statistics for firewater pumps showed that leaking packing tended to ruin bearings. Well-designed mechanical seals were selected by the reliability-focused multinational because these seals generally leaked far less than packing. It was reasoned that mechanical seals were less likely to allow water spray to enter an adjacent bearing housing. Old-style, brittle mechanical seal faces might shatter when abused, but intelligent seal face material combinations have been available for some time. Today, seals that are properly designed, selected and installed are highly unlikely to fail unexpectedly. Moreover, floating throttle bushings represent a "second line of defense" and advanced bearing protector seals clearly represent a "third line of defense" in firewater pumps.

Testing & Operation

The use of packing in modern firewater pumps is not recommended. The finding that packing no longer represents best practice is amplified by the frequent lack of training of maintenance personnel observed at some plants. Included in best practices is periodic testing of all standby equipment. A frequently asked question relates to the testing and alternate operation of standby equipment. Operators ask if switching the "A" and "B" pumps and running each for one month, or if turning on the standby pump once a month and then running it for four to six hours, is the preferred choice. When people argued—many decades ago—that plants might get away by testing only twice a year, responsible reliability professionals took the position that testing only twice a year would not be acceptable and monthly testing was needed. Depending on lubricant selection and lube application method, switching "A" and "B" every two or three months is considered best practice. This keeps the bearings lubricated and prevents seal faces from sticking.

The well-publicized reliability-focused practice of implementing mechanical seals for firewater pumps had not been accepted by the overseas refinery that experienced the fire in 2015. After this event, the refinery investigated why its major firewater pump was unavailable at a critical time. The feedback is not all there, but it can be assumed they closed the case after establishing that "a 50-year-old specification clause was adhered to and so the incident is nobody's fault." Nevertheless, the claim that packing is safer was disproved by the corporation that had collected worldwide statistics for insurance purposes. It determined that consistently using modern cartridge seals would be the first step toward ensuring that future outcomes will be more favorable for pump availability and asset protection.

Any industry standard should explain the intent of its clauses. If there are better ways than following an outdated clause, follow the path of reason and use what is safest for the plant and the community. Of course, when informed users deviate from an old industry standard, they carefully and authoritatively document why they deliberately moved on to less risky methods. Corporate lawyers at the author's petrochemical company agreed that in case of litigation, statistically proven best practices will prevail over an occasional but demonstrably outdated clause found in old industry standards. ■

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Understanding Back-to-Back & Face-to-Face Bearing Arrangements

What happens when bearings are overloaded?

ABHIJEET KEER | Pump Design Engineer

Bearings are an essential part of rotating equipment. The final load, whether it be axial or radial, is finally grounded with the help of bearings. Bearings may be considered analogous to ground connection in the case of electrical circuit. Bearings can be classified depending on various criteria such as the design, loading conditions, arrangements, type of lubrication and so on. Proper selection of the bearing is important but not as important as proper installation. Following the correct assembly procedure while installing the bearings is paramount to achieving the intended service life of the bearing.

Understanding duplex bearing arrangements during selection as well as assembly is important. Incorrect installation and a failure to understand what the application is could result in

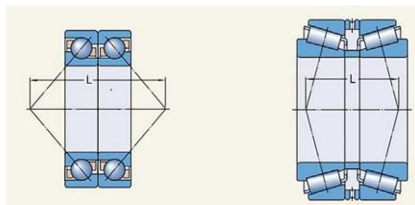

IMAGE 1: Back-to-back arrangement (Image courtesy of SKF)

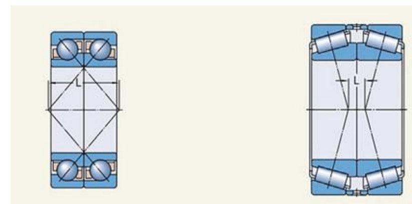

IMAGE 2: Face-to-face arrangement (Image courtesy of SKF)

problems while running the equipment, such as skidding or overheating. This article aims to present the underlying concepts and what actually happens when the bearings are preloaded.

Duplex bearings are a set of two bearings that attain greater radial and axial rigidity when arranged on a shaft with the inner and outer rings clamped together with preload. Single-row angular contact ball bearings and tapered roller bearings are generally preloaded axially by mounting them against a second bearing of the

IMAGE 3: Proper lubrication of bearings is important. (Image courtesy of the author)

same type and size in a back-to-back (load lines diverge) or face-to-face (load lines converge) arrangement.

The bearings are matched pair bearings and the faces of the bearings are precisely machined and grounded to provide preload when installed. As mentioned above, these different types call for the different faces of the bearings to come in contact, causing preload. These arrangements are typically used in connection with angular contact ball bearings and tapered roller bearings. The preloading is achieved either by closing the gap between outer-race faces or inner-race faces, depending on the type of arrangement.

Types of Arrangements

Back-to-back arrangement

Also known as an "O arrangement," this is known to give maximum stability and rigidity. In this arrangement, inner ring faces are designed to touch each other to achieve preload and radial and axial loads in both directions can be taken (Image 1).

The important thing is to understand why this arrangement gives more rigidity and stability. Looking closely, what actually happens is that outer races are radially and axially restricted completely. So now, the internal clearance of the bearing will be closed when the inner races of the two bearings touch. That is called preloading.

When preloading, the inner races of the bearings are being pushed toward one another. The inner races obviously have a rolling element with a cage above them, and pushing inner races will in turn push these rolling elements in the direction of the force. Now the rolling elements are restricted by the outer races. Hence, the outer race will exert the reaction to the applied load, which will be toward the shaft centerline. Now, as per the contact angle, the reactions from both the bearings will be diverging, with distance L between the two reactions.

Because of this constant reaction force from an outside stationary body (ground) acting on the shaft, and with L being more than the width of the bearings, the shaft will be tightly held in the position covering length L at the bearing location. This tightness is realized in terms of higher rigidity and the stability of the shaft. That is why back-to-back arrangements have better resistance to moments in the shaft.

Face-to-face arrangement

Also known as an X arrangement, this is known to tolerate misalignments and cannot support moment loads as effectively as back-to-back arrangements. If misalignment cannot be avoided between the bearing positions, face-to-face bearing arrangements are recommended (Image 2).

Here in this arrangement, one can see the reaction load lines are converging inside reducing the distance L, as compared with back-to-back arrangements. However, the noteworthy point here is that the inner races are touching each other at the face and the gap is initially present at the outer races. Hence, the preload is achieved by closing the gap between the outer races. In the same way as described for back-to-back arrangements, one can imagine that while pushing the outer races closer, it will move the rolling elements with the cage along.

Since the movement of the inner races is completely confined, there will be a reaction force arising inside out, i.e., the reaction will be given by the inner races against the applied force. This is due to the load lines coming closer to reducing the length L. The reaction force coming from the shaft (inner races) reduces the stiffness of the arrangement and then it can tolerate some misalignments. After understanding these arrangements, it makes clear the advantages that are normally outlined in the manufacturer's catalogs.

The primary benefits resulting from preload include, but are not limited to:

- enhanced stiffness
- reduced noise levels
- improved shaft guidance
- compensation for wear and settling
- extended bearing service life ■

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How to Match Seal Technology to the Application

With multiple options, selecting the most effective technology is the first step in increasing rotating equipment reliability.

STEVE HALL & CHUCK TANNER | SEPCO

A plant has a process application that needs to be sealed. Which sealing technology should be used? The options to seal the process include:

- braided compression packing (hundreds of fiber types and lubricants/ coatings available)
- mechanical seals
- air seals

How do end users and equipment manufacturers determine the ideal seal for their application?

Environmentally Safe Fluids

Clean, environmentally safe fluids can often be sealed with braided compression packing. Hundreds of packing fibers are available, and these can be combined with several different lubricants and coatings for compatibility with the pH, temperature, fluid makeup and shaft speed of the application. Properly specified and installed packing can efficiently and successfully seal these applications.

If the fluid being pumped is cool and clean enough to lubricate and clean the packing, flushing through a lantern ring may not be required. However, the majority of compression packing applications need a flush line into the flush port. This flush can be from the process fluid if it is cool enough or from a separate flush water setup. This ensures that the stuffing box environment is properly cleaned and cool to prevent shaft wear and increase packing life.

However, a stuffing box with packing installed must leak. Even if the fluid is environmentally safe, this leakage may not be allowed in the plant.

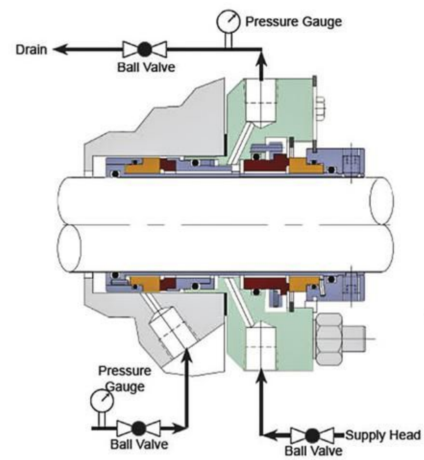

IMAGE 1: Double seal arrangement with barrier fluid (Images courtesy of SEPCO)

IMAGE 2: Compression packing is the most frequently used fluid sealing technology.

Some reasons for this are:

- housekeeping issues that prevent the small amount of leakage from the stuffing box
- the possibility of slip and fall safety issues around the equipment
- the product is too costly to allow for leakage

In instances where leakage from the stuffing box is prohibited or not ideal, a mechanical seal may be used instead. Relatively clean process fluids with adequate lubricating properties can be contained with a single-seal arrangement. These seals are typically less expensive to install and simpler for teams to operate and maintain.

A separate lubrication system is required if the process fluid inadequately lubricates the seal faces. In these cases, a double seal arrangement must be installed. A

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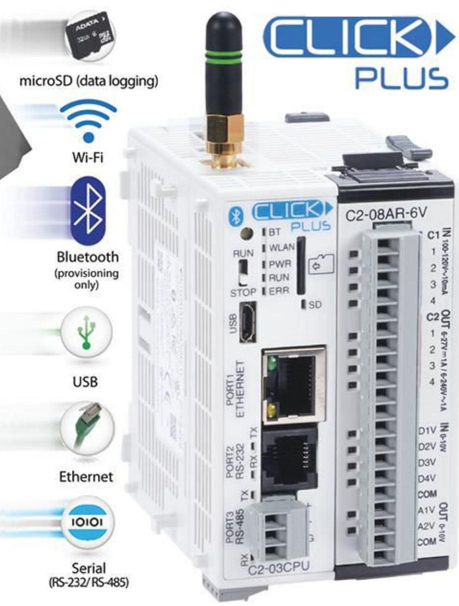

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High-speed I/O	**8 inputs** 100kHz with up to 6 counters, including option slot modules		**8 inputs, 2 outputs embedded w/ 3 optional plug-in inputs** 100kHz for embedded I/O, 250kHz for plug-ins with up to 7 counters - 4 embedded counters + 3 plug-ins
Option Slot / Plug-in I/O	starting at **$54.00** 16 modules available w/ analog, discrete, relay, and combination options		starting at **$69.40** 13 modules available w/ analog, discrete, temperature, high-speed, relay, and combination options
Expansion I/O	starting at **$37.50** 27 modules available w/ analog, discrete, temperature, and relay options		starting at **$121.72** 13 modules available w/ analog, discrete, temperature, and relay options
MQTT	✓		X
Wireless Communication	✓ Wi-Fi (802.11b,g,n), Bluetooth (used with Mobile app to provision network settings)		X
Programming Software	**FREE** CO-PGMSW		**FREE** Connected Components Workbench

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double arrangement (Image 1) helps ensure mechanical seal reliability and prevents the flush or barrier fluid from entering or diluting the process fluid.

Environmentally Hazardous Fluids

Because compression packing must leak and single seals allow vapor to escape, they cannot be used to seal hazardous fluids. Hazardous or corrosive fluids must be sealed with a double seal configuration and be lubricated with an exterior barrier fluid, such as water, synthetic lubricant or glycol. Another option is magnetically sealing these applications.

Slurries

When handling process fluids with heavy solids content, such as municipal wastewater, food processes (syrup or ketchup), black liquor in pulp and paper, and mine tailings—robust seals are required. Seal technology that eliminates or reduces shaft wear is critical. In these processes, compression packing may not be the first choice. Particulates may embed in the packing and be difficult to flush away. They will cause excess wear and friction making packing less than ideal for slurry applications.

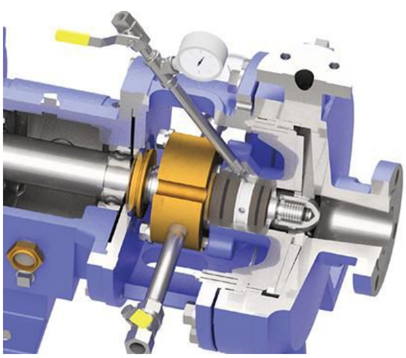

IMAGE 5: An air seal system

The first solution for these types of applications is a single mechanical seal with an external flush system. The next solution is a double-arrangement mechanical seal. Another option is an air seal system (Image 5). The system is made up of a noncontact tandem seal that uses air to seal and water to clean and cool the stuffing box—minimizing or eliminating particulate

IMAGE 3: Heavy leakage from a screw conveyor moving gypsum

damage to the seal components. The system includes:

- two shaft-supporting bushings (to minimize shaft deflection)
- air seal
- lantern ring (for flush water)

Because the air seal is noncontact and floats above the shaft, the system uses little energy. It is also resistant to system conditions that damage or destroy traditional seals and pumps, such as:

- pipe strain
- misalignment
- off-best-efficiency-point (BEP) operation
- cavitation

Dry Powders or Heavy Mixtures

Mixers, blenders, agitators and screw conveyors are some equipment types that move or mix powders or heavy slurries. These assets experience many issues if not sealed properly (Image 3), including:

- seal or equipment failure
- downtime and lost production
- replacement equipment or parts costs (this may require a crane or other service to remove the equipment or access the location to replace the parts)

IMAGE 4: An air seal installed on the gypsum screw conveyor, which eliminated all leakage

- product waste
- other equipment contamination
- housekeeping issues
- personnel safety
- labor costs (operations, maintenance and housekeeping)

For these applications, a recommended solution is the noncontact air seal (Image 4). This seal uses a knife of air to seal the process, eliminating particle ingress into the seal. The floating throttle of these seals does not contact the shaft, so they cause little to no shaft or sleeve wear. They can also withstand ±0.125 inch of parallel movement, meaning they can handle the deflection that often occurs in these processes. ■

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Visual Inspections Increase Centrifugal Pump Life

Checking for factors like oil level and color can make a big difference.

MARK BARNES | Des-Case

While there are many reasons why centrifugal pumps fail, a large percentage can be attributed to bearing failure caused by lubrication issues. In fact, according to a leading bearing manufacturer, lubrication accounts for as much as 80% of all bearing failures (Image 2). Key factors that induce tribological failures include contamination, insufficient lubricant quantity, unsuitable lubricant and overextending relubrication intervals, all of which are preventable. Pump life could be extended by as much as 30% to 50% by focusing on these four factors.

1 Proper Lubrication

Proper lubrication entails more than selecting the right oil or grease for the application. Lubrication refers to how lubricant is maintained in a clean, healthy state within the pump.

Users cannot simply fill a pump full of oil and expect reliability—they need to continuously monitor lubricant health, oil level and contamination to avoid unnecessary failures.

One way to do this is through oil analysis. However, for many smaller pumps, the size of the oil sump coupled with an inability to extract a representative oil sample often means that the oil in many pumps remains unmonitored. To overcome this limitation, it is recommended to implement daily or weekly visual inspections, executed by operators, lubrication technicians or mechanics. To be effective, inspection should include visual clues to help determine the health, cleanliness and overall oil level in the pump. Inspection check sheets should be developed that ask simple questions with binary answers such as:

IMAGE 1: Ideal configuration for visually inspecting a pump (Images courtesy of Des-Case)

- Is the oil clean and clear?
- Is the oil level halfway up the sight glass?

Done correctly, visual inspections can pick up 80% to 90% of all lubrication

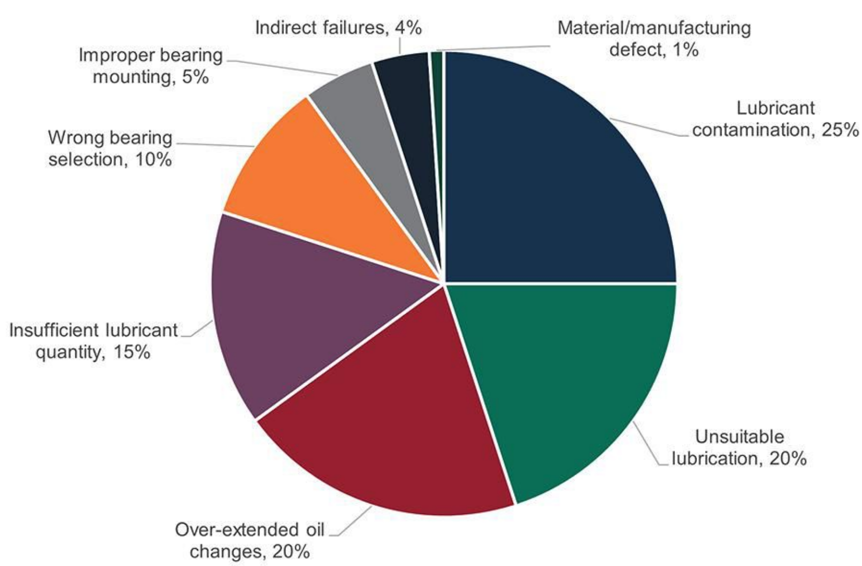

IMAGE 2: Common causes of bearing failure in pumps

problems before they become catastrophic and should be mandated whenever operator rounds are used.

Unfortunately, many process pumps are not set up for visual inspections and must be modified to include simple hardware to permit key lubrication issues to be detected. Image 1 illustrates some simple, inexpensive hardware additions that greatly enhance the “inspectability” of a small centrifugal pump.

Once suitably modified for visual inspections, inspection routes and check sheets should be developed to check for the following:

Oil level

Proper bearing lubrication requires that the oil level be maintained halfway up the rolling element in the oil sump (Image 4). If it is too low, lubrication starvation can occur. If it is too high and churning, increase in temperature and aeration can occur. For smaller pumps, this can be a challenge since some ball bearings can be

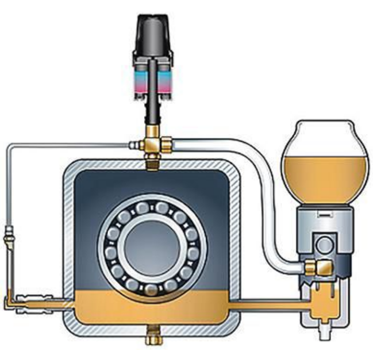

IMAGE 4: The correct oil level for a pump is halfway up the lowest rolling element.

as small as a half-inch, meaning controlling oil level to within ±1 inch. Most pumps are equipped with a level plug at the correct level or a flat-face bullseye. Flat-face bullseyes work well when the pump is new and in good lighting conditions. However, over time, flat-face bullseyes can become stained or opaque, making oil level checks challenging. Instead, pumps should be equipped with a 3D bullseye that can be viewed more easily and is less prone to staining. Under no circumstances should a constant level bottle oiler be used to

IMAGE 3: BS&W bowl showing free water inside the pump housing

Because water is heavier than oil, it will naturally settle to the lowest point in the bearing housing.

gauge if the pump is properly filled. The feed tube from the oiler to the pump can become plugged such that the bottle oiler can sometimes be full of oil while the pump is running on empty.

2 Bottom Sediment & Water Bowls

Water and process fluid contamination is a constant issue in some industries. Whenever water enters the bearing housing, it will either become emulsified with the oil or will settle on the bottom of the oil sump. Either way, water can impair lubrication performance. A pump running with an emulsified oil-water mixture will see as much as 50% to 75% reduction in bearing life.

A simple way to detect the presence of water is to install a bottom sediment and water (BS&W) bowl. This simple device should be installed in the drain of the pump, ideally below the lowest point in the oil sump. Because water is heavier than oil, it will naturally settle to the lowest point in the bearing housing. By installing the BS&W bowl at the lowest point, water can often be observed before it contaminates the oil that is lubricating the bearings (Image 3).

The inclusion of a BS&W bowl has been added to the latest version of the American Petroleum Institute (API) 610 centrifugal pump standard used by the refining, petrochemical and natural gas industries.

3 Oil Color

Whenever oil degrades, the color and clarity of the oil can change. While a change in oil color is not always indicative of a serious issue, a sudden change as shown in Image 5 should be reason enough to further investigate with oil analysis.

IMAGE 5: BS&W bowl showing clear oil discoloration

BS&W bowls and 3D oil sight glasses are both great ways to visually observe and record oil color.

4 Desiccant Breather Inspections

In a previous Pumps & Systems article ("The Impact of Water on Pump Bearing Life," August 2021), the author discussed the importance of controlling headspace humidity inside the bearing housing using a desiccant breather. However, a desiccant breather is more than just a means of preventing water from getting into the pump. It can also serve as another visual

IMAGE 6: The direction of color change from top to bottom indicates internal water is present.

inspection point. Because of the way air flows through a desiccant breather, the color indicator, which turns from blue to pink when saturated with moisture, will change color from the bottom up or top down, depending on circumstance. A color change from the top down indicates that water is present inside the bearing housing, likely from seal failure (Image 6).

Like most rotating assets, pump life is closely aligned with lubricant health and cleanliness. By adding a few simple visual inspections to daily operators' rounds, early warning signs of impending lubrication failures can be found before functional failure occurs. ■

Get More Info

To read more about lubrication, visit **pumpsandsystems.com/tags/lubrication.**

Mark Barnes is vice president of reliability services at Des-Case Corp. For more information, visit descase.com.

Bearing & Rotor Dynamics Analysis in Vertical vs. Horizontal Pumps

How design differences affect system dynamics and how to account for these effects.

ROMAN KOCHUROV | SoftInWay

One of the biggest contributors to pump failure is issues related to rotor-bearing systems. Today, pumps are often designed to operate at increased speeds and loads to improve efficiency. These operating requirements demand that special attention be paid to rotor dynamics analysis during the design stage. This includes simulations of bearings, seals and other components of a pump.

There are numerous pump types available for industrial applications. These pumps can be classified based on design, operating principles, special features, characteristics of the working fluid, configuration (centrifugal, axial, screw, helical, positive displacement) and much more. With each type of pump, there are challenges in terms of modeling and analyzing the rotor-bearing system. On the other side of the coin, many rotor dynamics methods and principles are similar for every rotating machine.

This article will focus on two basic types of pumps: horizontal and vertical, without further specification of the design, to outline common approaches and differences with respect to rotor dynamics, bearings and seals simulations.

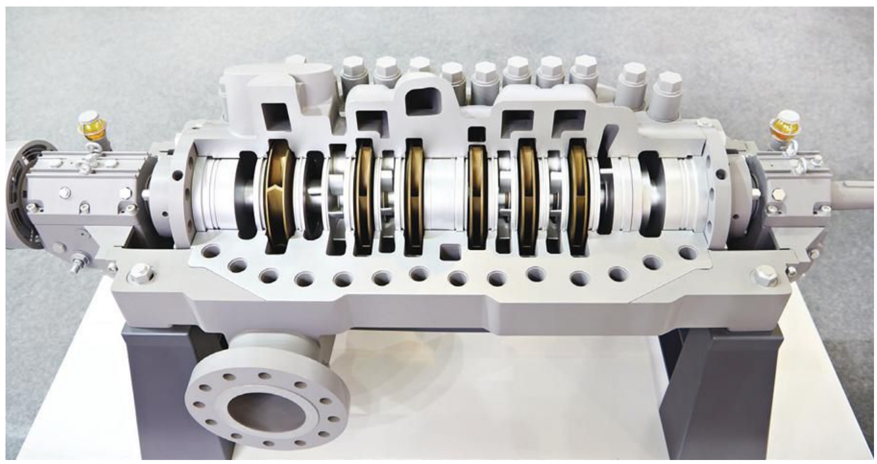
IMAGE 1: Multistage horizontal centrifugal pump (Images courtesy of SoftInWay)

Vertical vs. Horizontal Pumps: Design Differences

The primary difference between vertical and horizontal pumps is the orientation and the shape of the shaft. A horizontal pump has a shaft that is placed horizontally (Image 1), between the bearings or overhung position. The shaft in the vertical pump is positioned vertically. The most common type of vertical pump is the vertical turbine pump (VTP)—Image 2. Vertical pumps (like VTPs) usually have long, spaghetti-like shafts that are connected to the motor (above or below) through the coupling and supported by a thrust bearing at the top or bottom. Another design feature of vertical pumps is the column pipe casing that influences pump dynamic characteristics. These design specifications make a difference in how to approach rotor dynamics modeling and vertical pump analysis.

What Makes Vertical Pump Rotor Dynamics Different?

Flexibility

Vertical pumps have long shafts that cause more flexibility. These flexible shafts have closely spaced modes and a dense range of frequencies. In this case, resonance vibrations with elevated amplitudes may occur, especially if the pumps operate in a wide range of rotating speeds.


IMAGE 2: Multistage vertical turbine pump

The casing structure of vertical pumps (pipe) is also flexible. With that in mind, the pipe casing flexibility, as well as bowl assembly, should be considered when calculating the stiffness characteristics of intermediate radial

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Pelle Olsson
National Sales Engineer
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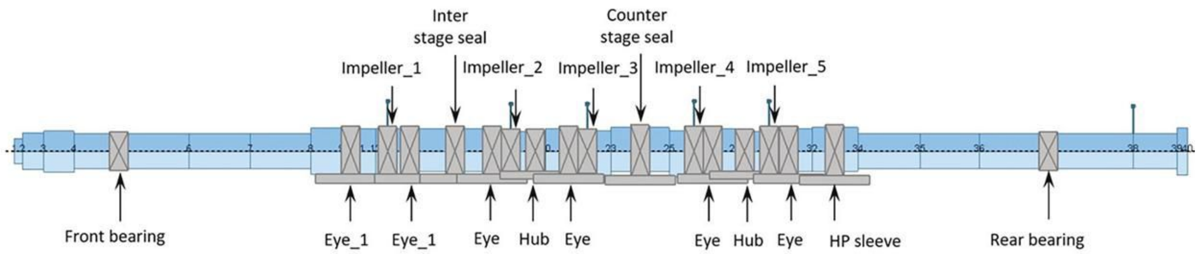

IMAGE 3: A horizontal centrifugal pump (FE rotor dynamics model)

shaft supports. Additionally, the casing structure of a vertical pump may experience high vibrations due to its flexibility, so frequencies of the pipe should also be analyzed.

Axial forces

Overhung vertical pumps supported by a thrust bearing located at the top of the machine are loaded with axial tensile force resulting from gravity loads. Conversely, if the thrust bearing is placed at the bottom of the machine, a compression force acts along the shaft. Thrust force from the impellers is an even higher contributor to the shaft tension and stiffening. All these forces change rotor bending stiffness, natural frequencies and critical speeds, so it is important to account for these factors through rotor dynamic analysis before a machine ever gets put into operation.

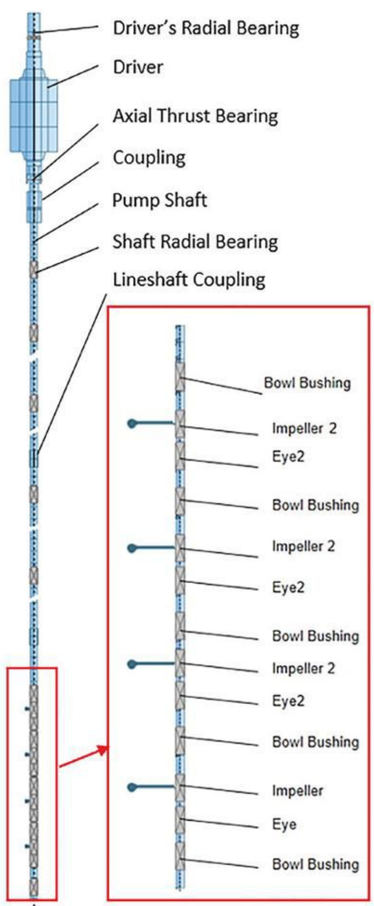

IMAGE 4: Multistage vertical turbine pump (FE rotor dynamics model)

Bearings and seals

The bearing is one of the most critical parts of any pump. Bearings support the shaft and reduce friction on the pump's moving parts by maintaining smooth rotation of the rotor. Bearings also bring stiffness and damping to the rotor-bearing system. Bearings that are used for pumps can be classified as radial (support the shaft in the lateral direction) and axial (suited for axial loads). The most common types of bearings that are used for pump applications are ball and roller bearings, hydrodynamic oil film (babbitt) journal bearings and pivot shoe bearings (axial thrust load support).

In the context of pumps, seals are no less important. Like bearings, pump seals are the source of stiffness, damping and additional "mass" coefficients to the rotor-bearing system, which change the entire system's dynamics. A pump's natural frequencies for systems with bearing and seals differ compared to systems on rigid supports.

Modeling the bearing-seal system differs in vertical pumps compared to horizontal pumps. One difference is a potentially high number of radial bearings that support long shafts in vertical pumps. In many cases, a high number of stages (for example helical/spiral stage types) in a pump increase the number of bearings and seals—the total number of bearings and seals may reach dozens. Image 4 gives an idea of how many elements will need to be modeled to obtain accurate rotor dynamic results. The combination of a long shaft, increased tolerances and misalignments with what is objectively a large number of radial bearings may result in a rapid, nonlinear change in bearing stiffness in bearings where the shaft line gets close to the bearing wall.

The second difference, and potentially even more important than the above, is that radial bearings in vertical pumps are lightly loaded (no gravity force in the radial direction), which makes the estimation of dynamic bearing coefficients more complicated. Unloaded cylindrical bearings are a cause of stability issues in vertical pumps. Thus, nonlinear analysis is essential for an accurate assessment of the rotor behavior of vertical pumps with long shafts and unloaded bearings.

Finally, in submerged pumps, which are mostly VTPs, the bearings are in a pressurized environment and lubricated by the process fluid, often with contaminations. Additionally, the working fluid mixture may change the composition, and the operating conditions of a pump (rotational speed) are often variable. Thus, these radial bearings experience accelerated wear, and the prediction of their characteristics is complicated considering the random characteristics of applied conditions. A worst-case model approach can be used to predict the dynamics and reliability to avoid critical failures.

Which Effects Should Be Considered Regardless of Pump Type?

There are areas where analysis is similar. Some other effects that are important and should be considered in rotor dynamics analysis of both vertical and horizontal pumps are:

- static and dynamic radial loads arising in the location of the impeller due to uneven clearance distribution between impeller and volute
- inertias and hydraulic imbalance forces that should be introduced at the impeller location
- effective added mass at the impellers and along the shaft
- dry, wet and process fluid conditions, as well as "as new" and "worn" clearances considered during bearing and seal analyses
- the Lomakin effect: a force created at the wear rings and throttle bushings within a centrifugal pump
- other general effects and techniques that are similar for most rotating machines and presented in American Petroleum Institute (API) 684 standards[2]

Though the approaches and methods for modeling and analyzing horizontal and vertical pumps are often similar, vertical pumps have their own set of features that make rotor dynamics analysis and bearing and seal simulations more complex. The major challenges found in vertical pumps relate to the construction and operating specifications including:

- long shafts
- a high number of stages
- its bearings and seals
- unloaded radial bearings
- axial forces due to gravity

Because of these design features, vertical turbine pumps are more prone to vibration problems and structural/lifetime issues. This can lead to headaches for the rotor dynamics analyst who is dealing with these kinds of pumps. Luckily, today's engineers have access to digital tools that can be used to solve these headaches. Through advanced simulation software, dynamics standards and technical publications (for instance references 1 and 2 below), these effects can be modeled and analyzed to ensure safe and reliable operation. ■

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Roman Kochurov is a rotordynamics engineer at SoftInWay. He can be reached at r.kochurov@softinway.com. For more information, visit softinway.com.

IMAGE 1: Pilots for autonomous production are probable in the future. (Images courtesy of NOV)

Using Digital Solutions to Cut Costs & Increase Uptime

Combine pumping systems with integrated remote capabilities for long-term value.

SHANE HECK | NOV

Automation, control and monitoring solutions for pumps have been available for decades. The technology and value provided today far exceed what was available even 20 years ago, yet many oil and gas producers have been resistant to advanced digital solutions.

Hard-wired supervisory control and data acquisition (SCADA) systems have been around since the 1970s, while wireless and remote technology accessed by cellular modems came about in the early 2000s. By the mid-2000s, remote and advanced control technology was available for production well sites. Operators, however, have not prioritized these solutions. Remote capabilities have become second nature in other industries, especially in business to consumer markets—such as smart home devices and self-driving cars. Automation, control and monitoring solutions can offer similar value to operators, however, the lag in the industry is a real challenge to overcome. But there is hope.

Industry Adoption

This shift would not take anything away from operators. An ever-increasing number of production well sites means there are fewer people for more operations, and there will always be an abundance of tasks to perform. Operators are working on profitability goals with fewer people than ever seen before in the industry. Five to 10 years ago, a production or field engineer may have overseen 20 to 30 wells. This same person may be managing up to 100 wells in today's resource-constrained environment. Greater efficiency is needed to manage the increased workload.

The evolving market strives to help operators manage tasks and run businesses more efficiently. With integrated remote capabilities for pumping systems comes increased visibility and notifications, informing and empowering users to make adjustments on the fly. This facilitates the overall improvement of their equipment and overall production site processes. Despite this, the market has not fully allowed users to change their philosophy and invest in this technology.

In some ways, the industry is more open to automation, control and monitoring; still, challenges associated with such an industry-wide mindset change exist.

These include budget and planning challenges, operation in remote locations with harsh environments, and leadership not native to digital technology. And younger generations, who are often digital natives, not only desire but expect the added benefits of the latest digital advancements.

As oil prices rise, the industry is witnessing financial gains. At the same time, there has been brain drain from early retirements and attrition. However, automation, control and digital solutions can make up for the lost knowledge and expertise of those who have left the industry. This practical knowledge can feed the automation and control systems to develop parameters to support industry leaders.

IMAGE 2: Pumping systems with digital and integrated remote capabilities can keep production on schedule. By shedding light on anomalies, adjustments can be made, either remotely or on-site.

Quick Wins & Long-Term Advantages

Once users introduce automation, control and monitoring into their pumping systems, they can experience both immediate and long-term advantages.

For example, without full visibility into their system performance, operators could be making decisions blindly, spending valuable time investigating and troubleshooting without critical information. Monitoring can help to solve this dilemma. Added control can also bring safety benefits with fewer people at the well site, vehicle and insurance costs decrease due to operators not having to drive from site to site, and reaction time is diminished so that processes can continue on time.

If failures can be accurately predicted on production sites through analytics, there could be environmental advantages that would improve sustainability efforts. Remote visibility and autonomous systems allow users to run systems at more efficient energy levels, which is better for operational costs and emissions management, making them environmental, social and governance (ESG) friendly.

If users monitor equipment health, various operational challenges that could impair production or even damage the environment can be prevented. Inventory and uptime can be improved as unforeseen incidents are eliminated and every step of operations is predicted.

For example, a user was running their progressive cavity pump too fast, which was drawing the fluid level down at a high rate. A digital solutions provider was able to visualize the issue and automatically adjust to regulate the pressure. Using a variable frequency drive pump controller and monitoring technology, the provider saved the user the cost of a new pump, kept the well running and production continued.

IMAGE 3: Visualizing data in real time is a powerful tool for operators, enabling swift and informed process improvements.

An Evolving Market & the Future of Pump Packages

The future of oil and gas production will vary by operator and geography. However, as millennials continue to advance in their roles, they will expect a connected well site. While fully autonomous production is not something that will have widespread adoption anytime soon, there are expectations to see prototypes and pilots within the next 20 years.

The value of integrated remote capabilities for pumps is quantifiable today. A cost-benefit analysis can be performed at a well site to understand how a user's bottom line would benefit from introducing new automation and control technology.

Users can prevent shutdowns and provide alerts when preventative maintenance is needed. What cannot be seen cannot be fixed, and the better processes are understood, the better they become. ■

Shane Heck is an automation systems product line director at NOV in the Process and Flow Technologies business. For more information, visit nov.com.

How Shale Fracking Is Enabled by a Massive Pumping System

Pumps for fracking must deal with high pressure extremes.

IAN PALMER | Petroleum Engineer & Consultant

Before 2005, natural gas production was declining in the United States. With incentives from the U.S. government, such as tax credits, industry had experimented in the 1970s with tight gas or sandstone layers that had low flowability, or permeability, to gas. This arrested the gas shortage for a decade or two. Same thing for coalbed methane or natural gas that was trapped in coal seams. This took off in the 1980s and eased the shortage for a couple of decades.

But the U.S. appetite for natural gas kept growing—industrial manufacturing, gas-fired power plants, gas heating in homes and offices and plastics that are made from natural gas liquids such as ethane and propane for use in offices, homes, clothing and drugs. As a last-ditch effort, horizontal wells were drilled into shale layers with essentially zero permeability.

Like most vertical wells, the new horizontal gas wells needed to be fracked, but how many frac treatments were needed for a long horizontal well? Operators needed a robust and reliable source of pumping power to inject enormous volumes of frac fluid under challenging pressure conditions.

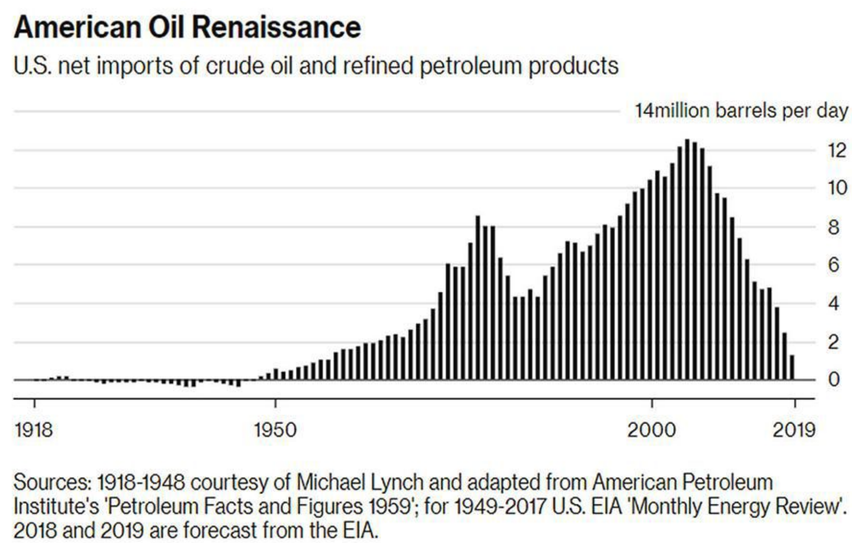

IMAGE 1: U.S. net imports of crude oil and refined products (gasoline and diesel). Source: Bloomberg (Images courtesy of the author)

The Key to Shale Fracking

Conventional fracking methods and fluids did not work well enough.

Then, an engineer in the Barnett shale out of Fort Worth decided to pump straight water instead of conventional gelled water as the frac fluid. Gas flow rates improved and water was cheaper, so shale wells finally made a profit.

The key was to crack up the shale rock all around a horizontal well. In fracking, water is forced down a vertical well and then along a horizontal well. Small holes called perforations direct the water into the shale layer, and if the force is great enough, it splits the rock like an ax splits a log of wood. This is where the frac pumps come in, and a massive pumping system is required.

The result is a network or mesh of tiny cracks in the shale layer. If several separate fracking operations are conducted along a horizontal well, the well can be surrounded by a mesh of tiny cracks. In this way, the operator has enhanced the permeability of the shale layer and gas molecules can flow more easily to the horizontal well after the fracking campaign is over. By 2003, shale wells became profitable enough to open the door to a shale revolution that includes shale oil as well as shale gas; the new technology worked well for both.

Pushing the Limits

Adventurous oil and gas companies pushed the limits. They drilled horizontal wells up to 2 miles long and conducted up to 40 separate fracking operations along each horizontal well. It is a large operation requiring many huge pumping units to be synchronized.

First, to force the water to crack the shale rock, the pumps have to overcome the natural stress in the rock at depths up to 12,000 feet underground. This means roughly 12,000 pounds per square inch (psi). The pressure would be like crushing your hand under a steamroller building a highway.

Second, in a typical shale well, the volume of water used would fill a football stadium to 40 feet over the

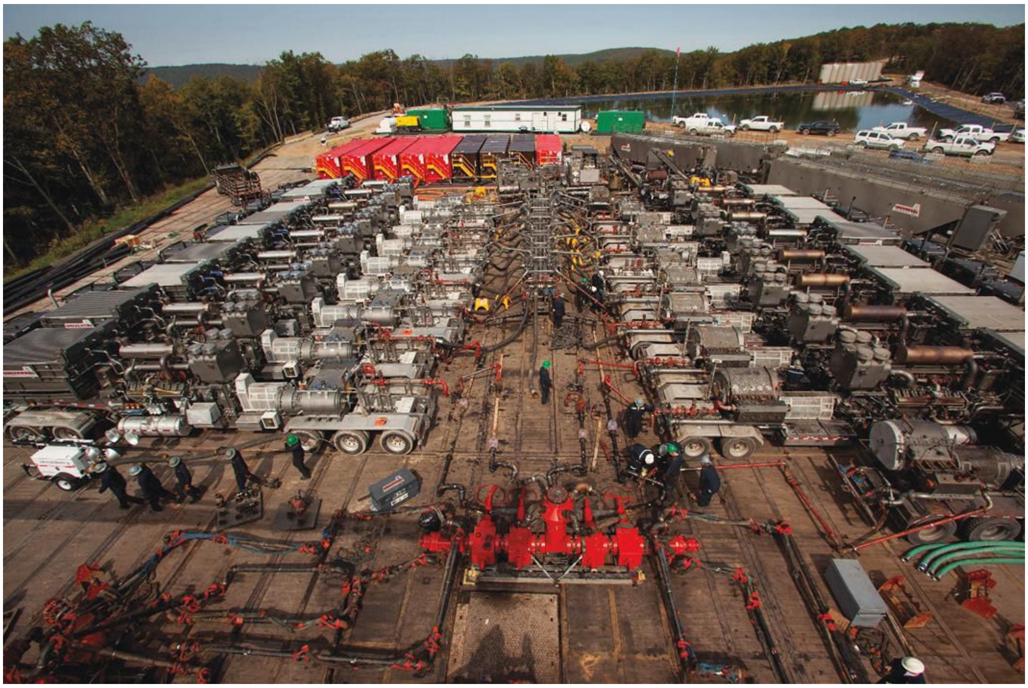

IMAGE 2: Massive frac pumping equipment in a modern Marcellus shale project. Source: Universal Pumping Services

grassed area—and that is just for one well.

Third, the frac pumps must deliver tiny sand grains, as well as water, in the later stages of a frac treatment. These sand grains lodge in the cracks that have been created around the horizontal well and prevent the cracks from closing after the fracking operations have been completed. In a typical shale well, about 100 railcar containers of sand are pumped down for just one well.

The Shale Revolution

The success of shale fracking enabled the U.S. to become self-sufficient in oil and gas—the first time since 1947 (Image 1). The shale revolution led to cheap gasoline, inexpensive power for industry, cheap plastics and other manufacturing benefits for the U.S. Around the world, cheap and reliable oil and gas energy have lifted world populations to a higher standard of living.

In February 2022, the U.S. became No. 1 in liquefied natural gas (LNG) exporters, beating out Australia and Qatar. The hope is that this will help countries like China and India switch from coal-burning power plants to natural gas and reduce their greenhouse gas (GHG) emissions (gas burns much cleaner than coal).

The Pumping System

Traditionally, high-pressure, high-volume water fracs require diesel-fueled combustion engines. A frac pump has to inject frac fluid, mostly water and sand, under huge pressure to crack up the rock deep underground to allow oil or gas easier inflow to the well.

The success of shale fracking enabled the U.S. to become self-sufficient in oil and gas—the first time since 1947.

A normal frac fleet is limited to 15,000 psi but there are several fleets within the U.S. capable of 20,000 psi. The typical injection pressure for shale wells is about 8,000 psi.

Typically, each separate fracking operation pumps water and sand at a rate of 30 to 75 barrels per minute (bpm) but this can be as high as 150 bpm. After two to three hours of pumping, the injection moves one stage back along the horizontal well and the next frac operation begins.

Frac pumps are reciprocating positive displacement (PD) pumps that contain a fluid end and a power end. A mixture of sand and water has to be forced down a well and through small perforations so the pumps have to endure abrasive fluids. The pumps also must deal with pressure extremes, especially if the fracking pressure gets so high it threatens to split the well casing.

A diesel fleet of pumps typically needs 20 separate pump trailers at the well site. If there are multiple wellheads at a fracking site, frac pumps can run without interruption. Each fracking fleet requires a crew of about 30 people, about 15 for each 12-hour shift. Total power can reach 20 million horsepower (hp).

There is a trend in the industry to go to a technique called simul frac, which means the frac fleet is fracking two wells at the same time. This cuts the completion time in half and improves operational efficiency.

In the Marcellus shale (Image 2), eight to 14 gas wells can be drilled on each pad location, with 40 separate frac stages deployed in each well. By doing six fracking operations per day, the time elapsed is 53 to 93 days. So approximately two to three months of rig activity at each pad site is not uncommon.

Quintuplex pumps have achieved higher hp. One company reports an 11-inch stroke rated at 5,000 hp. This can mean a lower operating speed to reduce fatigue cycles, extended pump lifetime and fewer pump trailers.

Fracking pumps must be rugged and reliable. Downtime is expensive, so operational efficiency is highly desirable.

E-Fracking

The world is entering a gradual transition from fossil fuels to renewable energies, driven by climate changes attributed to greenhouse gas emissions. Fossil fuels provide 83% of the world's energy and 73% of the world's GHG emissions.

In the oilfield, one way to reduce GHG is by companies greening their own operations by using wind or solar electricity to pump fracking operations. Alternatively, diesel-fueled combustion engines can be replaced by e-frac systems where electric pumps are driven by gas turbine generators that use LNG, compressed natural gas (CNG) or flared gas.

Gas turbines are much lighter than diesel engines, which allows for two turbines on one chassis. This means half of the trucks normally required on location are no longer needed. A typical diesel unit will supply 2,200 hydraulic horsepower (hhp) whereas a typical gas turbine will supply 4,400 hhp with the same GHG footprint.

One fracking consultant said the e-fleets he had seen were using field gas to generate electricity that power the fleet. This reduces the GHG footprint by two-thirds and allows the operating company to complete many more wells under the same GHG emission license.

E-fracs are only 10% of the market now but this stands to increase because of worldwide demand to lower GHG. GHG is typically reduced by 50% by using e-fracs. Cost savings exist in fuel and pump engine repairs but upfront costs are higher than a new diesel system. One oilfield services operator reported a longer life for components of his e-frac system versus a diesel system. The electric motor, transformer and variable frequency drives (VFDs) replace the engine and transmission in the diesel system, meaning fewer moving parts and longer maintenance intervals.

While a diesel fleet typically needs 20 pump trailers at the well site, an e-frac system requires only eight. Another e-frac advantage is noise reduction—95% less frac pumping noise.

The author would like to give grateful thanks to Carl Montgomery for input on frac pumping systems. ■

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New Industrial Pump Station Ensures Reliable Water Service to Refineries

Most of the infrastructure supplying five major petroleum companies needed rehabilitation or replacement.

MELISSA MACK | Lockwood, Andrews & Newnam &
BRANDON WADE | Gulf Coast Water Authority

IMAGE 1: Most of the existing pump station's infrastructure needed repair or replacement. (Images courtesy of Lockwood, Andrews & Newnam)

IMAGE 2: Pump discharge piping showing the below grade installation and the pipe support for future above-grade discharge.

IMAGE 3: Custom-designed carbon steel pipe support for future above-grade pump discharge piping

The Gulf Coast Water Authority (GCWA) provides raw water to the Texas City Industrial Complex via the Industrial Pump Station (IPS) and two transmission lines originating at the IPS. These two lines cross the industrial complex with branches supplying five major customers—Dow, BP, Valero, Marathon Petroleum Corp. and Eastman Chemical Company.

The IPS was originally constructed in 1949 with three vertical turbine pumps. Subsequent expansions in 1952, 1957 and 1965 added six more pumps for a total capacity of approximately 96 million gallons a day (mgd). Although the pumps were well maintained and functioned adequately, most of the infrastructure needed rehabilitation or replacement. The valves were in poor condition and were essentially inoperable. Visible portions of the steel discharge piping exhibited major corrosion. The integrity and reliability of the entire discharge piping and header were compromised. The pump station building's brick wall cladding, roofing system, doors and windows also had several defects.

In 2010, the GCWA retained a national planning, engineering and program management firm to evaluate the condition of the existing pump station and develop rehabilitation alternatives. The IPS has a long history of uninterrupted service to its industrial users. Any interruption to the water supply meant these users would lose millions of dollars a day in revenue. As such, maintaining pump station operations and ensuring continuous water supply to GCWA's industrial users during construction was of paramount importance.

While evaluating the various rehabilitation alternatives, the firm determined that the risks associated with rehabilitation far outweighed the risks associated with constructing a new pump station on the existing site. Consequently, GCWA decided to design and construct a new 96 mgd pump station on the existing site, while maintaining the existing IPS in operation throughout construction. After obtaining funding, GCWA, in February 2013, hired the firm to provide design and construction engineering services for the new pump station.

The scope of work included performing transient calculations to design surge relief facilities; site civil design of drainage and utility improvements; design of a new intake structure to accommodate three existing 5-foot-wide traveling screens and three new 8-foot-wide traveling screens; relocation of the nine existing vertical turbine pumps; new steel pump discharge and header piping,

IMAGE 4: Relocating the pumps required a specific construction sequence, detailed scheduling and extensive coordination.

IMAGE 5: Three existing 5-foot-wide traveling screens that were well maintained were also reused.

including pump control valves, isolation valves and other appurtenances; cathodic protection for buried metal piping and appurtenances; a new pump building; demolition of the existing pump building and above-grade pump discharge piping; electrical instrumentation and controls; and truck access and other miscellaneous site improvements.

In June 2017, construction of the new pump station started. In December 2020, once substantial completion was achieved, GCWA opened the $20.04 million Joseph A. Willhelm Industrial Pump Station, named in honor of its first general manager. On July 1, 2021, the entire project was completed.

Innovative Design

Typically, when a new pump station is built, new pumps are installed. Over the decades, GCWA had maintained its existing vertical turbine pumps in almost new condition. As such, the water authority wanted to install these pumps in the new pump station. While the existing pumps have a below-slab discharge, GCWA also wanted the option to install future replacement pumps with the discharge above the pump house floor. This arrangement would facilitate removal of pumps for

IMAGE 6: The new pump station is the largest capital investment by the GCWA in decades.

IMAGE 7: The new pump station is expected to last at least 75 years.

maintenance and eliminate the need to enter the wet well for pump removal. To accommodate this request, the discharge piping design included novel provisions for connection above or below the slab with minimal modifications.

Custom-designed type 316L stainless steel pump bases that can be easily modified without removal gave GCWA the option to install the existing below-grade discharge pumps as well as above-grade discharge pumps in the future. Two different types of pump bases were designed to accommodate both the existing variable frequency drive (VFD) and constant speed motors. Constant speed pump stainless steel bases were designed to be installed flush with the floor while the VFD bases had to be recessed approximately 10 inches below floor level. Both types of bases can be field-modified in the future for above-grade discharge pumps.

Pump discharge piping and control valves for the existing pumps were connected to the 42-inch discharge header with a straight pipe run terminating at a 24-inch by 42-inch tee. The branch of each of these nine tees was installed in a horizontal position. However, when the above-grade discharge pumps were installed, this straight piping connection would not accommodate the new above-grade discharge pipe. To address this challenge, innovative pipe connections were used to facilitate these future connections to minimize cost and installation time.

Usually, pump discharge piping is joined with bolted and gasketed flanges. However, this type of joint is not easily removed and cannot be rotated exactly 90 degrees to allow for the future vertical connection. So, instead of flanged joints, the design incorporated rigid roll-grooved joints and couplings. Sections of the 42-inch discharge header can be isolated with valves so a pump can be taken out of service and the below-grade, 24-inch pump discharge pipe and control valves can be removed as a complete assembled piece. Then, the 24-inch by 42-inch tee can be rotated to a vertical position by loosening four bolts and installing a long radius 90-degree bend, and the discharge pipe and control valve pipe section can be reinstalled.

To support this new above-grade pump discharge piping, a custom-designed carbon steel pipe support was installed with imbed bolts during the construction phase. The steel support is designed to be partially welded to the future carbon steel pipe so it will resist transients associated with pump startup and shutdown and is still removable for maintenance and repair.

Complex Challenges

The scale and complexity of the project created numerous design and construction challenges. Chief among them was maintaining the existing pump station operations during construction of the new station to provide uninterrupted water supply to GCWA's industrial users. Once the new intake structure, wet well, building, discharge header and yard piping at the new pump station were completed, the existing pumps were relocated one by one until operations were completely transferred to the new station.

There were periods during which both the new and the existing stations remained in operation simultaneously. In addition to reusing the pumps, three existing 5-foot-wide traveling screens that were well maintained were reused. Taking out a screen from the existing building meant that associated pumps couldn't operate anymore. Solving this complex relocation required a specific construction sequence, detailed scheduling and extensive coordination.

Typically, when a new pump station is built, pump bases are laid out for new pumps. Since the existing pumps were being reused, the pump bases required custom drilling for the anchor bolts. During the pump relocation, GCWA and the firm worked with the millwright to install the anchor bolts in these custom-designed steel pump bases. The firm provided designs on how to transfer the pumps and fit them on the pump base, as well as the drilling location to install the anchor bolts.

Before bidding, GCWA divided the project into four phases to ensure the new pump station was up and running as quickly as possible and set project milestones for the contractor. Phase 1 involved installing underground piping for the new pump station, constructing and initial commissioning of the pump building to get the station ready to install the new pumps. Phase 2 involved relocation of the existing pumps. Phase 3 included demolishing the old pump station, backfilling a portion of the existing canal, and building the new parking lot. Phase 4 involved project closeout.

During bidding, the contractor expressed concerns over the cost/risk of relocating the existing pumps given their age. To solve this issue, GCWA assumed the responsibility of implementing Phase 2—relocating the pumps. However, the contractor got behind schedule during Phase 1 and continued working while the owner was relocating the pumps. This added another layer of complexity. Furthermore, there were also challenges when the contractor did not install some of the piping at the right location. In such instances, the firm worked with GCWA staff to make design changes on the fly to modify piping and connections.

Built for the Future

The new pump station—the single largest capital investment by the GCWA in decades—is expected to last at least 75 years, through good maintenance. Using the existing pumps has also allowed GCWA to delay some of its upfront capital costs. Over time, GCWA will gradually replace its existing pumps with new ones. Once these new pumps are installed, GCWA will be able to expand its delivery capacity by almost 25% to accommodate future industrial growth.

The new pump station is also built with sustainable materials such as stainless steel, fiberglass and concrete that provide energy efficiency, long life cycle and lower life cycle costs and do not corrode. The new pump station building was constructed with insulated structural precast concrete panels and steel framing. All below-grade structures were constructed with cast-in-place concrete for long-term durability. The building is equipped with a robust ventilation system to remove motor heat and sound attenuation panels to reduce operational noise.

Additionally, the original pump station was not hurricane-proof and was potentially susceptible to extreme weather events given its age and deteriorated condition. The new facility is designed to withstand 140-mile-per-hour hurricane winds (Category 4 wind scale)—20 miles higher than required wind load requirements. The facility's design makes it more resilient and allows continuous operations during extreme weather events in the future. ■

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What to Consider When Commissioning a New Oil & Gas Pumping System

The system should be in compliance and integrated into an existing SCADA environment.

HANNAH DUNCAN | Romtec

When a new oil and gas plant is built or remodeled, new pumping systems for industrial process water and waste are inevitable. This was the case at one company in Port Arthur, Texas, and St. Charles, Louisiana. The requirement was two identical above-grade, skid-mounted systems that need to deliver 540 gallons per minute (gpm) against 80 feet of total dynamic head (TDH) in existing force mains. Working with an engineering firm, one pump station design and supplier prefabricated, delivered and commissioned both systems.

Pumping into a high-pressure existing force main required an above-grade, self-priming end suction centrifugal pump for several reasons. First, there are more motor/pump combinations to select from for a given duty point. Additionally, how the pump is coupled to the motor will dictate the speed at which the impeller rotates. High impeller speeds (to a point) help to overcome large duty points (gpm at TDH).

An above-grade pumping skid is also ideal for pumping into a high-pressure existing force main because it keeps the pumps out of the process fluid and allows for easy maintenance as all aspects of the pump are accessible.

On any construction site, the time it takes to construct is critical, and on a construction site such as a refinery in Port Arthur, there is no room for errors. That is why it was necessary to handle the complete design and supply of the system

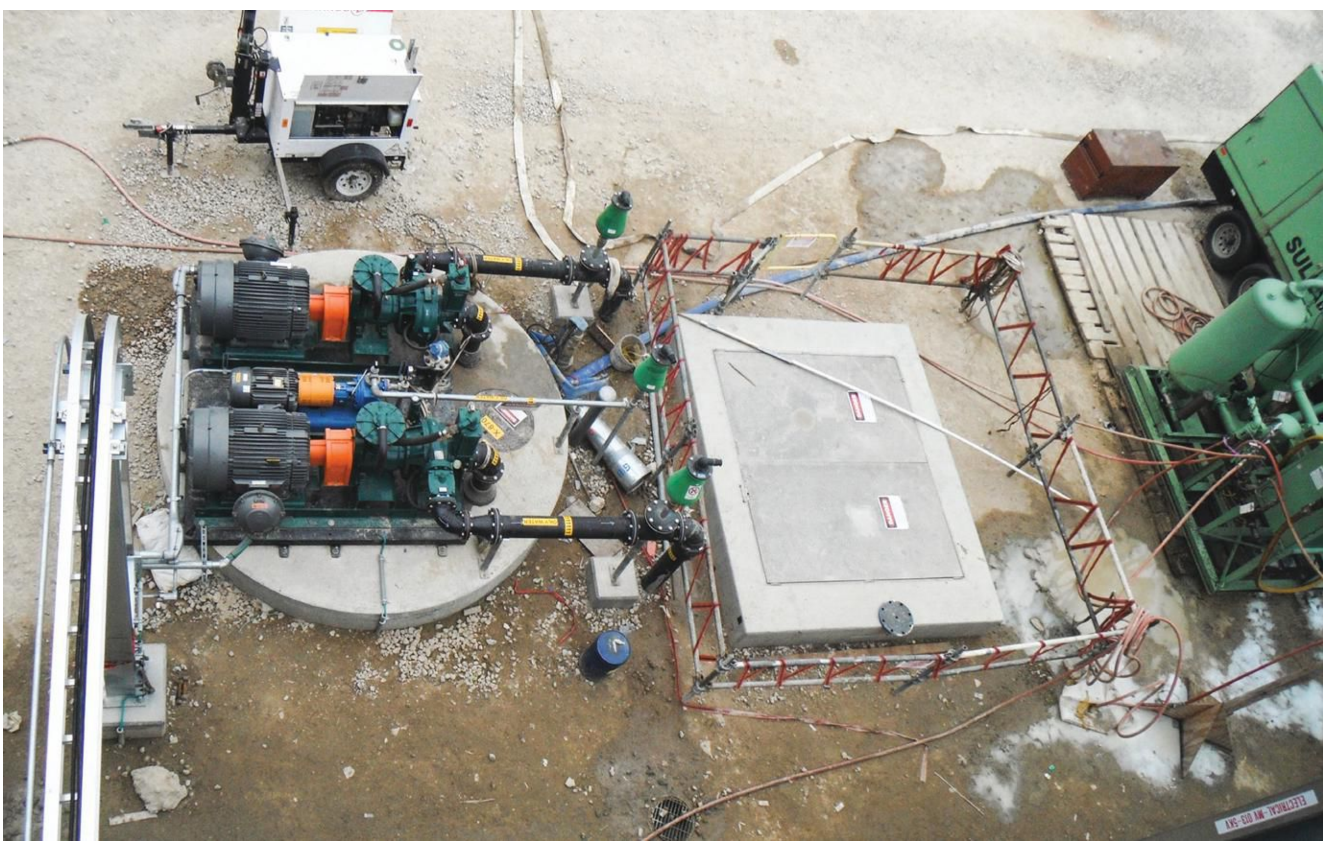

IMAGE 1: Aerial view of skid-mounted system for oil and gas plant (Images courtesy of Romtec)

IMAGE 2: Skid-mounted system for oil and gas plant

On any construction site, the time it takes to construct is critical.

that will be integrated into the site to ensure the project's overall success. The design criteria must be considered, along with the larger system, before designing the best pumping system to meet the application. These criteria must be considered instead of just providing a model that is expected to fit into the application of the facility. This is also in addition to using the staff's preferred equipment, since they will be owning and maintaining the pumping system.

After the design is complete, the sump (wet well) is prefabricated along with the pumping skid, the valve vault and the controls. This allows for an easy installation on-site. This is critical at an oil and gas facility as space can be limited and precise construction is needed. All aspects of the system also need to be easily maintained to ensure the facility can maintain production.

To ensure the installation and startup are handled correctly, pump station design and supply personnel are sent to the construction site. A refined commissioning process is followed, working through all aspects of the system (controls, structural/mechanical, electrical, etc.) while adhering to safety policies at the facility. Before leaving, the responsible personnel is trained to guarantee the long-term success of the system.

Oil and gas facilities are complex and involve incorporating the use of many equipment types and manufacturers. For these locations to operate seamlessly, everything needs to be integrated and designed to the standards of the end user.

IMAGE 3: Skid system at Port Arthur, Texas, refinery site

IMAGE 4: Pumping system at Port Arthur, Texas, refinery site

In addition to being functional, these facilities need to be safe and easily operated and maintained. To accomplish this, it is important that the user knows exactly what is needed and that they have a good understanding of how the equipment operates.

While there may not be many design preferences in structural and mechanical terms, the end user interfaces primarily with the system's control panel, which is where it is important to design according to the user's standards. In the case of the refinery project in Port Arthur, a complete control panel centered around a programmable controller, ultrasonic transducer primary level sensor and an automatic dialer. All components were approved by the user to meet the operators' needs.

Pump station controllers are selected by the user's standards and requirements, which in this case was an ultrasonic transducer to be used for the primary level sensor. Ultrasonic transducers are common within industrial applications and provide many advantages versus other forms of level sensing such as floats and pressure transducers. One of the primary advantages of an ultrasonic transducer is that it is a noncontact level sensing device. In other words, the transducer does not come into direct contact with the media that is being pumped. In an environment where fluids with extreme pH and temperatures are being pumped, this can prove to be useful in the life span of the unit.

In any environment, compliance with and integration into an existing supervisory control and data acquisition (SCADA) is a must. Oil and gas plants typically have existing and well-oiled control and communication standards that must be adhered to. Building consistency in an industrial facility is key to developing a safe and efficient working environment.

Regarding SCADA/telemetry in the case study, the owner of the facility chose to incorporate the use of an automatic dialer to call out specified alarms. Automatic dialers are an accepted form of telemetry that provide the ability to both report and often acknowledge alarms remotely. In an oil and gas facility, maintenance personnel may not be able to respond immediately to an alarm; so, having the ability to be notified of a specific issue will help drive the sense of urgency of their response.

An oil and gas application requires precision and flexibility—in terms of components and mechanical and structural design, as well as precision in terms of engineering and installation. It is important to understand the application and the existing systems in place to then design, supply, install and start up the correct system type with the correct components, all while taking the owner's preferences into consideration. The right components can be the difference between a system's success and failure. ■

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Progressive Cavity Pumps for Challenging Oil & Gas Applications

An efficient solution was needed for a flare knockout drum vessel sump and waste oil storage tank reinjection.

JASON BALCERCZYK | NETZSCH Canada

In the past, centrifugal pumps were the norm for many oil and gas applications. But such pumps require relatively high net positive suction head available (NPSHa) levels and are often susceptible to cavitation. Operators at two different types of oil and gas facilities have found progressive cavity pumps to be an efficient alternative solution, offering better suction capabilities at lower net positive suction head required (NPSHr) levels than centrifugal pumps. Progressive cavity pumps are also an energy efficient option, resulting in operational cost savings.

IMAGE 1: Customized progressive cavity pump (Images courtesy of Netzsch)

Pump Solution Needed

Engineers for a pipeline company that transports lighter hydrocarbon liquids produced in Canada were designing a high-pressure flare system for a bulk storage terminal project. They needed a pump solution to empty the flare knockout drum (FKOD) vessel, an integral part of the flare system.

FKODs are essential components of industrial pressure relief systems at gas and petroleum sites and play a crucial role in safe operations. Also called vapor liquid separators or knockout pots, liquid knockout drums capture and remove accumulated liquids that condense during the ordinary expulsion of relief gases. Flare systems generally require an FKOD to separate liquid from gas and to hold the maximum amount of liquid that can be relieved during an emergency situation or maintenance activities.

Knockout drums are typically located on the main flare line upstream of the flare stack. These vessels are either above-grade or below-grade and typically operate at vapor pressures of up to 103 kilo-pascals-absolute (kPaA). There is often not a lot of energy to get the fluid into the pump suction. In this project, the fluid was light oil/condensates (C5+) with a low viscosity of 0.2 to 0.7 centipoise (cP), so the engineer sought pump options other than typical centrifugal pumps, which require higher NPSHa levels and can be susceptible to cavitation. The client also required a pump that can achieve high discharge pressure.

The project engineers were trying to make the FKOD pump more efficient because they wanted to operate within the specified best efficiency point (BEP). They eventually selected a vertically mounted progressive cavity pump, which provides better suction capabilities at lower NPSHr levels than some other pumps. Progressive cavity pumps can handle low (or high) viscosities; they can operate more efficiently with less wasted energy.

Progressive cavity pumps work well for above-grade and below-grade sump tanks. Semi-immersing the pump in the tank enabled operators to drain the tank down to only a few inches of liquid at the bottom.

Moreover, progressive cavity pumps are better at handling variable flow and pressure rates where the time needed to empty the tank also varies. They are also able to adapt to changes in viscosities, vapor pressure and specific gravity—factors that influence pump performance and reliability.

Another benefit of the vertically mounted progressive cavity pumps over horizontally mounted pumps under an above-grade tank is the availability of a sealing design that channels any leakage from the mechanical seal back into the sump, reducing the risk of environmental contamination.

IMAGE 2: Oil and gas facility

Waste Oil Storage Tank Reinjection

A major energy pipeline company was seeking to streamline its waste oil storage tank pumping system. It wanted an option that could replace its two-pump system, in which a cantilever pump lifted the waste oil out of the tank and a high-pressure piston plunger injection pump moved the oil back into the pipeline system.

Two pumps for each storage tank resulted in double the maintenance. In addition, the high pressure required to operate the piston pump resulted in significant pulsation that caused pipe stress. The company wanted to eliminate the pipe stress and simplify the system with one pump that could provide smooth, pulsation-free conveyance.

The company operates one of the world's longest crude oil and liquids transportation systems, conveying crude oil and other liquid hydrocarbons to refining markets in the Midwestern United States and Eastern Canada. Pumping stations are located all along the pipeline powering the liquid fuels through the pipeline. At each pump station, a 5,000-gallon (19,000-liter) underground storage tank (buried below the frost line to prevent the liquid from freezing) is used as a collection point for waste oil from service work that is performed on main pipeline pumps. As the collection tanks filled, the company needed to pump the liquid from the tank back into the pressurized pipeline.

The company eventually opted to replace the two-pump system with a

IMAGE 3: Progressive cavity pump installed on top of a knockout drum

vertical, semi-submersed progressive cavity sump pump that could lift the heavy oil out of the tank and had the capacity to achieve 700 pounds per square inch (psi) (48 bar)

IMAGE 4: Knockout drum

of differential pressure, should the system require it in an upset condition.

The pump included a customized mechanical seal and a common pump length with a drop tube and strainer to accommodate any changes in sump depth. The pump also eliminated the need for universal joints by incorporating a flexible connecting rod; even if it leaked, the oil would drop back into the tank. The pump was also designed to operate in reverse, requiring the seal to be on the discharge side and the entire housing to be pressurized. The pump's rotor/stator system was located at the lowest point, thus avoiding dry-running. The entire pump's space-saving design (besides the drive and discharge flange) disappeared into the tank, providing for a clean installation. No additional effort was needed to heat and isolate external equipment—an important attribute in ambient operating temperatures down to -40 F (-40 C).

To date, there are many of these pumps operating in the field. A number of these pump stations operate in remote locations, so the single pump solution has reduced operational costs and field maintenance.

Great distances must often be covered to reach ports or refineries. Progressive cavity pumps can maintain a high conveying pressure at the lowest possible pulsation, making them an optimal solution for such applications. ■

Jason Balcerczyk is president of NETZSCH Canada, Inc. For more information, visit pumps.netzsch.com

Hydraulic Valve Selection in Oil & Gas

Understand the benefits of guided piston valves in pressure protection systems.

DAVID LOCAPUTO | Fulflo Specialties Co.

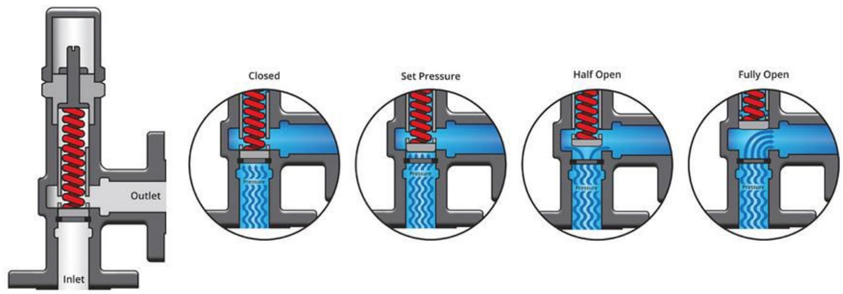


IMAGE 1: This cross section shows the operation of the spring mechanism that allows a guided piston valve to self-modulate and maintain the set pressure. (Images courtesy of Fluflo Specialties Co.)

When selecting components for fluid systems used in oil and gas applications, the type of hydraulic valve chosen can make a critical difference in the consistent operation of that equipment. Whether installed to manage oil pressure to compressors or lubrication to bearings, guided piston valves offer certain flow and stability characteristics for reliable performance without chatter. Understanding the relative advantages of guided piston valves will ensure long service life of pumps and other oil and gas process equipment.

One advantage of guided piston valves is the provision of a constant line pressure unaffected by transient pressure surges. In every part of the oil and gas processing life cycle, from fracking rigs to refinery fill operations, there is potential for system pressure to fluctuate. An auxiliary pump activating to supply additional oil to motor fan bearings on a lubrication system, or a valve shutting once an oil drum is filled, can both alter the pressure up and down the line.

These fluctuations are hard on equipment, particularly pumps and mechanical seals. As pressure and friction build inside a pump, temperature rises and creates vapor that results in cavitation that can damage the impeller and casings. Increased temperatures also compromise the integrity of mechanical seals and

Use Case: Tanker Loading

In Image 2, a typical truck loading process using either a centrifugal or positive displacement pump has a manual shutoff installed at the point of tanker loading. When the loading operation closes this valve without warning, considerable pressure builds in the line leading back to the pump, creating strain on the pump and risk for failure.

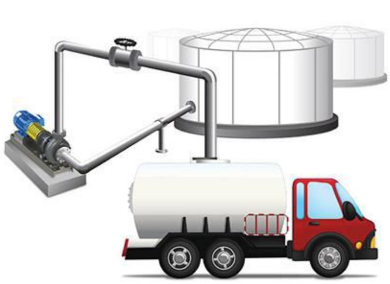


IMAGE 2: Truck loading process

The solution is to add an external pressure relief valve to protect the pump and systems. The self-modulating guided piston valve is ideal for this type of installation as it requires no additional controls.

A new recycle line with a guided piston pressure relief valve is installed between the pump and the loading line. When the tanker truck is full and the loading valve is closed, the pressure back to the pump begins to build. The valve then activates automatically, diverting flow back to the tank and relieving pressure on the line to the pump.

When the next truck lines up and the valve is reopened, and the pressure on the line returns to normal, the pressure relief valve returns to the closed position automatically.

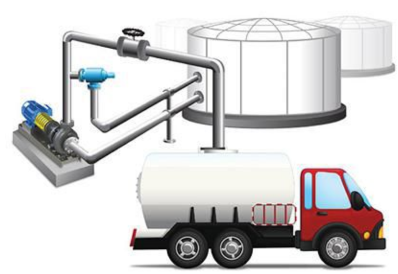


IMAGE 3: Installation of guided piston relief valve

As this is a guided piston relief valve, the orientation of the valve does not impact the valve operation or set pressure. It can be mounted upright, sideways or even upside down—however space permits. This characteristic of the guided piston valve provides design flexibility in retrofitting problem processes.

IMAGE 4: A guided piston valve controls line pressure at an oil refinery

bushings. This cracks and scores the seal's face and burns up the seal's elastomers. The culmination of this component damage is pump failure.

A pressure relief valve reduces strain on downstream equipment by mitigating this inevitable system pressure fluctuation. Guided piston valves are particularly suited to this type of pressure management. They reduce velocities through all but the controlling interface of the valve, thereby minimizing system power loss and even preventing system shutdown. The valves operate reliably at pressures as low as 3 pounds per square inch (psi) and as high as 1,000 psi and are, therefore, suited to a wide range of oil and gas equipment applications.

As a flow-modulating device, the pressure flow characteristics of a guided piston valve are different from spring loaded poppet or ball check valves. While a typical hydraulic valve has two operating settings—totally closed or fully open—a piston-guided valve fluctuates on a spring to maintain the set pressure. As pressure on the line increases, the valve opens a corresponding amount to maintain the set pressure. As pressure on the line decreases, the valve closes to the degree needed to maintain the set pressure. The valve returns to the closed position when the pressure on the line normalizes. Image 1 illustrates this self-modulating operation. The guided piston valve functions consistently and modulates at any degree of opening and closing. This operation does not require any external sensing or control systems for operation. The valve's self-

> The guided piston valve's immunity to viscosity ensures consistent operation.

modulation is pressure actuated and self-powered. This modulation prevents pressure drops that might normally trigger low oil pressure alarms.

The simplicity of the guided piston valve's mechanics results in reliable performance. With fewer moving parts, there are fewer opportunities for valve breakdown. These valves have long service life, even in extreme conditions.

Guided piston valves operate effectively with all types of liquids in the full range of viscosities, including hydraulic oils, water, solvents and chemicals. For equipment destined for outdoor use, temperature can play a large role. Lubricants thicken on cold days and become less viscous on warm days. Oxidation, moisture and ordinary wear can also contribute to changes in viscosity over time. The guided piston valve's immunity to viscosity ensures consistent operation regardless of viscosity fluctuation. Guided piston valves can also be mounted in any position during installation, without affecting performance.

In almost all oil and gas settings, from offshore platforms to mobile fracking rigs, space is at a premium. The guided piston valve's mounting flexibility, coupled with the ability to handle large flows without excessive bulk, enables more compact equipment footprints. This allows guided piston valves to be easily designed into original equipment or retrofit to replace underperforming valves.

A final benefit of the guided piston valve is its quiet operation. Ordinary direct acting relief valves can pound, squeal or chatter as they pop suddenly open or closed in response to transient pressure surges. As the guided piston valve floats open and closed on a spring, it operates smoothly and quietly, not contributing any additional noise pollution to already loud jobsites.

Guided piston valves merit consideration for use in oil and gas applications. Their operational and performance advantages better protect downstream pumps and systems from ongoing damage. This protection prevents failure, downtime and the associated repair and operational costs. ■

Get More Info

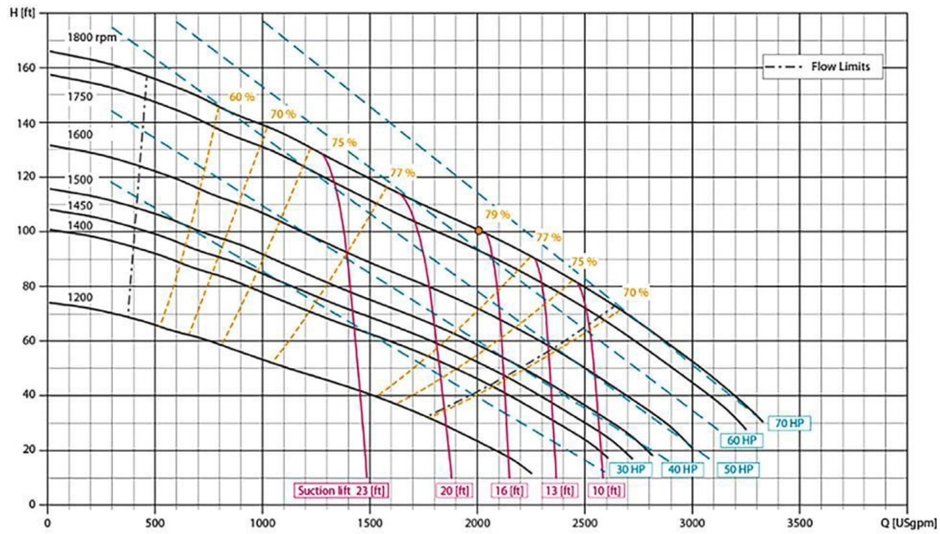
P&S Read more about valves at **pumpsandsystems.com/tags/valves.**

David Locaputo is the general manager of Fulflo Specialties Co., a division of Ruthman Companies. Locaputo also serves as corporate operating manager of sister Ruthman Companies division BSM Pumps. For more information, visit fulflo.com or ruthmancompanies.com.

What to Know When Working With Corrosive Liquids

Learn how to select the proper pump for transporting hazardous liquids in oil and gas dewatering.

HUNTER POWELL |
Atlas Copco Power Technique



| IMAGE 1: Performance curve (Images courtesy of Atlas Copco Power Technique)

A corrosive liquid is a fluid that will attack and destroy the materials with which it comes in contact. Metals, stone, glass and even some types of plastics can be susceptible to corrosion from corrosive liquids or chemicals, which broadly fall into six categories: strong acids, weak acids, strong bases, weak bases, dehydrating agents and oxidizing agents. Some chemicals can belong to more than one category. For example, sulfuric acid is a strong acid, a dehydrating agent and an oxidizer. Corrosive materials can also belong to other hazard categories such as toxicity (poisonous) or flammability.

If corrosive liquids can destroy materials such as glass and metal, they are obviously dangerous to humans. The United States Occupational Safety and Health Administration (OSHA) recognizes the health risks posed by these substances, defining them as "a chemical that produces destruction of skin tissue, namely, visible necrosis through the epidermis and into the dermis, in at least one of three tested animals after exposure up to four-hour duration. Corrosive reactions are typified by ulcers, bleeding, bloody scabs and, at the end of 14 days of observation, discoloration due to blanching of the skin, complete areas of alopecia and scars."

When using a pump is used to transfer hazardous liquids in oil and gas dewatering—such as flammable, combustible, toxic and corrosive chemicals—it is essential that several factors are considered. These considerations are critical to selecting the proper pump for the job.

Considerations

First, the fluid characteristics. What type of fluid will be pumped? What are the characteristics of that fluid? This information can be found in the fluid's safety data sheet (SDS, formerly known as the material safety data sheet, or MSDS).

According to an OSHA brief on the SDS, "HCS 29 CFR 1910.1200(g) requires that the chemical manufacturer, distributor or importer provide SDSs for each hazardous chemical to downstream users to communicate information on these hazards … such as the properties of each chemical; the physical, health and environmental health hazards; protective measures; and safety precautions for handling, storing and transporting the chemical." The fluid's SDS provides critical data such as concentration, specific gravity, resistance by temperature, viscosity, flammability (if any) and specifics on the content of solids.

Application Requirements

To ensure the pump is properly sized, users must also consider the pump manufacturer's head-capacity curve. A pump curve (also called a pump selection curve, pump efficiency curve or pump performance curve) gives the information needed to determine a pump's ability to produce flow under the conditions that affect the machine's performance.

Reading pump curves accurately—or consulting a pump professional who can—ensures users are getting the right pump based on application variables such as: head (as the energy required to discharge water from a pump to an equivalent height expressed in feet or meters); flow (the volume of liquid to move in a given time period, i.e., gallons per minute [gpm] or cubic meters per hour [m^3/h]); rotations per minute (rpm); impeller size, as related to pump performance; power; efficiency; and net positive suction head (NPSH).

The Proper Pump for an Application

The most used equipment for transferring corrosive oil and gas fluids is the centrifugal pump. Centrifugal pumps are energy efficient, available in both standard flooded suction or self-priming, and come in a wide range of sizes that are designed to pump

IMAGE 2: Pump for transporting hazardous liquids in oil and gas

from a few gpm to thousands of gpm.

When pumping corrosive liquids, centrifugal pumps offer another advantage—mechanical seals. These seals will prevent leakage where the internal rotating shaft protrudes through the stationary pump housing. This is similar to how an automobile's water pump uses a mechanical seal to prevent coolant leakage from the pump. A mechanical seal uses carefully machined flat rings of a durable material—such as ceramic carbon or silicon carbide—where one rotates with the shaft and the other is stationary. The fluid being pumped moves between the seal faces and provides a lubricating film. If the pump is operated without liquid (dry run), the friction causes the seal faces to rapidly heat up, resulting in seal failure.

If a mechanical seal should fail as a result of dry running, liquid will leak from the pump. If the liquid being pumped is water, this may just be an inconvenience. With corrosive fluids, a leak can result in harm to humans, potentially causing extensive damage to the surrounding infrastructure, and possibly creating an environment where users are no longer in compliance with regulatory agencies, such as OSHA. In addition, there are downtime and cost considerations (or mean time between failures [MTBF]) when a pump must be pulled from service and repaired.

Proper Materials of Construction

It is important to choose the proper pump construction materials. This is especially critical when moving corrosive liquids. Not doing so will lead to corrosion of the components that encounter the corrosive fluid—such as gaskets and O-rings—which can impact both the pump's performance and length of service.

According to corrosionpedia.com, corrosion is defined as "the deterioration and loss of a material and its critical properties due to chemical, electrochemical and other reactions of the exposed material surface with the surrounding environment. Corrosion of metals and nonmetals takes place due to the gradual environmental interaction on the material surface."

Now, corrosion by itself is usually not that big of a problem. The proper materials of construction—such as cast iron, bronze, manganese bronze, nickel-aluminum bronze, cast steel and stainless steel—are readily available and capable of handling most corrosive fluids safely and efficiently. It is important to understand the various types of corrosion, as well as the factors that contribute to the rate of corrosion, to select the appropriate materials.

It can be difficult to choose a material that can withstand corrosion and additional factors, such as erosion and cavitation. A general rule of thumb in choosing proper materials of construction is to first select materials that will withstand corrosion and then select the one with the most appropriate resistance to abrasion and/or cavitation. Here are a few examples of corrosion users can encounter when using a centrifugal pump to move corrosive fluids.

Abrasion-Corrosion

Abrasion, or abrasive wear, is the removal of metal caused by the mechanical cutting or abrading action of solids carried in a pumped liquid. When the corrosive liquid being pumped also contains abrasive solids (abrasion-corrosion), higher alloyed materials such as stainless steel are often required to ensure the performance and life of the pump. In centrifugal pumps, the impeller is particularly susceptible. Although the casing can be damaged by this, the bigger problem is usually the impeller, along with wearing rings.

Cavitation-Abrasion-Corrosion

Most often occurring with high-suction energy pumps, cavitation is the removal of metal because of high, localized stresses produced in the metal surface from the implosion of cavitation vapor bubbles. In an abrasive-cavitation and corrosive environment, the base material is eroded away as abrasive particles are accelerated toward the impeller surface by the implosive force of the cavitation bubbles, hastening the corrosion process.

Consult a Professional

While this is not a comprehensive guide to pump selection when transferring corrosive fluids, this will hopefully provide users with a snapshot of the challenges, as well as some of the critical factors to consider, when choosing a pump. There is much to consider, from the type of fluid being transported to the selection of proper pump construction materials.

Users should start by gathering information on the fluid to be pumped. Second, gather information on application requirements and environmental conditions. Then, consult a pump professional who can advise in selecting the proper pump for the job taking all of the above factors into consideration. ■

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Case Study: Sealless Caustic Circulation Pump Failure

Learn what the inspection findings, operational trends, caustic lab sample analysis and metallurgical analysis discovered.

DHEDAN AL DOSSARY & FAISAL AL DOSSARY | Saudi Aramco

The caustic regeneration loop that ensures the removal of the total sulfur from natural gas liquids (NGL) at a gas plant has two lean caustic circulation sealless pumps. These pumps are responsible for delivering the lean regenerated caustic with natural gas (naphtha) from the disulfides separator to the natural gas wash settler.

Review of the Pump Design

These pumps are 178-horsepower (hp) sealless magnetic drive pumps with a rated flow of 294 gallons per minute (gpm) and total differential head of 638 feet (ft). The process fluid is totally contained inside the pump containment shell and depended on to remove the generated heat through internal lubrication paths.

Therefore, any slight restriction to the lubrication flow paths will jeopardize the condition of the pump's internal parts, resulting in catastrophic failure. Additionally, the fluid runs between the inner magnet, the containment shell and through the shaft holes to the rear of the pump shaft where it returns to the pump's suction through the thrust balance hole in the impeller (Image 3). The pump shaft that is connected to the inner magnet is rotated by the action of the magnetic flux circuit between the inner and outer magnet. The outer magnet is coupled to the driver motor through another shaft to transmit the rotation to the inner magnet.

Background Information

Within normal operating conditions, the pump was tripped due to the motor thermal overload fault signal. All process conditions were checked and found within normal parameters. Later, the pump was started again and immediately tripped on the stalled motor fault signal.

The decision was to remove the pump for dismantling and internal inspection. The major findings include:

1. There was excessive rubbing between the impeller front cover and the pump casing. Also, there was thinning on the impeller shrouds. This is an indication of high thrust movement as shown in Images 1 and 4.
2. Rear thrust pad, thrust washer and sleeve bush were not found in place. The silicon carbide bearings had failed and its traces were found inside the pump casing (Images 2, 5 and 6).

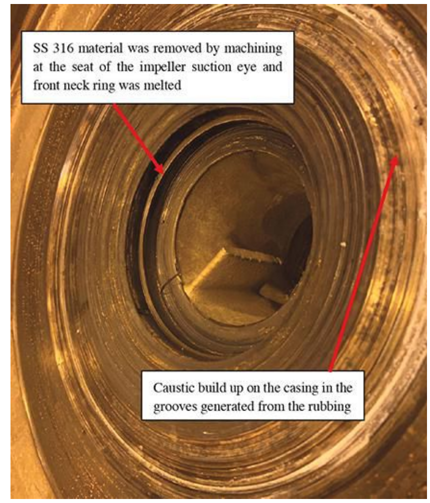

IMAGE 1: Casing severe rubbing and caustic crystallization (Images courtesy of Saudi Aramco)

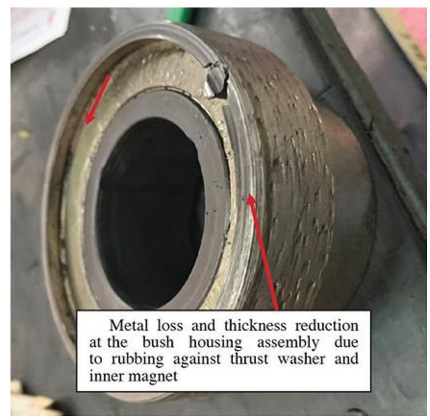

IMAGE 2: Rear bush housing assembly (bush carrier) with damaged thrust pad and corrosion/ erosion impact

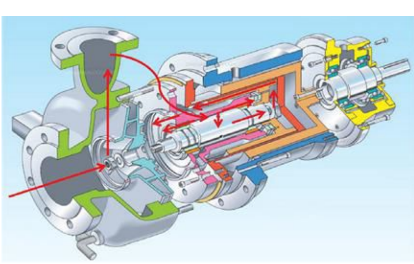

IMAGE 3: Magnetic drive pump lubrication flow regime

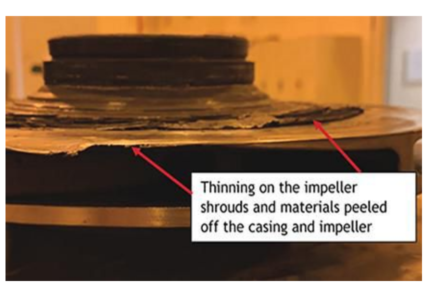

IMAGE 4: Impeller rubbing impact (thinning)

IMAGE 5: Signs of chemical attack (corrosion) in the front nondestructive evaluation (NDE) titanium bush housing assembly

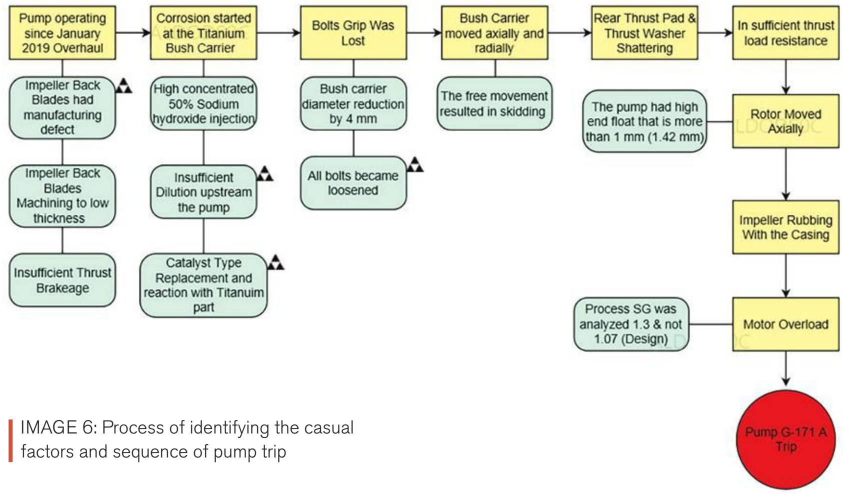

IMAGE 6: Process of identifying the casual factors and sequence of pump trip

Investigation & Findings

A conclusion was reached based on the above inspection findings, operational trends, caustic lab sample analysis and metallurgical analysis. Material analysis showed that grains of the titanium sleeve bush were colored blue, consistent with the newly introduced process catalyst in 2019. This was considered a sign of a corrosion reaction.

It is suspected that the catalyst has filled the standby pump and when it is not in operation, the pump would have been unable to disperse the liquid. The product would have then attacked the front sleeve bush as this is mounted in the casing volute, whereas the rear sleeve bush is in a less accessible area of the pump.

Occasionally, the process is subjected to high caustic concentration. Material analysis shows that there should be an accelerated rate of corrosion of the titanium sleeve bush carrier in the instances where the pump is exposed to the higher 40% to 50% caustic concentrations.

As shown in Image 6, it is suspected that the corrosion and loss of the titanium sleeve bush circumferential were enough to allow the bolts to lose the grip between the bush carrier and holder. Hence, all the bush carriers became free to move radially and axially, leading to thrust pad and thrust washer silicon carbide to shatter.

The failure of the rear thrust pad and thrust washer (active bearing) increased the negative thrusting and axial movement of the whole rotor toward the pump casing. This resulted in heavy wear on the casing, impeller and radial bush failure.

Recommendation

The impact of the intermittent 50% caustic concentration and the new catalyst type corroded the titanium part, resulting in thrust bearing failure.

The user confirmed that the use of titanium is not a common selection but it was requested by the user during the project design. In addition, the other pump components are made of duplex stainless steel and did not experience any corrosion attack. As per the findings, the user's experience and the corrosion chart, it was recommended to upgrade the bush housing material to duplex stainless steel material. ■

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Using a Digital Twin to Boost Value in Pumping Systems

Improve lifetime value of pumps and valves with a digital twin-powered IoT strategy.

AARON GANICK | Preddio Technologies

Internet of things (IoT) programs deploy digital twin concepts to make sense of complex data coming from pumps and valves. However, data without relevant context is redundant to existing systems, but multidimensional data represented by a digital twin can add value to enterprises.

This digital representation can provide insights into how physical assets are operating, how they have worked and how they could be managed better. Think of a digital twin as a three-dimensional object—key indicators and attributes, which are constantly updated. It contains a combination of dynamic sensor data, static asset data and performance analytical insights, all managed and represented as a single entity. Here are insights into an IoT strategy using digital twins to maximize pumps and valves.

The Full Pump System Picture

IoT provides the ability to detect changes in parameters on equipment such as pumps, valves, fans, motors and more. Many values can be analyzed to understand what, when and why things are changing. As teams find solutions for preventative maintenance and increased optimization, utilizing IoT to observe changes in equipment parameters such as vibration, surface temperature, moisture, pressure, speed, level and flow can save time and money.

Maintenance teams detect changes in equipment to understand why things are changing, but there is a lot of analysis that needs to occur to see the big picture. IoT and digital twins are the next steps as they allow these parameters to integrate to form the equipment digitally. Digital twins put those values together to create the equipment for users.

By laying out the data in a way that forms the equipment, it allows for faster decisions to be made. Therefore, there is less need to look at individual values to understand issues and correlate them. Digital twins combine these parameters so that users no longer look at if the vibration is high or low but how that value of pulsing correlates to pressure change. Those values together tell the history of the equipment and how each parameter affects the other. Digital twins also open up the option to add artificial intelligence (AI) to predict, analyze and assess equipment health.

Accurate Virtual Representation

A digital twin is a digital replica of a physical entity such as assets, processes, people, places, systems and devices used for various purposes. The representation shows how a pump, valve or piece of equipment lives through its life cycle.

First, this includes connecting the physical model and the corresponding virtual model or virtual counterpart. Second, the connection is established by generating real-time data using sensors. There are two distinct concepts in the definition of digital twins and in practice with two different use cases.

In the first part of the definition, a virtual model is used for computer simulation of the real-world system or device. The model is created to run as an executable model, driven by stimulus or various tests. The output of the simulation then produces data that replicates the corresponding real-world device. While this approach provides possibilities for testing, the output is only as good as the fidelity and accuracy of the model. The primary use for this approach is when users want to test numerous design options to see which is the most optimal.

The second key component of using digital twins uses sensors to represent the device, asset or system. The challenge here becomes having enough sensors to represent the entire asset properly. But the most critical part is the organization of data into an object-orientation.

The primary use for this second approach is where users have established, well-proven designs and a requirement to monitor the performance in the field. As such, sensors with digital twin object-orientation are the enabler for increased IoT-driven optimizations.

Key Benefits of a Digital Twin

Unlike real-world devices, implementation of the digital twin enables real-world machine learning algorithms to aggregate operational and performance data. Additionally, the data from the digital twin allows traceability, history and data analytics of the real-world device, thus making decision-making more data driven.

With the ability to monitor the behavior of physical pumps versus the ideal operating parameters, maintenance teams can compare all technical attributes and operational insights from similar equipment. Therefore, when starting with a well-thought-out data object, the digital twin analytics transforms the maintenance and management team's work, providing a tool for comparisons, analytics, what-if scenarios and traceability.

Compared to simply collecting unorganized raw sensor data, the digital twin approach, when combined with the power of IoT, abstracts various sensor outputs into a digital twin framework, making physical assets come to life in meaningful ways. ■

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The Misunderstood Liquid Ring Vacuum Pump

Benefits include solvent recovery, construction flexibility and cost savings.

BENJAMIN CAMERON | Busch Vacuum Solutions

IMAGE 1: Liquid ring vacuum pump (Image courtesy of Busch Vacuum Solutions)

When selecting the right capital equipment for an application, the liquid ring vacuum pump may be seen as archaic and inefficient. However, labeling this technology that way can be an oversimplification. This article is intended to help adjudicate the liquid ring vacuum pump's reputation by describing its middle ground and its positives (and potential negatives) with technical guidance.

There is a reason why liquid ring pumps are chosen for critical infrastructure applications like power generation and offshore oil and gas—when properly applied, they are reliable. That said, it is important to first summarize the drawbacks of liquid ring vacuum pumps: they consume more energy than alternative technologies and use too much water.

Energy Consumption

In applications with little or no condensable vapor loads, liquid ring pumps will consume more energy to accomplish the same compression than a comparably sized alternative technology like a dry screw, dry claw or rotary vane vacuum pump. The excess is usually published as 20% to 25% however, depending on the vacuum levels, it can be more than that.

In applications that have high amounts of condensable vapors, that efficiency gap can be closed (if not overcome) due to the "condensing effect." In such applications, liquid ring pumps act as a direct-contact condenser, reducing the volumetric gas load inside the pump and, therefore, increasing the overall intake volumetric capacity. The greater the difference between the saturated gas temperature at the inlet of the pump and the seal fluid temperature, the greater the effect. The condensing effect occurs with little to no consequence on the absorbed power. In the right circumstances, the energy gap can be closed and a supplemental generator is not required.

Water Consumption

Liquid ring pumps require fluid to create the seal between the inlet and discharge pressures, thus fundamental to their operation. In many applications, this fluid is water, which is why liquid ring pumps are commonly referred to as water ring pumps. After performing its duty as a pressure seal, the seal fluid is expelled at the discharge in combination with the process gas. The liquid and gas phases are promptly separated, and what is done with the fluid establishes the pumps' net thirst.

There are three potential scenarios.

1 In some applications, this seal fluid is sent to a floor drain or some other treatment system. This is referred to as a once-through configuration and often what users believe makes the liquid ring vacuum pump wasteful.

Applications applying this mode of operation are generally those that expect a high amount of particulate carryover from the application since the once-through operation continuously flushes the pump from potential product buildup. Essentially, this design helps prevent a sticky situation.

2 In other installations, the seal fluid can be recycled, passed through a heat exchanger to remove the heat of compression and condensation, then sent back into the pump to perform another round of its mission. Referred to as "total or full" recovery, applications implementing this method are usually cleaner in the sense that process gases are not expected to contain excessive particulate carryover. Furthermore, full recovery installations are often those where the continuous disposal of contaminated water or condensed solvents is undesirable.

There will be other trade-offs to consider, depending on the heat exchange type/design and the required vacuum level. Put simply, a water-cooled heat exchanger will increase facilities' cooling water requirement, while an air-cooled heat exchanger will increase overall power consumption and require consideration paid to installation surroundings and max ambient conditions.

For operation at rough vacuum levels or for liquid ring pumps with large seal fluid flow rates, a recirculation pump may be required to overcome head losses in seal fluid pipework from the discharge separator back to the pump.

3 In a partial recovery configuration, a portion of the warmer discharge seal fluid is recycled and combined with a supply of fresh fluid before entering the pump. This effectively minimizes the amount of fresh fluid required. Pump manufacturers will often cite partial recovery modes saving up to 50% fluid usage. The actual amount of savings will depend on the vacuum level requirement, temperature of freshwater and how much heat is added to seal liquid throughput.

The seal fluid configuration can seem like a boundless game of puts and takes, or worse, a shell game of "hide the utility requirement." The good news is that application characteristics (particulate carryover, presence of solvents, degree of condensable vapors) will often deem one method more pragmatic than others. Corporate energy and water initiatives can then be addressed by implementing the design and control scheme intelligently.

If there are liquid rings in a facility, users should check to see how they are configured. If installed in a once-through configuration, a bit of minor pipework can save money. Energy and water consumption are the two most cited deficiencies of liquid ring vacuum technology. Hopefully the above helps explain the circumstances in which one might mitigate those gaps.

Additional Advantages

Other advantages of liquid rings include:

Solvent recovery

In some chemical and pharmaceutical applications, it is desired to recover the process gases (solvents) for sale as a byproduct or re-use in the application. Using a liquid ring pump with the solvent as the seal fluid can be a solution to accomplish this (see condensing effect above) while maintaining a space-conscious footprint.

Temperature rise

When pumping gases with relatively low auto-ignition temperatures, it is desirable to keep temperatures low. After all, fires are not good for productivity. In a liquid ring pump, the heat of compression and condensation is absorbed by the seal fluid. Since liquids have higher specific heat capacities than vapors, the temperature rise across a liquid ring pump is much lower than alternative dry running technologies.

Construction flexibility

Mechanically speaking, liquid ring pumps are much less complex than other technologies (especially dry running alternatives). The shaft-mounted impeller is enclosed in the cylindrical body, which is capped by port plates and end casings, with tie rods holding it together. The tolerances between the impellers, body and end plates are wider than those found in dry running claw or screw pumps, which require tight tolerances to create the seal between the inlet and discharge pressures.

These wider tolerances, in addition to the lower temperature rise (and consequently, less thermal expansion), make liquid rings more suitable for construction in varieties of metals. Furthermore, liquid rings have seemingly endless design options for rotational speeds, bearing locations/lubrication and seal types. Whether the application involves air or potentially toxic/corrosive vapors, there is a suitable liquid ring configuration.

Pumping capacities

Because of the mechanical simplicity, liquid ring pumps are available in larger sizes for applications requiring high flow rates. For installations not requiring redundancy, this means only a single piece of equipment needs to be installed and maintained versus the multiple pumps that would otherwise be required. ■

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Improve Variable Frequency Drive Troubleshooting

De-energized and energized motor testing are techniques used to spark a VFD's performance.

WILLIAM KRUGER | All-Test Pro

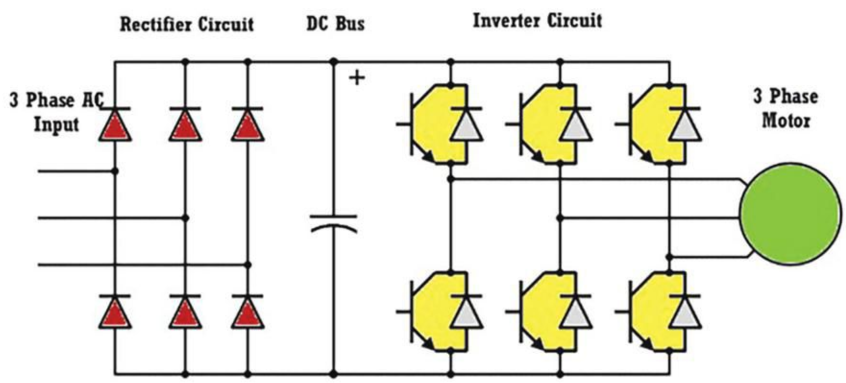


IMAGE 1: Basic VFD schematic (Images courtesy of All-Test Pro)

Improvements in variable frequency drive (VFD) technology have resulted in lower costs, improved reliability and increased use. Most modern VFD systems have internal diagnostics that create automatic shutdown on faults. However, the cause of these faults can sometimes be elusive to locate and correct. However, de-energized and energized motor testing can provide valuable insight to help identify many of these problems. This article highlights how to incorporate these motor testing techniques into VFD troubleshooting.

Basic Operation

A VFD rectifies the incoming three-phase, alternating current (AC) power to create a direct current (DC) bus. The DC bus uses capacitors to smooth the rectified DC as input to the invertor section. In the invertor section, the controller uses microprocessors to control semiconductor switches that convert the DC voltage to a variable three-phase AC voltage and frequency input to the motor. By controlling the amount of time the semiconductors (silicon-controlled rectifier [SCR] or insulated-gate bipolar transistor [IGBT]) are firing, the width of the DC pulses modulate the DC to produce a simulated three-phase input voltage with variable voltage and frequency. The frequency of the input voltage determines the speed at which the magnetic field rotates around the stator. The speed at which the magnetic field is referred to as the synchronous speed (SS).

$$SS = 120\ F/P$$

Where:
F = frequency of supply voltage
P = number of poles in the motor

Equation 1

Due to the switching nature from the invertor circuit, VFDs can create power quality (PQ) issues by introducing harmonics into the plant's electrical system. Additionally, VFDs can also be sensitive to incoming PQ issues, causing them to shut down. Many VFDs have internal electronics that indicate the cause of the shutdown. These common codes assign the cause of the overvoltage, over current, overload, voltage, current unbalance, over temperature or external faults. This information is important, but the real question is: What caused the fault condition? Is the fault condition caused by the VFD or experienced by the VFD?

If the fault is experienced by the VFD, it could be the result of incoming power, connections issues, any one of many motors issues or faults in the driven machine or the process itself. If the fault is caused by the VFD, it could be the result of the breaking down or failed electronic components. Among the common failures are diodes in the rectifier section, capacitors' on the DC bus or breakdown or failure of a semiconductor in the invertor section.

De-Energized Motor Testing

Motor circuit analysis (MCA) is a motor testing technique that injects a series of low voltage AC and DC signals through the motor windings to thoroughly evaluate the entire motor system while the motor is de-energized. MCA motor tests can be performed directly at the motor or remotely from the output of the VFD. Unlike traditional de-energized motor tests that fail to identify rotor problems or developing winding insulation breakdown, MCA tests provide early indication of developing faults in the ground wall insulation system and the insulation surrounding conductors used to create the coils in the stator as well as existing or developing faults in the electrical portion of the rotors. MCA can identify faults in the earliest stages but can also quickly confirm the motor is

MCA tests provide early indication of developing faults.

"good," which can eliminate the motor as the cause of the VFD trip. By performing the three-minute test from output of the VFD, a "good" result not only indicates the motor is in good condition but also that all the associated cabling and electrical components in the tested circuit are in good condition as well. However, if the results indicate "bad," an additional three-minute test directly at the motor is performed. If the motor tests "well," this means the test was conducted properly and the fault is in the cabling or controller. If the motor indicates a developing fault, there are optional MCA tests available to determine if the fault is in the rotor or the stator electrical circuit.

The low-voltage DC tests provide indication of connection issues in the circuit under test to confirm all of the external and internal connections are sufficiently tight. The series of AC tests exercise the winding insulation and identify the small changes that occur in the chemical makeup of the winding insulation as the insulation between conductors begins to degrade.

The optional dynamic test requires manual rotation of the motor shaft under test and develops a stator signature that identifies any developing faults in the insulation surrounding the conductors in the coils making up the stator winding system. The rotor signatures identify faults in the rotor electrical system such as static or dynamic eccentricity, cracks, breaks or casting voids in the rotor bars or end rings.

Energized Motor Testing: Electrical Signature Analysis

Electrical signature analysis (ESA) uses the VFD's input and output voltage and current to quickly analyze the condition and quality of power being supplied to the

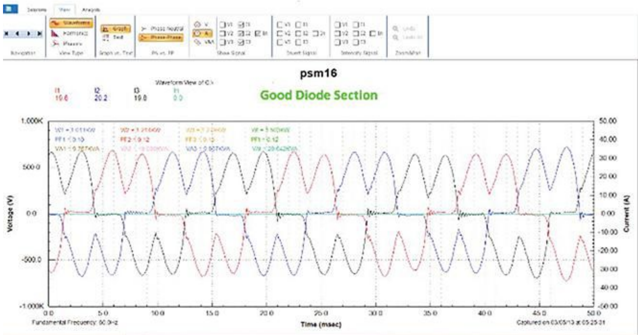


IMAGE 2: Good diode section

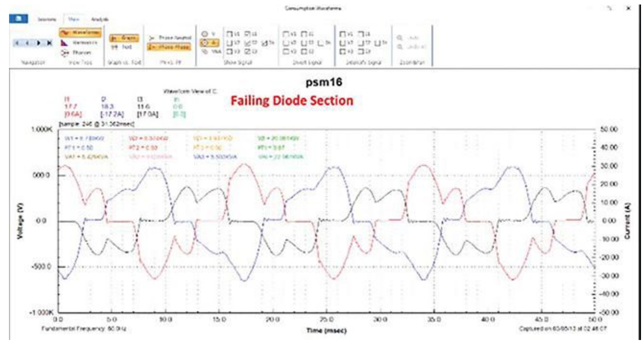


IMAGE 3: Faulty diode section

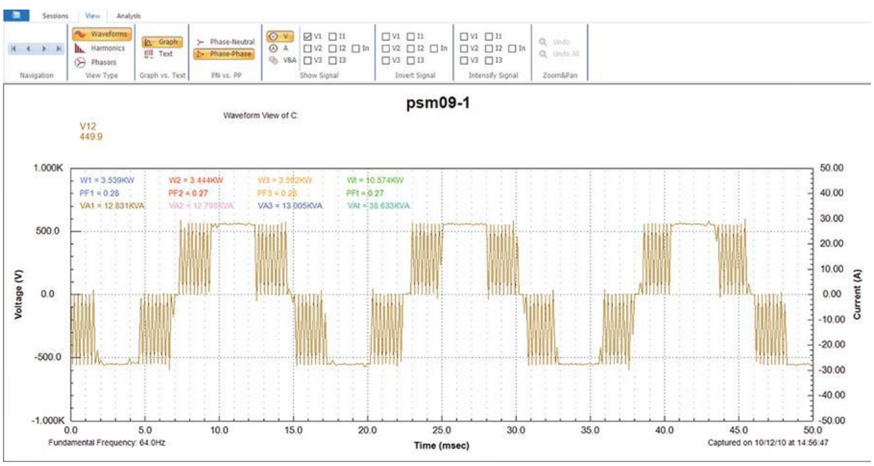


IMAGE 3: Properly operating IGBTs

drive as well as the voltage and current output from the drive to the motor. Each of these tests requires less than a minute. Performing ESA motor tests on the input and output of the drive provides a complete profile of input and output power. Each test performs a simultaneous data capture of all three phases of voltage and current to create PQ tables for each of the three phases, captures and displays and stores 50 milliseconds (msec) of the voltage and current waveforms for all three phases. Additionally, 50 seconds of the voltage and current waveforms are digitized and used to perform high and low frequency fast Fourier transforms (FFTs) on both the input and output voltage and currents.

Input Power

The input voltage to the drive provides valuable information indicating the condition of the incoming voltage supplied to the drive. It calculates any voltage, current unbalance or harmonic content in the incoming voltage or current. The input current indicates the diode's condition in the rectifier section of the drive. Image 2 shows the current waveform with all diodes firing properly. In Image 3, it can be quickly determined that one or more of the diodes are not firing properly.

Output Voltage

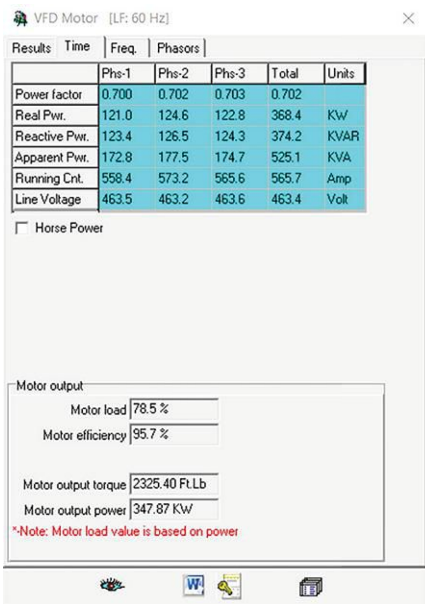
The output voltage from the drive provides information about the condition of the drive itself as well as the quality of the power being provided to the motor. This is including, but not limited to, the proper or improper operation of the semiconductors in the invertor circuits and developing failure of the DC bus capacitors. Image 3 provides a snapshot of one phase of the voltage output of the drive, which is the input voltage to the motor. All of the output voltage waveforms should be relatively uniform and symmetrical. Nonsymmetrical voltage waveforms indicate failing or failed IGBTs. Ripples on the flat portion of the positive and negative portions of the waveforms iare an indication of failing capacitors on the DC bus. A failed $20 capacitor can destroy an entire drive.

Output Current

The motor's current acts as a sensitive transducer for the motor system. Any existing or developing faults in the motor, the driven machine or the process itself will cause the motor's current to modulate. These modulations in the output current indicate the electrical or mechanical condition or any anomalies in the process itself. An FFT on the digitized voltage and current waveforms identifies faults in the motor such as cracked or broken rotor bars, static or dynamic eccentricity. Early indication of developing rolling element bearing failures, balance and the alignment condition of the rotating components of the motor or the driven machine can also be quickly identified using the same fault frequencies long recognized in vibration analysis.

Automatic Analysis

The ESA software combines all the information gathered in the 50-second data acquisition process and compares them to predetermined standards, guidelines and algorithms to create the graphs, tables and displays required to evaluate the condition of the entire motor system from the incoming power to the process. On completion of the evaluation, ESA creates a complete, detailed report that not only highlights developing problems in the electrical portion, developing faults in the driven machine or other equipment connected to the motor but also anomalies in the process that could cause the VFD to trip. The report produced also details measurements that are



VFD Motor [LF: 60 Hz]

Results | Time | Freq. | Phasors

	Phs-1	Phs-2	Phs-3	Total	Units
Power factor	0.700	0.702	0.703	0.702	
Real Pwr.	121.0	124.6	122.8	368.4	KW
Reactive Pwr.	123.4	126.5	124.3	374.2	KVAR
Apparent Pwr.	172.8	177.5	174.7	525.1	KVA
Running Cnt.	558.4	573.2	565.6	565.7	Amp
Line Voltage	463.5	463.2	463.6	463.4	Volt

Horse Power

Motor output

Motor load 78.5 %

Motor efficiency 95.7 %

Motor output torque 2325.40 Ft.Lb

Motor output power 347.87 KW

*-Note: Motor load value is based on power

IMAGE 5: PQ table on output of VFD

VFD Motor [LF: 60 Hz]

Results | Time | Freq. | Phasors

Power factor	PF is below 0.85
Current	OK
Voltage	OK
Load	OK [Ld:78.5%]
Vlt-GND ref.NOT neutral	OK
Connection	OK
Rotor	OK (C:1)
Stator (mechanical)	OK
Air gap	OK
Harmonic distortion	OK
Misalignment/Unbalance	OK
Bearing/Unidentified	OK
Bottom line	Abnormal indications

IMAGE 6: Results screen

within predetermined guidelines, thereby eliminating most of the guesswork normally associated with VFD troubleshooting.

By incorporating MCA and ESA into the VFD standard troubleshooting process, the analyst has the most detailed information available to quickly determine if the fault is caused by the VFD or experienced by the VFD. The three-minute MCA identifies bad motors and can eliminate the motor as the cause of the failure and ensure that if a new motor is being installed, it is fault-free. ESA confirms power into and out of the VFD is fault-free in a test that takes less than 1 minute. ■

William Kruger joined ALL-TEST Pro as the technical manager in 2004. He may be reached at wkruger@alltestpro.com. For more information, visit alltestpro.com.

How Often Should I Check the Calibration of My Pressure Gauge?

Ensuring a gauge is giving an accurate reading is vital to avoiding downtime and maintaining efficiency.

ROB RYCHLIK | Ashcroft

Did you know that pressure gauges can lose accuracy over time? No gauge can stay completely accurate forever; so, users need to regularly check a gauge's accuracy to ensure it continues to provide correct readings for the application.

If gauges are not regularly checked, inaccurate pressure readings can cause equipment to malfunction and break down, which can lead to downtime. But how often should users check the accuracy of pressure gauges? There is no official defined accuracy interval for the industry, but there are best practices that users should follow.

IMAGE 1: Pressure gauges being calibrated (Image courtesy of Ashcroft)

Typically, the suggested time to check instrument calibration is once every 12 months.

Why Does Calibration Matter?

Pressure readings are important to almost all operations, so accurate, reliable and repeatable devices must be maintained to ensure maximum performance and efficiency.

The calibration interval is the period between the instrument's last verified calibration and its next scheduled checkup. Keep in mind that units are often removed from the process and either validated on-site or forwarded to an outside party for servicing. This means users will have to contend with downtime. This can take several days to weeks depending on the scope of service. So, it may be wise to inventory identical models and rotate units as deemed necessary. Replacement units will also need to follow the same calibration check interval and should not be used only in times of trouble like a spare tire for a car.

Generally, organizations such as the National Institute of Standards and Technology (NIST) or the American Society of Mechanical Engineers (ASME) do not establish calibration intervals, and users cannot depend on an outside party to determine when they should reevaluate instruments.

This places the ultimate responsibility on the user, as they are the most familiar with the application and the conditions the instrument will need to operate. As such, the user will need to determine the duration of the interval. Users should consider reducing this interval as process conditions become more unstable or fluctuate by degrees so each instrument may have a distinct correlation with the calibration interval.

Determining Pressure Gauge Calibration Intervals

As an instrument's accuracy will eventually degrade over time, users must proactively manage when it is checked. This takes time to establish, though it is better to check gauge accuracy early rather than extending any interval to save time and/or cost.

When determining an instrument's calibration interval, be sure that the instrument provides accurate, reliable and stable pressure readings over the established period. Schedule recalibration immediately if the gauge pointer is off zero or out of the zero box. This will reduce the impact on the process. Gauges used in extreme applications will require more frequent (shorter) calibration intervals because harsher environments can quickly degrade instruments. Process conditions with excessive vibration, pulsation and/or high cycle rates can result in mechanical wear and have an adverse effect on accuracy, repeatability and reliability. Units recently calibrated should be clearly identified with a serial number and the date they were calibrated. This allows for easy tracking and identifying process trends that can provide an alert to future process issues.

Recommended Calibration Intervals

Typically, the suggested time to check instrument calibration is once every 12 months. But, as mentioned before, the timing should be decreased or increased by the end user depending on both application and process parameters. In some instances, it may not even be possible to recalibrate the instrument. For example, some gauges have a nonremovable front ring that makes recalibration impossible. Low-cost gauges are typically not meant to be recalibrated, as they would cost more to be calibrated than simply buying a new gauge. Be sure to look at cost-effectiveness for the business—is it economical to calibrate or should users simply buy a new product?

Finally, be sure to communicate with the quality assurance department. It can be of vital importance when developing the calibration intervals for products based on a company's checks and balances. ■

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Rob Rychlik is the marketing manager, lead generation at Ashcroft. He earned an MBA from Sacred Heart University. For more information, visit ashcroft.com.

Seal Face Modifications & How VFDs Change Motor Speed

HYDRAULIC INSTITUTE

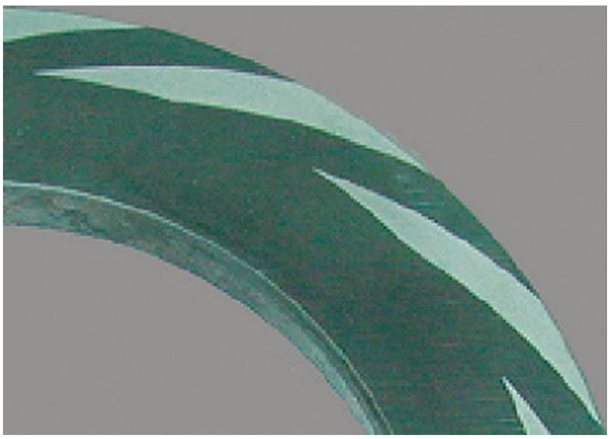

IMAGE 1: Spiral grooves (Images courtesy of Hydraulic Institute)
IMAGE 2: Hydropads

Q | How do modifications to seal faces improve their operation?

The most common seal face pattern is a plain flat surface designed to operate with minimal friction. However, various treatments can be done to seal faces to meet specific application needs. In general, seal face treatments are a means of modifying the pressure distribution between the seal faces. Images 1 and 2 show two more common face treatments that include spiral grooves and hydropads.

The most common objective of face treatments is to increase the opening force and thereby reduce the force of the mechanical contact. It can be useful when friction must be reduced to prevent vaporization of the fluid film or in applications involving a combination of high pressure and low viscosity of fluid.

Face treatments increase the opening force by hydrostatic or hydrodynamic methods. Hydrostatic forces do not depend on the rotational speed, whereas hydrodynamic forces vary with the rotational speed and viscosity of the fluid.

The simplest face treatment is a plain face that is angled. This design produces forces that are primarily hydrostatic. An example is a face subject to pressure at the outer diameter that is lapped so it touches the mating ring at the inside diameter. This means that the leakage path is converging. Care must be taken in determining the optimum angle, as too little taper will reduce the lubrication to the faces causing them to run hot. Too much taper will cause face separation with high leakage.

Several face patterns produce hydrodynamic opening forces. Hydropads (Image 2) are recesses that are machined into one face and develop hydrodynamic forces in the sealing gap. The size, quantity and location of the hydropads can be used to optimize the lubrication state for applications involving high pressure and speed or liquids with poor lubricating qualities—i.e., liquids with low viscosity. Other face treatments that generate hydrodynamic forces are spiral grooves (Image 1), wavy faces and laser-structured faces. The main difference between hydropads and the other types is the depth of the groove. Spiral grooves are typically used for noncontacting operation.

> An ECM can operate at about 85% efficiency at full load.

For more information on the design and application of mechanical seals in pumping applications, refer to "Mechanical Seals For Pumps: Application Guidelines" at pumps.org.

Q | How do variable frequency drives change the motor speed?

Variable frequency drives (VFDs) are used to control the speed of both induction and synchronous motors. The complexity of the

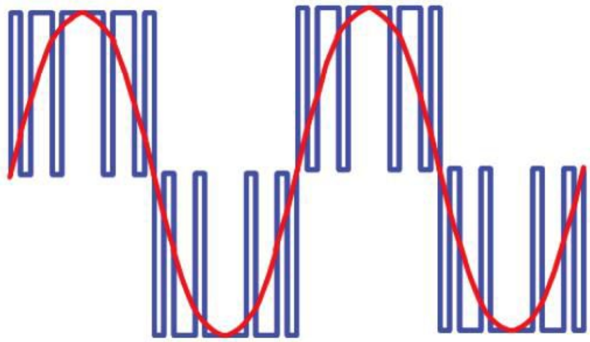

IMAGE 3: VFD output PWM (blue) waveform with corresponding sine wave (red)

controller can range from a simple, manually operated control panel to a more sophisticated programmable logic controller (PLC) that can automate control based on input from system variables such as flow, level or pressure.

Three-phase induction motors operated on line voltage have relatively smooth sine waves with a 50- or 60-hertz (Hz) frequency, depending on the location. For two-pole motors, this equates to a 3,000- or 3,600-rotations per minute (rpm) synchronous pole speed. Without a VFD, the speed of the motor is relatively constant and changes minimally as a function of load due to motor slip. With a VFD, voltage and current fed to the motor are controlled by turning on and off insulated-gate bipolar transistors (IGBTs). The amplitude of the voltage and current values is controlled by the frequency of the switching and on and off time of the IGBTs. This means the longer the switches are on compared to the time they are off, the larger the voltage and current values.

Pulse width modulation (PWM) is a high-frequency waveform generated by the IGBTs to simulate a sine waveform to the motor. The frequency of the sine wave can be varied by the VFD, resulting in a change in motor speed. PWM is advantageous because the power loss in the switching devices is low, resulting in relatively high efficiency and energy benefits when considering the reduced hydraulic power at lower speeds. With the power being switched on and off rapidly, the resulting power waveform closely approximates the average current and voltage that a utility power source would normally supply a motor (sine wave). Refer to Image 3.

For more information on VFDs and how they are applied in pumping applications, refer to “Variable Frequency Drives: Guidelines for Application, Installation, and Troubleshooting” at pumps.org. ■

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Support Systems for Dual Pressurized Pump Gas Seals

What are the best practices for ensuring the reliability of API Piping Plan 74?

MARK SAVAGE | FSA member

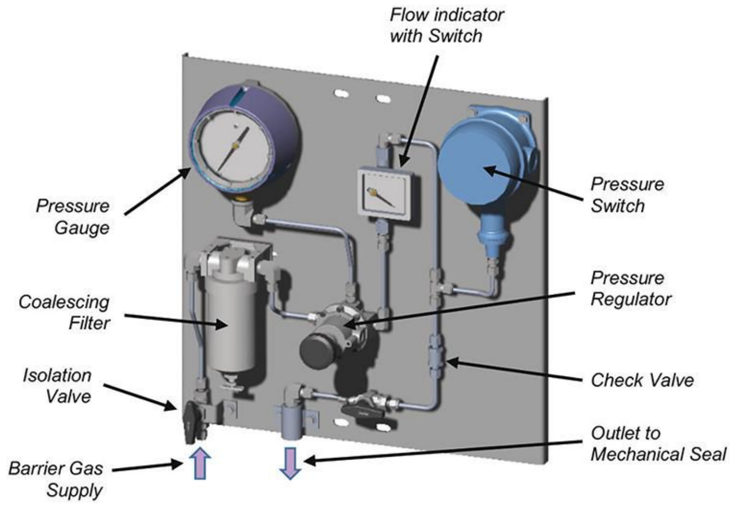

IMAGE 1: Typical Plan 74 gas panel (Images courtesy of the Fluid Sealing Association)

Dual pressurized pump gas seals that use technology adapted from compressor gas seals are more common in the shaft sealing industry. These seals can provide zero emissions of the pumped fluid to atmosphere, offer lower frictional drag on the pump shaft and operate with a simpler support system. These advantages deliver a solution with an overall lower life cycle cost.

These seals work by introducing an external source of pressurized gas between the inboard and outboard seal face pairs. Special surface topography features on the seal faces further pressurize the barrier gas causing the seal interface to separate, resulting in the seal faces floating on a film of gas. Since the seal faces are no longer in contact, frictional losses are low. Barrier gas flows across this film at a low flow rate, consuming the barrier gas that appears in the form of leakage—the majority of which is leakage across the outboard seal faces to atmosphere. The balance leaks into the seal chamber and is eventually carried away in the process stream.

Advantages of Pump Gas Seals

All dual pressurized seals need a pressurized fluid (liquid or gas) introduced between the inboard and outboard face pairs within a mechanical seal assembly. To deliver this fluid to the seal, a support system is needed. In contrast, liquid-lubricated dual pressurized seals circulate the barrier liquid from a reservoir through the mechanical seal, where it lubricates the seal faces, absorbs heat, and then returns to the reservoir where the absorbed heat needs to be dissipated. These support systems for liquid pressurized duals seals are complex. The heat loads increase as pressure and process temperatures increase, which can lead to reliability issues if incorrectly sized and installed.

The support system for dual pressurized gas seals has a small footprint, requires no cooling water, and has almost no maintenance requirements. Also, its reliability is independent of process pressure and temperature when supplied with a reliable barrier gas source.

Dual Gas Seal Support System

With the increased adoption of dual pressurized pump gas seals in the market, the American Petroleum Institute (API) added Plan 74 as part of the release of the second edition of the standard API 682.

A Plan 74 support system is typically a panel-mounted group of instruments and valves that clean the barrier gas, regulate the outlet pressure and measure the pressure and gas flow delivered to the mechanical seal. Following the path of the barrier gas through the Plan 74 panel, the first item is an isolation valve. This allows the supply of barrier gas to be isolated from the seal for replacement of the filter element or maintenance of the pump. The barrier gas then flows through a 2 to 3 micrometer (µm) coalescing filter to trap liquids and particles that can damage the seal face topography features that create the gas film at the seal face interface. Next is a pressure regulator and pressure gauge that sets the delivery pressure of the barrier gas to the mechanical seal.

Dual pressurized pump gas seals require a barrier gas supply pressure that meets or exceeds the minimum pressure differential above the maximum seal chamber pressure. This minimum pressure differential varies with seal manufacturer and seal type but is typically around 30 pounds per square inch (psi). A pressure switch is used to detect any problems with the supply barrier gas pressure and alarm if the pressure drops below the minimum pressure.

The performance of the seal is monitored by barrier gas consumption rate using a flow meter. Deviations away from the normal barrier gas consumption rate provided by the mechanical seal manufacturer indicate degrading seal performance. A decrease in barrier gas consumption can be the result of the pump spinning backward or liquid migrating to the seal interface (either from contaminated barrier gas or the process fluid).

Typically, after these types of events, damage occurs to the seal face and barrier gas consumption then increases. Damage to the seal faces can also occur as a result of pressure spikes in the pump or partial loss of barrier gas pressure. A high flow alarm can be used to determine at what point intervention is needed to rectify the high gas consumption. The set point for the high flow rate alarm is typically in the range of 10 to 100 times the normal barrier gas consumption rate, and it generally is not determined by the mechanical seal manufacturer but rather how much gas leakage into the pump can be tolerated.

Traditionally, variable area flow meters are used, and it is not uncommon to see a low-range and a high-range flow meter connected in series. A high-flow switch can then be fitted to the high-range flow meter to signal a high-flow alarm. Variable area flow meters can only be calibrated for a specific gas at a specific temperature and pressure. When operated at other conditions, such as temperature variations between summer and winter, the displayed flow value cannot be considered a precise value but rather something near the actual value.

With the release of API 682 4th edition, both flow and pressure measurement have changed from analog to digital with a local readout. Digital flow transmitters are available as either a variable area flow meter that has the float position converted to a digital signal or a mass flow meter where the mass flow is automatically converted to a volumetric flow. A nice feature of mass flow transmitters is that the output provided can compensate for pressure and temperature giving a true flow rate at standard atmospheric conditions. The drawback is that these devices are more expensive than variable area flow transmitters.

The challenge of using flow transmitters is finding one that can measure the barrier gas consumption rate during normal operation and at the high-flow alarm point. Flow transmitters have maximum and minimum values that they can accurately read. Between zero flow and the minimum, the output flow value may not be accurate. The catch is that when the maximum flow value increases for a particular flow transmitter model, so does the minimum flow value.

One solution is to use two transmitters (a low range and high range), but this is an expensive option. A second method is to use a flow transmitter for the normal operating flow range and a high-flow switch with an analog high-range flow meter. The last component the barrier gas flows through is a check valve before the barrier gas exits the panel and connects to the mechanical seal. This is to prevent reversing flow of the pumped fluid into the panel and damaging the instruments if an abnormal process upset were to occur.

The check valve needs to have a low cracking pressure. If incorrectly selected, or if the dual-pressurized pump gas seal has a low barrier gas consumption rate, pulsations in the barrier gas flow rate can be seen as a result of the check valve cracking open and reseating.

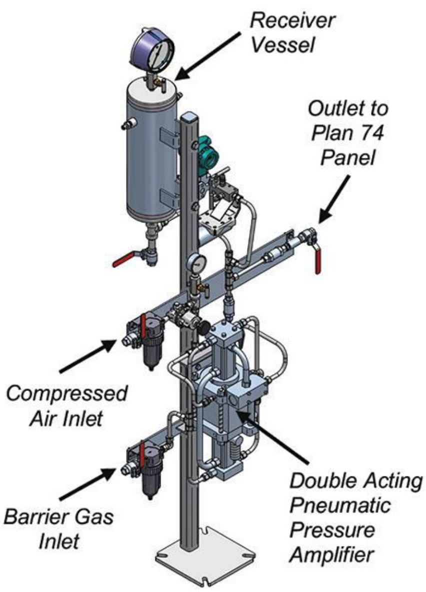

IMAGE 2: Typical pneumatic pressure amplifier with receiver vessel

Barrier Gas

Typically, plant nitrogen is used as the barrier gas since it is readily available, is inert and does not create any adverse chemical reactions in the pumped fluid. Less readily available inert gases, such as argon, can also be used. In cases where the required barrier gas pressure is greater than the plant nitrogen pressure, a pressure amplifier can boost the pressure and store high-pressure gas in a receiver that is connected to the Plan 74 panel inlet. Banks of bottled nitrogen are not generally recommended, as they require the constant changing out of empty bottles with full ones. If the seal experiences any degradation in performance, the bottles can be emptied quickly, forcing the pump to be stopped to prevent further damage and failure of the mechanical seal.

Installation & Commissioning

Unlike liquid barrier systems, a Plan 74 support system does not need to be immediately adjacent to the mechanical seal. The only note of caution here is with extended runs of small-bore tubing. A pressure drop between the Plan 74 panel and seal can occur in the tubing during high flow (deteriorating seal performance) that can reduce the barrier pressure margin being delivered to the seal. Increasing the tube size can eliminate this concern. Typically, the Plan 74 panel is mounted on a stand at a comfortable height to operate the valves and read the instruments. The stand can be mounted on the pump baseplate or adjacent to the pump in a location that does not affect inspection and maintenance activities for the pump. Avoid creating trip hazards with the pipe/tube that connects the Plan 74 panel to the mechanical seal.

For between-bearing pumps that have two mechanical seals, one at each end of the pump, it is not recommended to use a single panel and split the barrier gas outlet to each mechanical seal. The recommended solution is to use either a dedicated Plan 74 panel for each seal or use a Plan 74 panel that has two outlets, with each outlet having its own set of flow meters and flow switches. Winterizing the Plan 74 panel may be required for sites subject to cold winters. This is primarily to protect the panel's electrical devices and typically takes the form of encasing the panel in an instrument box and adding heating elements.

One interesting phenomenon is that barrier gas consumption rate increases with decreasing barrier gas supply temperature. This generally is unnoticed but may become apparent at sites with cold winters or large differences in temperatures between summer and winter. In some situations, this may require adjustments of the high-flow alarm set points to prevent nuisance alarms. Before commissioning the Plan 74 panel, the panel piping and interconnecting pipe/tube need to be purged of air. This is most easily accomplished by adding a vent valve at or near the connection to the mechanical seal. If a vent valve is unavailable, the system can be purged by disconnecting the pipe/tube from the mechanical seal and then reconnecting after purging.

With the Plan 74 panel connected to the seal and all fittings leak checked, the pressure regulator can now be adjusted to the set pressure for the application. The panel must deliver pressurized barrier gas to the mechanical seal prior to flooding the pump with process fluid. Once the pump commissioning and venting procedures have been completed, the seal and Plan 74 panel are ready for startup.

Operation

After one month of operation, the filter element should be inspected, and if no contamination is detected, inspection should occur every six months. The filter element replacement interval will be dictated by the cleanliness of the supply gas but should be no more than three years.

The barrier gas consumption rate should be checked and recorded during routine inspections. If the pulsations in barrier gas flow caused by the check valve opening and closing are large enough to trigger high-flow alarms, these alarm values may need to be raised to avoid nuisance alarms.

Decommissioning for Maintenance

The key step for decommissioning is that isolation and removal of the barrier gas pressure should be the last step. First, isolate and depressurize the pump casing. Once the pump is safe, the barrier gas supply pressure can be isolated and gas pressure vented from the piping connecting the Plan 74 panel to the mechanical seal. Drain any liquids from the system before commencing any maintenance activities.

The combination of dual-pressurized pump gas seals together with the Plan 74 support system offers operators a shaft sealing solution that provides zero emissions to atmosphere; lower capital investment (compared to seals with a liquid barrier system); lower life cycle cost; a small footprint for the support system; and little maintenance requirements.

When installed and operated with best practices, this sealing solution can deliver long-term reliability and improved rotating machinery availability. ■

We invite your suggestions for article topics as well as questions on sealing issues so we can better respond to the needs of the industry. Please direct your suggestions and questions to sealingsensequestions@fluidsealing.com.

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Mark Savage is a product group manager at John Crane. Savage holds a Bachelor of Engineering from the University of Sydney, Australia. For more information, visit johncrane.com.

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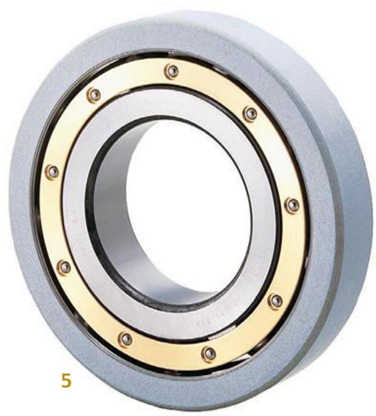

5

2

1

1 PLUG & RECEPTACLE

MELTRIC introduces a new and improved DR400. This standard duty plug and receptacle features a durable metal casing with upgraded impact resistance, environmental ratings and performance. A silicone double-lipped gasket is now assembled in the receptacle casing as opposed to the receptacle lid. This allows for Type 4X, IP69 watertightness when the receptacle casing lid is closed and/or the inlet/receptacle is connected.

■ *meltric.com*

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2 HIGH PRESSURE DAMPENERS

With innovations in design, **BLACOH**'s new generation SENTRY XP pulsation dampeners are more extreme. Engineered for reliability, SENTRY XP pulsation dampeners offer better performance and more options for high-pressure applications. New larger-capacity models up to 122 cubic inches are available as well as other models with pressure ratings up to 15,000 psi. All models are ideally suited for metering and dosing applications typical in the oil and gas industry.

■ *blacoh.com*

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3 DEWATERING PUMPS

GORMAN-RUPP's line of ValuPrime priming-assisted centrifugal pumps is designed to dewater the jobsite. The VPA Series pumps offer the same quality components users expect from Gorman-Rupp. ValuPrime pumps are available in 4-inch and 6-inch configurations and can handle solids up to 3 inches in diameter. These pumps provide flows up to 1,520 gpm and heads up to 150 feet, keeping the site dry and the project on track.

■ *gormanrupp.com*

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4 VALVE COMPONENTS

SEPCO's valve seats, gland packing, bottom packing energized seals, liners and backup rings for valves are available. Materials of construction are PTFE, filled PTFE, PPS or PEEK. Produced in Texas, they can be delivered quickly, eliminating supply chain delays. They are ideal for valve manufacturers or end users.

■ *sepco.com*

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5 INSULATED & COATED BALL BEARINGS

NTN's MEGAOHM series of insulated bearings has been designed to counteract electrical pitting. These bearings are available in both ceramic and resin versions suited to a variety of applications. Coating the outer ring of the bearing provides a barrier (capable of resisting at least 100 megaohms and up to 2,000 megaohms at 500 VDC) against any stray currents that would pass through the bearing.

■ *ntnamercias.com/industry/electric-motor*

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6 PRESSURE GAUGE

The **ASHCROFT** 50 mm HPS high-purity pressure gauge with reed switch is ultrasonically cleaned to provide quality and reliability in ultra-high purity gas delivery systems. The reed switch capability provides an additional safety feature through actuating an internal switch that triggers an alarm or a process condition change. It is an ideal choice for reducing installation costs and providing an added space reduction benefit. The gauge features stainless-steel construction and wetted components that are ideal for use with industrial gases in semiconductor and electronic manufacturing.

■ *ashcroft.com*

Check 206 on index.

To have a product considered for this section, please send the information to Drew Champlin, dchamplin@cahabamedia.com.

7

8

9

7 PERISTALTIC PUMP

The PERIPRO peristaltic pump from **NETZSCH** delivers large flow rates at a wide range of pressures. This means that the system provider for positive displacement pumps is now establishing itself as a specialist for pumping complex and difficult media. The PERIPRO expands the NETZSCH pump portfolio with its characteristics as a robust and powerful pump that can handle viscous and abrasive media at high pressures. These pumps have a long operating life and enable 30% energy savings.

■ *netzsch.com*

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8 SHAFT SEAL

THORDON BEARINGS' BlueWater seal, a new propeller shaft seal with a safe return to port (SRTP) design, specifically meets commercial shipping industry needs for a low maintenance and robust shaft seal. The Thordon BlueWater seal completes the COMPAC open seawater lubricated propeller shaft bearing system. Taking the TG100 and SeaThigor seal products as the technical benchmark, the Thordon BlueWater Seal is a cost-effective, commercial grade axial lip seal specifically designed for merchant shipping fleets.

■ *thordonbearings.com*

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9 WEAR RINGS & BUSHINGS

Pump wear rings and bushings made from **GRAPHALLOY** materials can improve the reliability and efficiency of horizontal and vertical pumps. Graphalloy is self-lubricating and nongalling. This means the material is "kind" to the shaft and will minimize damage in the event of dry-run, loss of suction and slow roll on standby service. Graphalloy can be designed to run at half of API's recommended clearances for metallic wear parts, decreasing vibration and leakage.

■ *graphalloy.com*

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- ❑ 21 Engineering & Construction, Including Environmental
- ❑ 24 Consulting
- ❑ 01 Food & Kindred Products
- ❑ 08 Oil & Gas
- ❑ 05 Paper & Allied Products
- ❑ 03 Lumber & Wood Products
- ❑ 07 Pharmaceutical & Cosmetics
- ❑ 11 Mining All Types
- ❑ 12 Primary Metal Industries
- ❑ 15 Building Services & HVAC
- ❑ 30 Agriculture
- ❑ 31 Marine
- ❑ 25 Aftermarket/Replacement, Parts & Repair Services
- ❑ 27 Pump & Related Product Distributor
- ❑ 26 Pump & Related Product Manufacturer
- ❑ 29 Pump & Related Equipment Rental
- ❑ 98 Other *(please specify)* ____________________

2. Your primary job function is:
(Check Only One)
- ❑ 01 Engineering (Including Project Man.)
- ❑ 02 Operations & Maintenance
- ❑ 03 Research & Development
- ❑ 04 Corporate Management
- ❑ 05 Environmental & Safety
- ❑ 06 Marketing & Sales
- ❑ 07 Purchasing
- ❑ 08 Consulting
- ❑ 09 Training/Education/Library
- ❑ 10 Management Other Than Corporate
- ❑ 98 Other *(please specify)* ____________________

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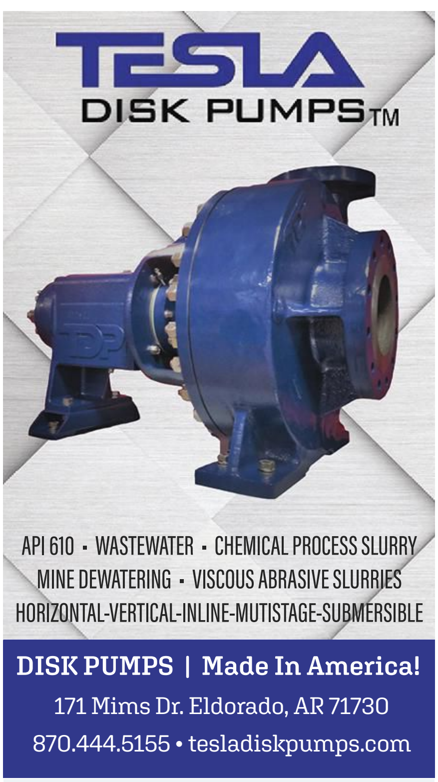
Check 141 on index.

Check 147 on index.

Check 148 on index.



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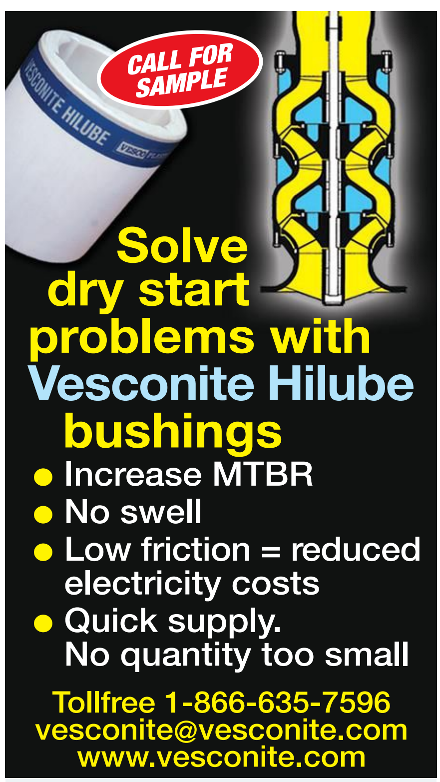

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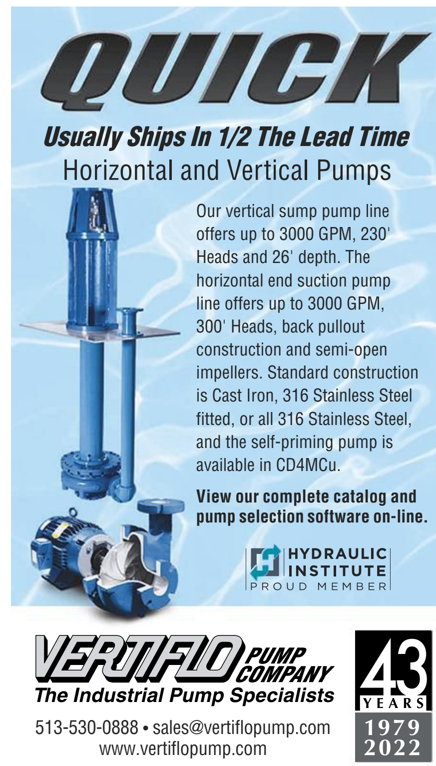

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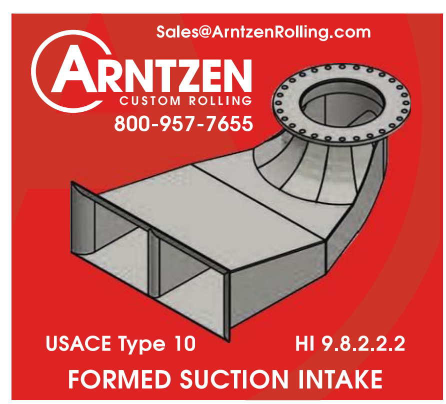

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Wall Street Pump & Valve Industry Watch

JORDAN, KNAUFF & COMPANY

IMAGE 1: Stock indices from March 1, 2021 to Feb. 28, 2022. Local currency converted to USD using historical spot rates. The JKC Pump and Valve Stock Indices include a select list of publicly traded companies involved in the pump and valve industries, weighted by market capitalization. Source: Capital IQ and JKC research

The Jordan, Knauff & Company (JKC) Valve Stock Index was up 3.9% over the last 12 months, and the broader S&P 500 index was up 12.1%. The JKC pump stock index rose 0.3% for the same period.[1]

The Institute for Supply Management's Purchasing Managers Index (PMI) rose one point to 58.6% in February. The Backlog of Orders Index was up 8.6 points and new orders rose 3.8 points, showing the continued imbalance between demand and supply. The Production Index rose 0.7 points. Pricing pressure eased with the Prices Paid Index down a half of a percentage point to a still-high 75.6%. The Employment Index fell 1.6 points to 52.9%, a five-month low. Some key inputs used in manufacturing semiconductors come out of Russia and Ukraine, which means the current conflict could exacerbate the existing shortage of chips. However, the U.S. manufacturing sector's direct exposure to the conflict could be minimal.

The U.S. added 678,000 jobs in February. Job growth was also stronger in prior months than initially reported with 481,000 jobs added in January and 588,000 jobs in December. Employers continued to boost wages as average hourly earnings of private sector workers rose one cent from a month earlier. Hourly pay has risen 5.1% over the past 12 months. The unemployment rate fell from 4.0% to 3.8%.

U.S. inflation reached a four-decade high in January, accelerating to a 7.5% annual rate as strong consumer demand met with pandemic-related supply disruptions. Prices were up sharply for some everyday items, including food, vehicles, shelter and electricity. A sharp uptick in housing rental prices, one of the biggest monthly costs for households, contributed to January's increase. Used car prices continued to drive overall inflation, rising 40.5% in January from a year ago. Food prices rose 7%, the sharpest rise since 1981. Energy prices jumped 27%, down from November's peak of 33.3%.

Following reports that Russian forces invaded Ukraine, the front-month futures price of both Brent and West Texas Intermediate (WTI) crude oil increased to more than $100 per barrel (b) on Feb. 24. The front-month Brent contract price closed below $115/b on March 2. The Brent crude oil price last rose above $100/b in late 2014.

The U.S. became Europe's largest source of liquefied natural gas (LNG) in 2021, accounting for 26% of all LNG imported by European Union member countries and the United Kingdom. Qatar supplied another 24%, while Russia supplied 20%. Pipeline flows of natural gas from Russia decreased during 2021.

On Wall Street, the Dow Jones Industrial Average, the S&P 500 Index and the NASDAQ Composite fell 3.5%, 3.1% and 3.4%, respectively, in February. The Federal Reserve Bank's next interest rate move, inflation and the conflict between Russia and Ukraine have impacted investors. ■

Reference

1. The S&P Return figures are provided by Capital IQ.

Jordan, Knauff & Company is an investment bank based in Chicago that provides merger and acquisition advisory services to the pump, valve and filtration industries. Please visit jordanknauff.com for further information. Jordan, Knauff & Company is a member of FINRA.

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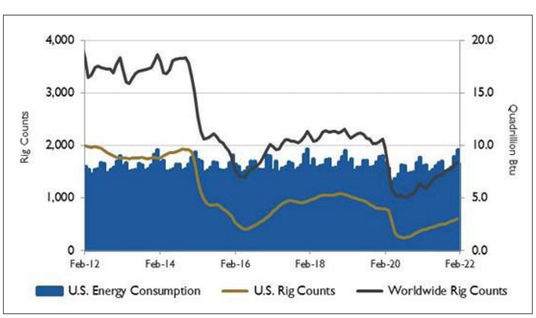

IMAGE 2: U.S. energy consumption and rig counts. Source: U.S. Energy Information Administration and Baker Hughes Inc.

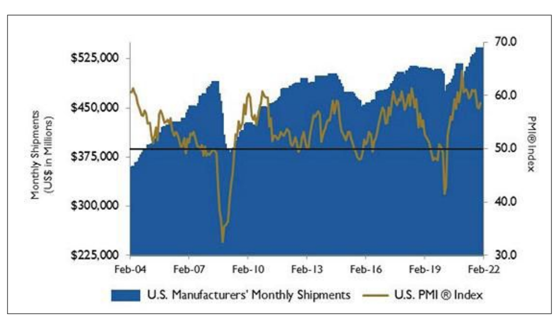

IMAGE 3: U.S. PMI and manufacturing shipments. Source: Institute for Supply Management Manufacturing Report on Business and U.S. Census Bureau