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insights

VOLUME 9, NO. 1

Featured in this issue of *insights:*

insights

VOLUME 9, NO. 1

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Listening. Innovating. Delivering.

candid visions

Brad Dickson,
Executive Vice President

Editor's Note:
In this issue of insights, the Candid Visions column is devoted to an interview with Brad Dickson, executive vice president, New Equipment Worldwide, at Dresser-Rand. Dickson responded to questions from the editor of insights regarding Dresser-Rand's role in the changing global market.

Advancements in Technology and "Green" Solutions Provide Growth Opportunities for Dresser-Rand

insights: What current market changes will have a direct bearing on Dresser-Rand's approach to the market in the coming year?

Dickson: We are well positioned for changes or shifts in the global market because of our breadth of products and services and worldwide presence. As a full-service energy solutions company, we specifically adapt our offerings to the unique requirements of our clients. Whether turbo or reciprocating compression equipment, steam turbines, control systems, expanders or our strategically located service centers and the range of services available, we fill a critical role in each segment of the energy market – upstream, midstream and downstream.

In addition to supplying the traditional upstream segment with compression to onshore and offshore oil and gas production projects like floating production, offloading and storage vessels (FPSOs) – a particularly robust market today – the liquified natural gas (LNG) market represents a significant growth opportunity as well. LNG fills the gap for increased energy demands, particularly in North America where the era of easy oil and gas accessibility is quickly diminishing. Numerous projects have recently been announced and have moved into front-end engineering and design contracts. Dresser-Rand is well positioned to participate in both liquefaction capacity expansion that is expected to double in the next 10 years and LNG import and storage terminal development – 30 more have been announced that could go around the world. We've historically supplied equipment for these applications, and we're positioning ourselves to continue to provide equipment and value-added expertise in this area.

The downstream refining market has been particularly strong for the U.S. this decade as a result of Clean Fuels activity. We are now seeing significant activity related to announcements in the U.S. for increases in refining capacity. This activity is being driven by the mismatch of heavy sour crude conversion and by refinery utilization rates that are at their highest levels in 25 years. Both the Asia Pacific and European Served Areas regions are experiencing similar demand, and we've been actively working with refiners and their process licensors to specify equipment and develop life cycle equipment profiles that will add value to their operations.

insights: What is the significance of Dresser-Rand's alliance clients in the company's overall strategy, and how are these alliances evolving?

Dickson: More and more, our end-user clients are recognizing that they have an opportunity to engage in strong partnering arrangements with their key suppliers to not only streamline their supply chains and increase their security and quality of supply, but also to create life cycle cost benefits that will help them be more competitive in their businesses. Many clients are recognizing the real value in acquiring technology through collaboration that puts total cost of ownership ahead of first price savings on any one piece of equipment.

“Globally, one of the most important areas of concern remains protecting people and the environment.”—

Brad Dickson, executive vice president, New Equipment Worldwide

We have alliance agreements with many of the world’s leading oil and gas companies. These agreements, which are beneficial to both the client and Dresser-Rand, can range from basic parts or service agreements to complex supply agreements that include a full range of new equipment and aftermarket solutions. We’re able to deliver innovative technologies combined with service under agreements to mutually reduce costs and improve revenues for both, helping make our clients more competitive in today’s marketplace.

insights: How have reduced cycle times for equipment affected Dresser-Rand’s role in the client supply chain?

Dickson: Dresser-Rand has implemented operational excellence, lean manufacturing and numerous process improvement projects that are resulting in greater manufacturing productivity, reduced scrap and rework, faster cycle times and lower material costs.

In 1997, Dresser-Rand launched the supply chain management (SCM) program to enhance efficiency, as well as add value to our clients’ supply chains. This ultimately led to the development of the Dresser-Rand Corporate Product Configurator, a sophisticated, custom-written software package that gives our project development engineers the information they require to rapidly select and configure machinery and services for clients’ specific applications.

With the Configurator, a Dresser-Rand representative can now meet with a client’s project team anywhere in the world and compile a firm, accurate product definition and proposal in the client’s office. Before development of the Configurator, accurately interpreting client’s specifications and writing a proposal could take several weeks, if not months. But this is really just the start. The Configurator greatly reduces the required time at the front-end engineering of a project, thereby reducing total cycle time by allowing us to develop an accurate roadmap of all aspects of a project, enabling us to “build what we bid.” This not only lowers the client’s project risk and cost, but the engineering contractor’s risk and cost as well.

insights: What significant new developments is Dresser-Rand pursuing in compression, and how will these opportunities fit the needs of the marketplace?

Dickson: The DATUM® C pipeline compressor represents a new concept in compression that we believe will significantly benefit clients in the gas transmission and storage (midstream) market. The industry is being challenged to provide natural gas at lower cost, and at the same time, address public concerns about operating gas pipelines in heavily populated areas.

The DATUM C can be installed indoors or outdoors, greatly reducing infrastructure costs for new installations and retrofit applications. As an inline, motor-driven, close-coupled compressor, the DATUM C provides a highly efficient, compact solution for the midstream markets. Because of its sealless design and use of magnetic bearings, it eliminates the need for an oil lubrication system and shaft seals, making it more reliable and easier to install. As a completely enclosed system, it is environmentally "green," eliminating harmful, on-site emissions, as well as significantly reducing noise emissions issues that have concerned the industry when putting transmission stations near residential communities. It can even be placed in an underground bunker. We’ve just received an order to supply a DATUM C to a gas company in New York State, USA.

In another extension of Dresser-Rand technology and innovation, Dresser-Rand is testing a new product concept that will combine our DATUM technology with a unique rotary separation and packaging design. This will potentially provide huge cost-saving benefits for clients and real added value – lower life cycle cost, high reliability, lower energy consumption, lower installed cost and shorter installation and commissioning cycle time. We’re already in discussions with clients regarding the use of these concepts in many applications including sub-sea compression opportunities. You will read more on this solution in future issues of insights.

Another environmentally "green" application that Dresser-Rand is addressing is the supply of compressed natural gas (CNG) as one of the best alternatives to gasoline-powered vehicles. Dresser-Rand is responding to a global demand for CNG solutions via our Naroda, India manufacturing and packaging facility. This facility has the capability to offer manufacturing, packaging, operation and maintenance or total turnkey solutions for CNG applications.

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Candid Visions ....

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insights: What other developments can we expect from Dresser-Rand in the near future?

Dickson: We continue to invest in research and development projects that focus on product and service growth opportunities to help our clients address their operating needs. Globally, one of the most important areas of concern remains protecting people and the environment. I've already mentioned several applications where Dresser-Rand is going "green."

By continually striving to provide greater efficiencies with our DATUM line of compressors, we can continue to reduce energy consumption, associated fuel consumption and emissions by the drivers that power these compressors. Together with Dresser-Rand dry gas seals (using our patented groove design) installed on these and other compressors, we can help reduce harmful emissions significantly.

While noise pollution may not seem like a major concern, pipeline compression stations, oil and gas production platforms, and refineries are continually trying to protect their personnel and neighbors, as well as meet tougher noise-reduction requirements. Dresser-Rand's duct resonator array – a unique development in our efforts to design quieter machines – is revolutionary in its ability to reduce operating noise on new or revamped machines efficiently and cost effectively.

Another area we are investing in is our VECTRA™ power turbine that is integral to our gas turbine product line. The VECTRA turbine is highly efficient, compact, lightweight and easily maintained – attributes that have gained it acceptance in the marketplace. As is the nature of the gas turbine business, there is continuous upgrading of the power output provided by the gas generator. With Dresser-Rand's scalable VECTRA power turbine design, we can accommodate the upgrades and provide a modern solution for existing gas turbines. This is another exciting growth solution offered by our company.■

BW Dickson

Bradford W. (Brad) Dickson
Executive Vice President,
New Equipment Worldwide
Dresser-Rand Company

David Hargreaves
1944 – 2006

Clients and colleagues who knew Dave Hargreaves were saddened by his unexpected death on July 25.

Hargreaves was a long-time Dresser-Rand employee and a respected expert in the energy and refining industries. He spent many years assisting Dresser-Rand refinery clients worldwide with flue gas and hot gas expander applications. He had extensive knowledge in all areas of refining processes, and enthusiastically met any challenge, most recently in the areas of power recovery and alternative energy.

Dave Vincent, director, Global Business Solutions, at Dresser-Rand, a longtime friend and co-worker, remembered Hargreaves as a jovial spirit who was always optimistic. "He had unconstrained creativity. He was an 'out-of-the-box' kind of guy who would always find a way to make something happen. You could talk with Dave about almost any topic. Whether it was fine wines, computers or chemistry, Dave was very inquisitive."

Hargreaves was employed at Ingersoll Rand before joining Dresser-Rand in 1968. Most recently, he held the position of director, Global Business Solutions.

A resident of Barrington Hills, Illinois, at the time of his death, Hargreaves is survived by his wife, Susie, and three daughters, Alison, Katherine and Stephanie. He and his family were building a home in the Upper Peninsula of Michigan; the family plans to relocate there and carry out the plans they made together.

In lieu of flowers, contributions in his name can be made to Save the Wild UP (http://www.savethewildup.org/donate/) or the Brain Injury Association of America (http://www.biausa.org/donations.htm).

D-R Field Operations Responds To Challenge of Two Deadly Hurricanes

Martin Luther King, Jr. once said, "The ultimate measure of a person is not where they stand in moments of comfort and convenience, but where they stand in times of challenge and controversy."

During the 2005 storm season, which devastated the U.S. Gulf Coast, Hurricanes Katrina and Rita claimed nearly 2,000 lives, and caused more than $90 billion in damage. The impact of the storms on the region's oil and gas industries severely tested the ability of Dresser-Rand's clients to maintain operations -- and challenged D-R to concentrate efforts to help keep them operational. Through planning and teamwork, D-R helped numerous clients throughout the region get back online despite the many obstacles.

Hurricane Katrina first formed as a tropical storm in the Caribbean Sea on August 23, 2005. Following a brush with the southern tip of Florida, the storm moved westward into the Gulf of Mexico, and swelled to a Category 5 hurricane with winds of over 160 miles an hour. In the days that followed, Katrina would become one of the most deadly, powerful and costly Hurricanes ever to hit the U.S. mainland.

In addition to D-R's typical service workload for clients in the region, D-R was faced with providing emergency aftermarket services to key clients in the wake of the storms. The company's ability to respond was assisted by a proactive plan put in place in an attempt to anticipate client support requirements and assess D-R's response capabilities. Peter Salvatore, vice president and general manager of D-R's Field Operations group, established a game plan and appointed Mike LaFrate, director of D-R's technical services as the company's Katrina emergency support leader. LaFrate quickly gathered a team of experienced field project managers familiar with the affected client base and collectively they mapped out a strategy to establish contact with client personnel at all potentially impacted sites. These plans were compounded by the fact that D-R's own regional service center in Baton Rouge, Louisiana, lay directly in the path of Hurricane Katrina.

"The first task at hand was to ensure the safety and basic needs of our own employees, as well as our client's employees," said Jim Kinneary, D-R's director of Field Operations in the Southern and Latin America Region. "Many D-R employees opened their homes to provide client families and D-R men and women affected by the storm a place to stay until they were able to return to their homes or find alternate living arrangements."

The project team communicated with client site managers to offer immediate assistance and to alert them to whom they should contact once they were able to bring teams in to assess the damage and begin recovery efforts. "Beyond that, ensuring that our Baton Rouge repair facility was up and running also was critical," Kinneary said.

As the center of the U.S. oil and gas industry – Louisiana alone is responsible for approximately 30 percent of the nation's refining – the Gulf Coast region's energy infrastructure was hit hard. Due in large part to the efforts of Mike LaFrate's emergency support team, and the efforts of D-R's Baton Rouge repair center team, the facility was powered up and fully manned on Tuesday, August 30, and in the process of installing emergency communication equipment to secure full response capability.

"Not only was it challenging to mobilize the right personnel with the proper skill sets to handle the critical work," said Tim Bodin, field service manager for the Gulf Coast region at Dresser-Rand. "But we had to be creative in finding a way to house them near the affected sites. Evacuees and refinery personnel

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occupied all of the hotels and we looked at every possible solution, including the possibility of renting barges and using them as housing. We ended up setting up a small "city" of eight travel trailers in the D-R parking lot to provide accommodations for D-R personnel, as well as some clients. It was rough conditions with no utilities or reliable transportation in or out. We maintained the trailers as housing from September through mid-November, when we moved them to New Orleans to be used by personnel there."

One of the first situations addressed by D-R in the region involved assisting a major refinery in Pascagoula. The facility had been hit hard by storms previously, and efficient planning by the company and improvements to levies and back-up pump systems helped reduce the potential impact by Hurricane Katrina. After the team made contact with the client's emergency response team, and it was determined that the damage was not as severe as originally thought, standby compressors from the facility were routed directly to Houston to prepare them for quick exchange with damaged units on site, and to get the facility back online as quickly as possible.

Other facilities more heavily hit by the storm and the subsequent flooding would still require weeks to resume operations. In many cases, damage to the equipment and surrounding infrastructure was extensive, and clients' available personnel often were limited. During this time, D-R personnel focused their activities on prioritizing service and repair projects to meet the most critical needs first. D-R worked with clients operating unaffected sites to shuffle schedules around in order to allocate more resources to those plants most heavily damaged by the hurricane.

D-R also provided critical repair services to other Louisiana plants, including a refinery in Meraux. "We're very active at that site now doing revamp work to some of the equipment there," Bodin said. "This kind of machinery can take a beating from wind and extreme conditions. But water damage can be significant."

Anticipating the threat of the hurricane, another client shut down its refinery in Chalmette, Louisiana, before the storm's arrival. During the shutdown, the company called on D-R to help prepare the compressors in the plant to return to service. A team of D-R *Availability* PLUS (A+) engineers accompanied the client's employees into the plant to inspect and assess damage to the 20 compressors on site. Amazingly, none of the compressors was affected by water damage. But because of extensive damage to other areas of the plant, the facility was unable to restart until November 1. During that time, a crew of D-R personnel performed preventive maintenance on a number of compressors in the plant.

But Katrina was just the first of the two deadly hurricanes to batter the region. While the force of Hurricane Rita, which hit barely three weeks later, was less than Katrina, seven people perished in this storm. In addition, if the hurricane hadn't veered to miss a direct hit with the Baytown, Texas area, the impact on the U.S. petrochemical industry could have been catastrophic.

Smart planning by one D-R client helped it minimize the potential damage when Hurricane Rita struck. With expectations that the hurricane would strike directly at the company's Baytown location, the company shut down its refinery and chemical plant in a defensive action. After the hurricane passed on September 24, D-R provided the company with a 24-hour crew to get the rotating equipment ready for startup. Despite water damage to the thrust bearings on two turbines, the facility was ready to resume operation on October 5.

In addition to affecting numerous D-R clients in Texas, Hurricane Rita forced the temporary evacuation of D-R's own personnel from their Houston offices.

The hurricanes that struck the Gulf Coast region late in 2005 called for quick thinking and the ability of D-R's service and repair team to respond under difficult circumstances. "Perhaps the greatest challenge came from needing to provide a balance between the needs of our clients, and the needs of the individuals themselves, many of whom lost everything," LaFrate said. "I feel very privileged that we were able to help during this time, and I hope that years from now people will think we met the challenge." ■

"Volunteering is a wonderful way to help those in need, and it also helps remind people of how blessed they are for what they have. The value of a meal or a roof over your head can be lost in the day-to-day grind."—

Deanna Mills, Executive Administrative Assistant, Dresser-Rand

Dresser-Rand Employee Joins Volunteer Efforts And Helps Reunite Family

In the aftermath of Hurricane Katrina, people across the country rolled up their sleeves to help families begin the arduous task of putting their lives back together. In the midst of all the chaos, volunteers came together and gave freely of their time and resources to assist those in need. Among them, Deanna Mills, an executive administrative assistant at Dresser-Rand, found a way that she, too, could contribute.

Mills is no stranger to helping those in need. Through her interest in the human services field, an area that often needs volunteers to meet the needs of its non-profit organizations, she had found plenty of opportunities to assist those less fortunate. She became a regular volunteer at a women's and family shelter of the Star of Hope Mission in Houston, Texas.

"Volunteering is a wonderful way to help those in need, and it also helps remind people of how blessed they are for what they have," Mills states. "The value of a meal or a roof over your head can be lost in the day-to-day grind."

While volunteering, Mills met a man, his son and daughter-in-law. The man explained that he had become separated from his wife, father-in-law, and brother-in-law when they were picked up by a military convoy that was taking people for medical treatment.

"The man and his son and daughter-in-law came to Houston because they had been told that was where they were taking everyone," Mills explains. "In fact, he had no idea where they had been taken. His only hope of contact was a cell phone with a dead battery. He never let it go, even though there was no possibility it was ever going to ring. It was just heartbreaking."

Mills began making phone calls and looking for information on the Internet. She entered the man's wife's information into more than 12 databases and message boards. Seven hours later, she had a lead. Mills received a phone call from a woman in Pearland, Texas who had been surfing the net and came across one of Mills' message board entries. At that exact moment, this woman had also been watching television and saw the man's wife being interviewed on CNN! The only information Mills was given, however, was that the man's wife had been taken to a shelter in Atlanta, Georgia.

Mills immediately contacted CNN and within 30 minutes was able to get in touch with the man's wife. A local Houston church donated funds for three Greyhound bus tickets to bring the man's wife and family to Houston.

The success story immediately lifted the spirits of other evacuees and volunteers at the shelter. "It shed some light at a very dark time," Mills affirms. ■

CNG Delivery Companies Rely On Expertise And Compression Solutions

At some point in their development cycle, alternative fuels achieved enough acceptance and use to be considered mainstream. Compressed natural gas (CNG) is rapidly approaching that status as a cost-effective and environmentally friendly field source for natural gas vehicles (NGV) worldwide.

In the late 1990s, CNG was widely viewed as an experimental source of power. Government agencies looking for clean fuel alternatives, particularly for mass transportation, saw CNG as a potential solution to improving air quality in highly populated areas.

According to a 1998 study by the Natural Gas Vehicle Industry, funded jointly by the Gas Research Institute and the Natural Gas Vehicle Coalition, there were only 80,000 NGVs operating in the United States at the time. That figure was projected to expand to 1.6 million transit buses, delivery vehicles and taxis using CNG as their primary source of power by the year 2010. With an estimated 530 billion cubic feet of natural gas required to operate these vehicles, the need for 4.4 billion gallons of gasoline would be eliminated.

Barely halfway to this projected target date, NGVs have established a firm foothold in the marketplace, both in the U.S. and worldwide. The Natural Gas Vehicle Association (NGVA) estimates that there are nearly 130,000 NGVs in use today in the United States, and more than two million worldwide.

The impact of this growing market has favorable environmental implications. NGVA data show that motor vehicles powered by traditional gasoline and diesel fuel emit more than 60 percent of all carbon monoxide (CO) pollution, and in metropolitan areas more than 50 percent of all hazardous air pollutants. While these vehicles degrade air quality, a single CNG-powered bus as a mass transit vehicle can replace dozens of automobiles greatly reducing hazardous emissions.

As global oil prices edge upward, CNG remains one of the best alternatives to gasoline-powered vehicles. There's an available supply of natural gas, making this clean-burning fuel an extremely viable option. "For most of the world, the challenge remains to develop the infrastructure necessary to support a growing demand for CNG," said Ravi Sukhia, vice president, Dresser-Rand Asia-Pacific. D-R is a world leader in providing gas compression equipment for natural gas pipelines and CNG applications. "As the network of dispensing stations is constructed, the ability to provide a clean, readily available and inexpensive supply of the fuel will take off, and the number of vehicles using CNG will grow exponentially," says Sukhia.

While the traveling distance between fill-ups of the typical NGV currently is less than a typical gasoline-powered vehicle – ranging from approximately 125 to 200 miles – at current prices, the cost of powering an NGV is approximately 65 percent of the cost of powering traditional gasoline-powered vehicles, while greatly increasing the environmental advantages. Although, the initial investment in the car or bus, or the necessary conversion of an existing gasoline- or diesel-powered engine, would be an additional cost.

Most large metropolitan areas (which have the greatest need for clean fuels) already have the necessary lower pressure gas pipelines in place, providing fuel for industrial consumption and electric power generation. For CNG purposes, natural gas is supplied through the low-pressure gas distribution pipeline network. CNG "on-line" dispensing stations are constructed along the pipeline to compress gas to usable higher pressures and to supply NGVs. These stations also can be constructed where a distribution network does not exist through the use of portable storage containers, also called "cascades," in some areas. On-line CNG stations compress gas into the cascades, which are then trucked to areas not served by the pipeline.

"These lower pressure compressed natural gas pipelines typically transport gas at pressures ranging from one or two psig to 300 psig. But CNG characteristics require compressor packages to compress the gas to pressures ranging from 3,500 to 4,500 psig," Sukhia said. It is at these pressures that the gas is dispensed at the stations and stored in the tanks of the fleet vehicles. The compressor packages are supplied with an intelligent "priority panel" that senses the demand and opens the required valves to direct the gas to the specific dispensers at the required pressures. The dispensers sense the pressure in the gas tanks of the vehicles and fill them to the predetermined pressure limits. The final pressure and the size of the tank determine the quantity of the gas dispensed and the amount charged.

As with nearly any fuel source, the volatility of the natural gas demands that strict safety precautions be taken to ensure the safe use of CNG. "Stringent safety standards apply to all compressor packages," Sukhia said. "In addition, alarms and fire-fighting equipment are required on-site, as well as a high degree of preventive maintenance." Staffing around the clock and PLC-based control and monitoring systems are required.

As a leading supplier of equipment to the CNG industry, Dresser-Rand offers total turnkey solutions for any CNG application, and has had direct experience in the design, manufacture, and installation of more than 100 CNG fueling stations. "In the past three years alone, D-R has supplied 84 compressor packages for use in CNG, with more than 75 of those already in operation," Sukhia said. "D-R compression packages in CNG service have accumulated more than 400,000 hours of operating experience, with the longest running unit having in excess of 35,000 hours on the job. We also have received orders for multiple units to be delivered."

D-R manufactures several models of reciprocating compressors suitable for CNG applications. "The three-stage PHE compressor has really been the workhorse," Sukhia said. "The unit can be driven by either an electric motor or a natural gas engine. The direct-drive DR100 and the high-speed A-VIP (Valve-in-Piston) reciprocating compressor give clients two proven alternatives."

The PHE compressor, designed for efficient operation and ease of maintenance, is capable of delivering 800 SCFM of natural gas up to 5,000 psig.

The DR100 is a vertical, oil-free, air-cooled, reciprocating compressor that is capable of compressing from 100 SCFM to 500 SCFM of natural gas up to 5,000 psig. D-R's VIP range of compressors are used in more than 200 gas field compression installations worldwide, and are available in four different frame sizes, using up to 6,000 horsepower and pressures up to 7,000 psig.

D-R has responded to global demand for CNG solutions, particularly in the rapidly growing Asia-Pacific region. The company is already working to supply CNG compressor packages to the leading CNG distribution companies in the Asia region, and provide manufacturing, operation and maintenance from the D-R facility in Naroda, India.

"As CNG continues to expand in the United States and gains even greater acceptance in other regions

profile:
George Lentek

George Lentek

Problem Solving For Reciprocating Products Clients

The official job description specifies that the product manager plans, organizes, and controls the product line from conceptual stages through product life cycle in order to optimize profit and meet marketing, financial, and corporate growth objectives. But George Lentek knows that this description doesn't fully describe his role at Dresser-Rand.

As product manager for reciprocating products, Lentek views his role as that of a problem solver, and his position as the result of a lifelong ambition.

"My father was a machinist, so I grew up working with all sorts of mechanical things," Lentek said. "From the time when I was holding the drop light for him while he was working on the family automobile, I got to see up close how things worked and how they were fixed. I knew even then that I wanted to be an engineer."

After graduating in 1972 from the University of Illinois with a degree in Aeronautical and Astronautical Engineering ("I'm the proverbial rocket scientist," Lentek jokes), he joined D-R as a project engineer working on proposals and after-order engineering. Following that, he worked as a project manager on a number of major installations. In 1994, Lentek was promoted to product manager, and served briefly as manager of project development engineering.

One of his greatest challenges has been merging the products of the various legacy lines in the D-R family. "When we became Dresser-Rand, we had to rationalize the product line, incorporating the best features of Ingersoll-Rand, Worthington, and Clark, and making them consistent throughout the line," Lentek said. "We solved the problems through teamwork and by applying best practices. We also undertook a major modernization effort a dozen years ago to evaluate all of our cast cylinders to make certain we were taking advantage of the latest machining and foundry practices. Similarly, we upgraded our frames to make them the best in class against global competition."

Lentek acknowledges that the greatest challenge is anticipating the changing needs of D-R's global client base, and responding with practical solutions. "Certainly, our clients have been under tremendous pressure to reduce their costs. Maintenance costs, new equipment costs, and operating costs have increased, and clients are looking for ways to better manage these expenses. We help by designing equipment that is easier to maintain and runs for longer periods between shutdowns with lower energy costs.

"Many of our efforts also focus on helping clients deal with environmental issues, so many of our upgrade projects are directed at finding innovative ways to reduce fugitive emissions."

The efforts of Lentek and other key D-R personnel have led to stronger relationships with major clients. "In 1994, I was part of a team that put together one of D-R's first alliance agreements, the Shell / D-R Partnering Arrangement. We looked at doing business from a whole new perspective – by sitting on the same side of the table and working together to streamline the process so we could both reduce our cycle times and costs.

"We looked at mechanical requirements, support protocols, selection methods, essentially everything from the first phone call to the final shipment and commissioning. We spent several years refining the process. But it was hugely beneficial to both companies, and helped establish D-R as a global leader in alliance agreement expertise."

While working with clients to solve their problems has remained D-R's focus, much of Lentek's work has involved improving efficiency within his organization. "We are constantly improving our products and services to meet the changing needs of our clients. D-R currently is working to create Global Singular Processes to ensure that we take advantage of our best practices to make us more effective and efficient. A perfect example of this is the Corporate Product Configurator (CPC). It allows our client facing organization to select and configure our products quickly, completely and accurately."

"Cycle time to prepare proposals is dramatically reduced and content of proposals is more robust, helping the client to better evaluate our offering and begin engineering earlier -- and it aids our order entry and execution processes. In addition, our new ProSize program supports the Configurator by establishing a logic tree to define the rules of the process and uses all of the latest available data to provide consistency and accuracy. Getting better solutions to our clients faster is a big benefit for both them and us."

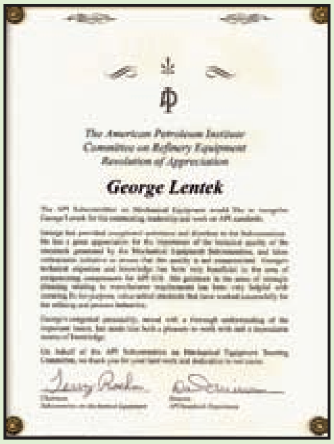
The results of these efforts have been an ever-increasing role with D-R clients worldwide. "We serve refineries, chemical and petrochemical plants, natural gas applications, gas field injection installations, landfill gas utilization, and much more. Process recips are used for everything from small 20 horsepower vent gas service that can fit on the top of your desk to 20,000 horsepower hydrogen service that are bigger than your house, with pressures from vacuum to 60,000 psi on polyethylene service. There is no shortage of interesting and challenging client applications in this business."

Lentek's expertise and leadership role in the industry has also led to him being recognized by the American Petroleum Institute for his work with that organization. (See related story below.)

"I get great satisfaction from working with clients to find the best way to address their compression needs, mechanical requirements and business methods," Lentek said.

When he isn't working, George and his wife, Sherry, enjoy hiking, as well as volunteering their time to support community projects by helping to build homes for neighbors and friends in their area. The couple recently celebrated 35 years of marriage. They have two adult daughters. ■

George Lentek Recognized For Leadership By API


The American Petroleum Institute
Committee on Refinery Equipment
Resolution of Appreciation

George Lentek

The American Petroleum Institute (API) Subcommittee on Mechanical Equipment (SOME) has recognized George Lentek, product manager, reciprocating products for Dresser-Rand Company, for his outstanding leadership and work on API standards.

SOME is an organization that develops and maintains a diverse set of mechanical equipment standards based on safety, performance, and reliability. These standards address the purchaser's total life-cycle costs by specifying minimum design requirements and, where applicable, default criteria, while being flexible enough to meet the needs of specific applications.

The award, signed by both the chairman of the Subcommittee on Mechanical Equipment and the director of the API Standards Department, includes the following passages:

George has provided exceptional assistance and direction to the Subcommittee. He has a great appreciation for the importance of the technical quality of the standards generated by the Mechanical Equipment Subcommittee, and takes enthusiastic initiative to ensure that this quality is not compromised. George's technical expertise and knowledge has been very beneficial in the area of reciprocating compressors for API 618. His guidance in the areas of strategic planning relating to manufacturer requirements has been very helpful with ensuring fit-for-purpose, value-added standards that have worked successfully for the refining and process industries.

George's congenial personality, mixed with a thorough understanding of the important issues, has made him both a pleasure to work with and a dependable source of knowledge.

"API plays an important role in the industry because it publishes standards that describe sound engineering practices for the design, operation, and maintenance of equipment," Lentek explained. "This helps keep everybody on a level playing field and ensures that equipment is safe and durable.

"Because API comprises both users and manufacturers, the standards reflect lessons learned from actual field experience as well as front-end design engineering. As API takes a more global perspective, we're looking to see how our standards coincide with those of other standards organizations such as ISO.

"I feel honored, especially when I think of the others who've been similarly recognized by API. We all work hard at our jobs and have extra responsibilities with things like standards writing, so it's nice to have someone recognize the extra effort.

"Dresser-Rand understands the importance of volunteering time to organizations such as API. Without the support of companies like D-R the process would fall apart."

API is based in Washington, D.C., and has offices in 27 state capitals. The organization represents more than 400 members involved in all aspects of the oil and natural gas industry. ■

engineer's notebook

Mechanism and Impact of Damper Seal Clearance Divergence on the Rotordynamics of Centrifugal Compressors

By *Thom M. Eldridge and Thomas A. Soulas*
Dresser-Rand,
Olean, New York, 14760, USA

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ABSTRACT

Damper seals (such as honeycomb and hole pattern seals) have been widely used in the turbomachinery industry to counterbalance destabilizing aerodynamic forces acting on the rotor system and to provide the necessary amount of damping for stable operation of the machine. Recent experience and research developments have focused the interest of the turbomachinery community on the dynamic characteristics of the divergent-taper damper seal. In addition to offering a review of the current literature on the subject of interest (in order to provide a comprehensive vision of the overall phenomenon), this paper extends the discussion for a better understanding of the mechanism and impact of damper seal clearance divergence on the rotordynamics of a rotor-bearing seal system (as applied to centrifugal compressors). The analysis of a damper seal alone is insufficient to assess the influence of this component on the rotordynamic stability of a turbocompressor. This paper will show the variation of a complete rotor-bearing-seal system's logarithmic decrement as a function of the hole pattern seal clearance divergence for a sample centrifugal compressor application, as analyzed with the proprietary, state-of-the-art rotordynamic software suite from Dresser-Rand. This divergence-based transition of system logarithmic decrement from positive to zero (thereby implying the onset of instability) leads to the definition of a "damper seal divergence stability threshold." Divergence in a damper seal can originate from numerous sources, including taper produced during manufacture, and pressure or thermal-driven distortion of the seal under operation. While small damper seal divergence may first produce an increase of the system logarithmic decrement, additional seal divergence has a dramatic effect on the first forward whirling mode natural frequency, as well as on the logarithmic decrement of that mode. This paper describes the analytical methods used to derive the stability of the rotor-bearing-seal system. It also presents a practical experience that stresses the necessity for a sound approach to properly evaluate the impact of a divergent damper seal on the stability of centrifugal compressors.

Keywords: Damper Seal, Stability, Rotordynamics, Centrifugal Compressor

INTRODUCTION

Damper seals such as honeycomb and hole pattern seals have found common application within turbocompressors as a means to reduce destabilizing aerodynamic forces acting on the rotor while providing the desired level of damping to produce stable operation of the machine [1,2]. Figure 1 shows the stator part of a hole pattern seal made from aluminum. Other materials may be used depending on operating temperature and nature of the gas being sealed. Some examples are graphitic cast iron and various polymers for hole pattern seals, and Hastalloy or stainless steel for honeycomb seals.

As applied to centrifugal compressors, damper seals may be installed at different locations in the machine, as shown in Figure 2. On a back-to-back compressor, a damper seal may commonly be found at the division wall (seal where the second section discharge pressure is broken down to first section discharge pressure, near center of the rotor). On occasion, a damper seal may also be located at the second section gas balance seal (seal where second section inlet pressure is broken down to first section inlet pressure, shown on right end of rotor). On a straight-through compressor, a damper seal may be found at the balance piston where the compressor discharge pressure is broken down to inlet pressure.

Moore, Walker and Kuzdzal [3], and Moore and Soulas [4] quantitatively demonstrate the positive effect of hole pattern seals on the rotordynamic stability of compressors by measuring the logarithmic decrement (log dec) at increasing discharge pressure conditions during full-load, full-pressure factory testing. The stabilizing effect of the hole pattern seal originates from the positive damping produced by the seal at the first forward whirling mode of the system [5]. The experimental and analytical data presented by Childs and Wade clearly show that the hole pattern seal's rotordynamic coefficients (stiffness and damping) depend on the excitation frequency which is one of the major characteristics of damper seals in general.

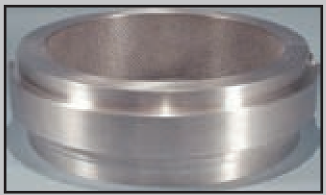

Figure 1 - Hole Pattern Seal

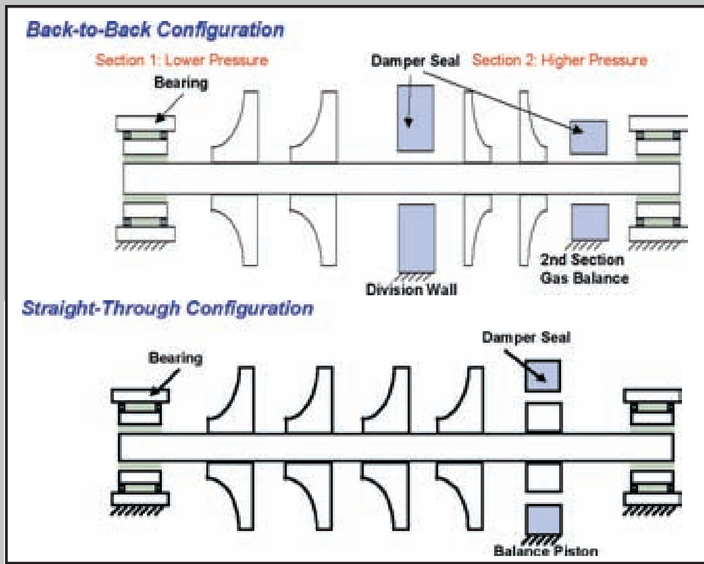

Figure 2 - Back-to-Back and Straight-Through Centrifugal Compressors with Damper Seals

LITERATURE REVIEW OF RECENT EXPERIENCE AND DEVELOPMENT

Recent field and test stand experiences, along with research developments, have focused the interest of the turbomachinery community on the dynamic characteristics of the divergent-taper damper seal. A divergent-taper damper seal is a seal in which the damper seal clearance diverges (exit clearance is larger than the inlet clearance in operation). Even if the seal is not purposely manufactured with a divergent clearance, deflection because of pressure forces, as well as manufacturing tolerances, may cause such a diverging profile.

NOMENCLATURE	
[C]	Damping matrix
[C_s]	Seal damping matrix
C_{ij}	Element of damping matrix
[K]	Stiffness matrix
[K_s]	Seal stiffness matrix
K_{ij}	Element of stiffness matrix
[M]	Mass matrix
s	Complex eigenvalue
X	Displacement vector
$\dot{X}$	Velocity vector
$\ddot{X}$	Acceleration vector
F(t)	Force vector
δ	Logarithmic decrement
λ	Real part of complex eigenvalue
$\omega\delta$	Damped natural frequency (imaginary part of complex eigenvalue)

Camatti et al., Kocur and Hayles, and Tecza et al. [6-8] describe damper seal clearance divergence as producing a destabilizing impact on rotordynamics in centrifugal compressors. Each of these papers presents a field or test stand experience where damper seal divergence is identified as the cause of rotordynamic instability. These theories are further bolstered by the elimination of said instability through specific steps taken to address the damper seal clearance divergence.

Camatti, et al. [6], describe a back-to-back compressor with a rotordynamic instability on the test stand which was attributed to damper seal divergence. The instability was eliminated with a convergent taper machined into the seal, along with the application of shunt holes providing deswirl of the gas at the entrance of the seal. Camatti, et al. note the analytical tools in use were unable to predict the rotor becoming unstable. However, the rotordynamic analysis did identify the depression of the first forward whirling mode of the system caused by the addition of negative stiffness originating from divergence of the damper seal.

Kocur and Hayles [7], describe a straight-through compressor with rotordynamic instability in the field. A low-frequency vibration appeared following the replacement of a toothed labyrinth balance piston seal with a honeycomb seal. The honeycomb seal became fouled because of gas deposits. The excess fouling concentrated near the inlet of the seal was believed to have essentially produced a divergent taper. Kocur and Hayles detail the analytical process that led to the replacement of the honeycomb seal with a toothed labyrinth seal and the elimination of the rotordynamic instability. Negative stiffness, produced by the "divergent" clearance of the balance piston honeycomb seal, reduced the first whirling mode of the system to near six percent of running speed. This negative stiffness, compounded by the diminished support stiffness from the damper bearings when subjected to this low frequency excitation, was identified as the source of the low-frequency vibration. Kocur and Hayles were successful in modeling the rotor system, including the divergent seal geometry, and predicting both the instability and the depressed first whirling mode frequency.

Tecza, et al. [8], present a statistical approach to quantify the potential for instability caused by damper seal divergence through a comprehensive "worst-case" analysis. They include application of this method to a back-to-back compressor that experienced instability on the test stand. This instability was attributed to damper seal divergence. The tools employed were able to demonstrate the potential for the analyzed system to result in instability. Following the addition of a convergent taper machined hole pattern seal, the compressor became rotordynamically stable.

In contrast, Smalley, et al. [9], present an analytical evaluation suggesting that damper seal divergence can contribute to improved stability of a rotor system. This approach is supported by testing performed on isolated damper seals with divergent clearances. The results of this testing, when applied to analysis of rotor-bearing-seal systems, indicate that increased effective damping (and therefore rotor stability) can be achieved with such a divergent taper damper seal. A divergent honeycomb seal was manufactured for back-up use on a large, straight-through compressor (which was predicted to have a negative log dec with either a toothed labyrinth or zero-taper damper seal). Low levels of subsynchronous vibrations were reported, but not at a level considered dangerous; therefore, the labyrinth seal was not replaced and the stabilizing influence of the divergent taper seal was not verified. Smalley, et al., note

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that attention must be paid to the effect of a divergence on a seal's effective stiffness, which can result in changes to the frequency of the rotor system's first whirling mode, and consequently the seal's effective damping.

These apparently contradictory conclusions leave the rotordynamic community uncertain as to how divergent clearance in a damper seal should be regarded -- as a potential cause of highly undesirable, uncontrolled vibrations, or as a means of eliminating those same uncontrolled vibrations.

Fortunately, what appears to be a division in thought on the effects of damper seal divergence is actually two snapshots of the expected behavior when viewing the continuum of response to increasing divergence in damper seal clearance. That this continuous behavior transitions from desirable to undesirable rotordynamic performance strongly emphasizes the importance of understanding the phenomena, and the interaction of multiple components of this complex rotor-bearing-seal system. This understanding then supports critical design decisions on the intentional convergent or divergent tapering of a damper seal to meet the needs of a particular rotor-bearing-seal system.

This paper seeks to describe the progressive behavior of a rotor system including a damper seal, from the perspective of increasing damper seal divergence (including possibly starting with some convergence), and the impact on rotor system stability. This approach strives to improve understanding of the system behavior as an extension to the more commonly presented view of damper seal rotordynamic coefficients over a range of frequency.

MECHANISM OF INSTABILITY

Much of the recent work discussing rotordynamic instability in centrifugal compressors has focused on hardware that addresses sources of the instability. Instability has been associated with an excess of excitation energy (cross-coupled stiffness or K_{xy}), which has been addressed with tilting pad journal bearings or swirl brakes/shunt holes, or a lack of damping to remove said energy from the rotor system, which has been provided by damper seals [1] or damper bearings [10]. Recently, negative stiffness, or a loss of stiffness, originating from a divergent-clearance damper seal has been identified as a contributor to rotordynamic instability [6-8]. The present authors believe the progressive development of negative stiffness, and subsequent impact on the frequency of the first whirling mode of the rotor-bearing-seal system, is essential to understanding and predicting the phenomena of instability caused by damper seal divergence. This thorough understanding is a necessary component to making appropriate design decisions about potential tapering of a damper seal, with the ultimate goal of ensuring stable operation of the equipment under service conditions.

The rotordynamic coefficients developed by a damper seal are largely frequency-dependent as described in Figure 3 [5,9]. Furthermore, the stability enhancing characteristics (as described by these rotordynamic coefficients) of a damper seal that lead to its application in the most challenging rotordynamic application range (higher speed, power and discharge pressure [3]) are positively correlated with the excitation frequency. Thus in the presence of a divergent taper damper seal, as the first whirling mode (w_d) falls (in response to the introduction of negative stiffness into the system), the seal provides less of the expected positive impact. The cause of the falling frequency (negative stiffness) also strengthens with this progressive change in frequency. This results in a rapid swing from stable to unstable behavior as the frequency falls into the transition range.

[1] In the simplest form, a natural frequency can be described as:

$$\omega = \sqrt{K/M}$$

The principal geometric condition necessary to produce negative stiffness is divergence in the clearance of a damper seal. As the magnitude of divergence grows, the beneficial damping increases, as does the undesirable negative stiffness. The net effect of increasing divergence can initially produce improved stability in cases where the damping increases faster than the negative stiffness drives the first whirling mode (w_d) lower. This balance is described by effective damping (defined in Equation 1) which is a reasonable proxy for stability. It can be seen that stability is enhanced by addition of direct damping (C_{xx}), and diminished with the addition of cross-coupled stiffness (K_{xy}). A third influential input to the stability is the

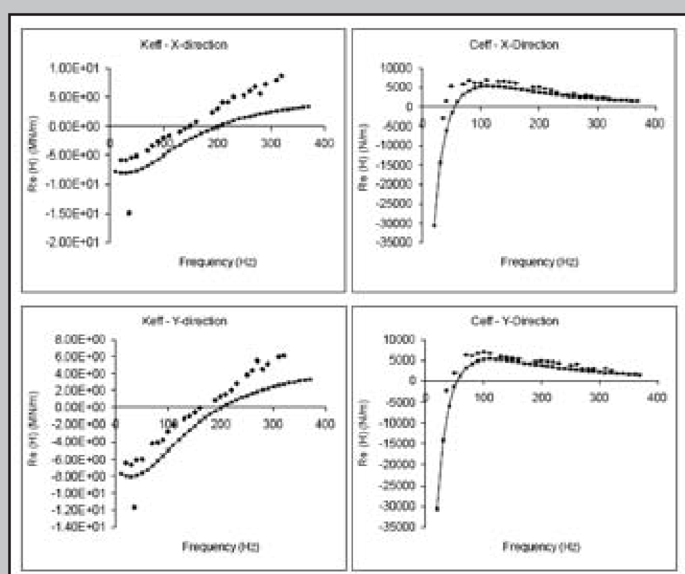

Figure 3 – Smalley, et al. [9] Previously Presented Predicted (Line) and Measured (Points) Effective Stiffness and Damping Values vs. Frequency for a Diverging Taper Honeycomb Seal (DTHCS) at 22,000 RPM, 18.27 Bar Supply Pressure and "High Clearance"

frequency of the first whirling mode (w_d), as this value falls toward zero, the negative term rapidly dominates the right side of Equation 1. (1)

$$C_{eff} = C_{xx} - \frac{K_{xy}}{\omega_d}$$

When a rotor-bearing system is relying on the damper seal for stability (requires additional "damping" in the traditional view), the effective damping (C_{eff}) of the damper seal must be positive to achieve system stability. Even if the geometry of the seal ensures a positive C_{eff}, a thorough analysis must be undertaken to ensure that the magnitude of C_{eff} provided by the seal is sufficient to produce a stable system (including worst case effects of seal divergence, bearing and damper clearance, etc.). It should be noted that calculating the effective damping (C_{eff}) of the seal alone requires some knowledge of the entire system (including the seal itself) in order to obtain the first whirling mode frequency (w_d).

The production of negative stiffness by divergent damper seals has been described and verified by a number of sources. Figure 3 presents an example of isolated seal testing for rotordynamic coefficient identification [9] where the existence of negative stiffness can clearly be observed at lower frequencies (typically below 150Hz). By inference, the presence of negative stiffness is observed through depression of the first whirling mode. This effect is verified during instability events in the field or on test where the first whirling mode is evident at significantly lower frequencies than would otherwise be expected [6-8].

ANALYTICAL APPROACH TO IDENTIFY INSTABILITY

From a rotordynamics perspective, evaluation of the stability of a centrifugal compressor is a rotor-bearing-seal system problem (as illustrated in figure 4). Numerous inputs representing the characteristics (typically mass, stiffness and damping) of the impellers, rotor, bearings and seals are incorporated into this analysis. Some of these inputs are depicted in figure 4.

A centrifugal compressor rotor can be modeled using finite element techniques resulting in the general linear system of differential equations, (2)

$$[M]\ddot{X} + [C]\dot{X} + [K]X = F(t)$$

For the homogeneous solution (free vibration), a harmonic solution is assumed as,

$$X(t) = \overline{X} e^{st} \qquad (3)$$

Each eigenvalue may be solved for and takes the form of,

$$s = \lambda \pm \omega_d i \qquad (4)$$

The imaginary part of each eigenvalue defines its damped natural frequency, while the real part (l) determines the level of damping or stability. The logarithmic decrement (d) is another common way to state the level of damping for a mode of the system:

$$\delta = \frac{-2\pi\lambda}{|\omega_d|} \qquad (5)$$

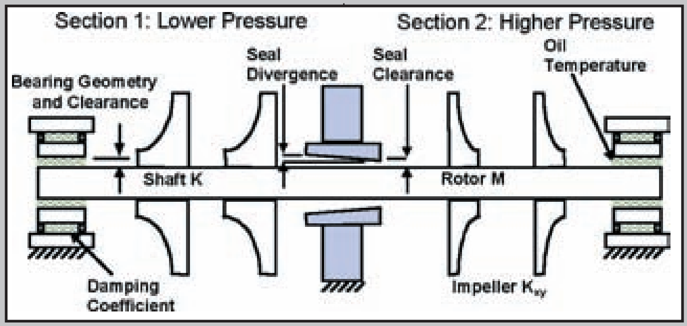

Figure 4 - Rotor-Bearing-Seal System for a Back-To-Back Centrifugal Compressor (Example) with a Diverging Damper Seal Clearance at the Division Wall

For this approach, the destabilizing cross-coupled stiffness arising from the centrifugal impellers is estimated using a modified form of the Wachel number [11]. The damper seal coefficients are determined using the techniques of Kleynhans and Childs [12] as calculated by the program ISOTSEAL developed by Texas A&M University. The synchronous tilt-pad bearing coefficients originate from the work of Nicholas, et al. [13].

Bearing and seal reaction forces may be modeled by linear stiffness and damping matrices: (6)

$$[K_s] = \begin{bmatrix} K_{xx} & K_{xy} \\ K_{yx} & K_{yy} \end{bmatrix}, \quad [C_s] = \begin{bmatrix} C_{xx} & C_{xy} \\ C_{yx} & C_{yy} \end{bmatrix}$$

These component models are incorporated into an automated rotordynamic software suite developed at Dresser-Rand, previously described by Ramesh [14], where a transfer function-based eigenvalue analysis is performed.

From the eigenvalue analysis, the logarithmic decrement (log dec) of the first forward whirling mode for the rotor system can be evaluated. A positive log dec indicates stable operation of the compressor, while a negative log decrement indicates instability is expected. The log dec of the mode of interest depends directly on the effective damping (C_{eff}) present in the rotor system. Equation 1 shows that effective damping (C_{eff}) of the system, and therefore the log dec, decreases with decreasing direct damping (C_{xx}), decreasing mode natural frequency (w_d), and increasing cross-coupled stiffness (K_{xy}). In turn, the modal natural frequency (w_d) decreases when the rotor system direct stiffness (K_{xx}) decreases.

The analytical tools described above can be used in conjunction with component testing (which produces rotordynamic coefficients for bearings and seals) in order to evaluate the impact of damper seal clearance profile on the rotor stability of a rotor-bearing-seal system. Figures 5 and 6 show the variation of a complete rotor-bearing-seal system first forward whirling mode frequency and logarithmic decrement as functions of the hole pattern seal radial clearance divergence. Convergence can be described as "negative divergence." For this example, an arbitrary centrifugal compressor was analyzed with the aforementioned rotordynamic software from Dresser-Rand.

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PROGRESSIVE IMPACT ON SYSTEM STABILITY CAUSED BY INCREASING DAMPER SEAL DIVERGENCE

Figures 5 and 6 clearly encapsulate the mechanism of rotor instability because of damper seal divergence as described earlier. While in this particular case, small damper seal divergence first produces an increase of the system logarithmic decrement (log dec rises to 9.5 with 25 microns, 1 mil, of divergence), the frequency of the first forward whirling mode has begun to fall because of negative stiffness. Additional seal divergence has a dramatic effect on the first forward whirling mode natural frequency, as well as on the system logarithmic decrement. The continuous depression of the first forward whirling mode natural frequency with increasing damper seal divergence eventually results in a drop of the rotor system log dec. Log dec becomes negative at the "damper seal divergence stability threshold" which is near 66 microns (2.6 mil) of radial divergence in this particular and arbitrary case. For comparison purposes, typical compressor hole pattern seal radial clearances range from 200 microns (8 mil) to 500 microns (20 mil), largely depending on the size (diameter) of the application. This log dec variation corresponds to the damper seal effective-damping values calculated at the system first forward whirling mode natural frequencies for each seal divergence step (Figure 7). This frequency (and the seal divergence necessary to produce instability) corresponds closely to where the log dec and effective damping begin to fall through zero.

On the other hand, for increasing damper seal convergence, the log dec reduction is smoother and followed by an increase of the mode natural frequency (also depicted in Figure 5 and 6). This consistent behavior depicted in Figures 5, 6 and 7 continues with increasing convergence. In spite of more robust dynamic behavior of the convergent damper seal, designing a seal with excessive convergence (to eliminate the potential for instability because of seal divergence) is undesirable. One effect of unnecessary convergence is the increase of system stiffness that serves to raise the first forward whirling mode. In extreme cases, this can result in that mode being pushed near the running speed of the equipment, resulting in excess vibration levels. From an aerodynamic performance standpoint, the lowest leakage is obtained with a cylindrical geometry.

The damper seal divergence stability threshold value described in Figure 6 depends on the major, relevant rotordynamic parameters involved in the system analyzed, namely impeller excitation, shaft stiffness, damper seal minimum clearance, journal bearing rotordynamic characteristics, and damper bearing damping (if any). To support necessary design decisions, this divergence threshold has to be compared with manufacturing tolerances and expected levels of seal deflection in real applications. These expected seal deflections could be derived from a finite element analysis (FEA) or other methods. Tecza [8] further describes a statistical method for performing a "worst-case" evaluation of compressor stability over these various inputs.

From a practical standpoint, an upper bound to damper seal divergent taper can be defined based upon a knowledge of the seal and support structure interaction, a history of deflection modeling along with controlled manufacturing

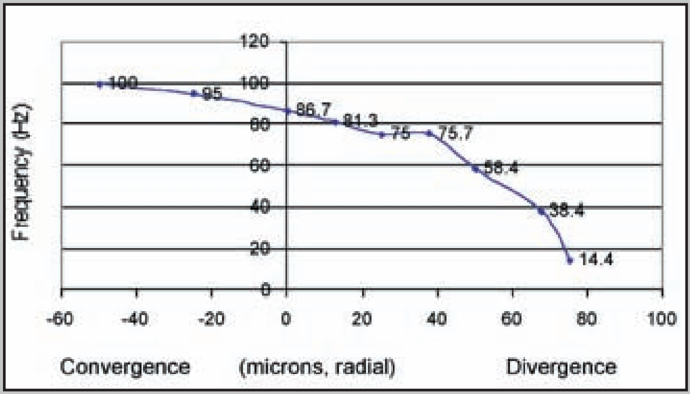

Figure 5 - Frequency of First Forward Whirling Mode vs. Damper Seal Radial Divergence for Arbitrary Compressor

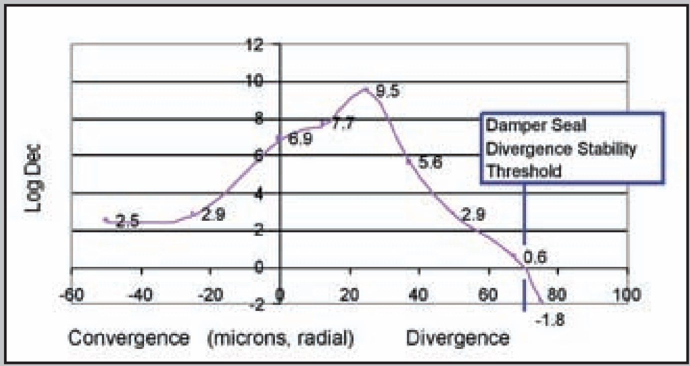

Figure 6 – Log Dec of First Forward Whirling Mode vs. Damper Seal Radial Divergence for Arbitrary Compressor

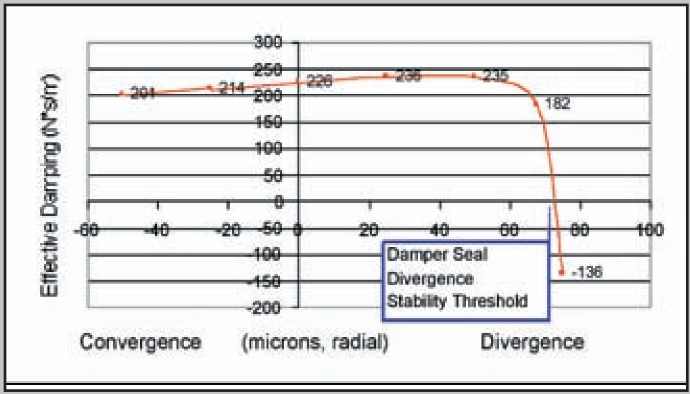

Figure 7 – Damper Seal Effective Damping (C_{eff}) vs. Damper Seal Radial Divergence for Arbitrary Compressor

methods and tolerances. As long as a particular machine's damper seal divergence stability threshold exceeds this upper bound of damper seal divergence, rotordynamic stability can be expected. This approach provides an effective screening process.

This proposed system approach enables proper evaluation of the impact of divergent damper seals on the rotordynamic stability of centrifugal compressors and stresses the necessity for a sound and accurate, case-by-case analysis if one wants to optimally design damper seals for leakage reduction and rotor stability purposes.

AN EXAMPLE OF FIELD INSTABILITY

The authors were recently involved in diagnosing a centrifugal compressor experiencing rotordynamic instability on start-up following a revamp. The compressor has six stages, straight-through configuration, tilt-pad journal bearings with squeeze film dampers and hole pattern damper seal at the balance piston, with a bearing span to rotor bore ratio of 10, bearing diameter of 89 mm (3.5 inches), damper seal nominal diameter of 178 mm (7 inches) and pressure ratio of 4.5:1. Before the revamp, the unit had a toothed labyrinth at the balance piston location and there were no indications of instability. The original unit clearly met all rotordynamic criteria of American Petroleum Institute (API) 617 - Fifth Edition, to which the compressor had been built.

On start-up, while operating at maximum continuous operating speed (MCOS) of 14,060 rpm, the unit experienced a sub-synchronous vibration (SSV) at 6.5 percent of rotational speed (900 cpm). The SSV peaked near 96 microns peak-to-peak (3.8 mil) and was eventually controlled by the machinery protection system. The behavior of this instability onset can be viewed in Figure 8 from 16:45:36 through 16:46:21. Subsequent analysis of the rotordynamics indicated that the system could be expected to become unstable with 47 microns (1.8 mil) of radial divergence (damper seal divergence stability threshold = 47 microns). Furthermore, pressure and temperature-based FEA of the compressor components predicts a collective 76 microns (3 mil) of divergent radial deformation in the balance piston and seal. With this magnitude of seal divergence, the first whirling frequency was expected to be ~800 cpm, which compares favorably with the 900 cpm experienced in the field.

Figure 9 details the predicted log dec for various configurations of the balance piston seal. Both the rotor-bearing system ("Rotor and Bearings alone") and the rotor-bearing-seal system with a toothed labyrinth balance piston seal with swirl brakes and shunt holes ("Toothed Labyrinth Seal") are predicted to have positive log dec values, 0.5 and 0.67 respectively. While these log dec values compare favorably with the API 617 - Seventh Edition stability requirement for a log dec greater than 0.1, there is insufficient stability margin (that is, robustness or ability to tolerate more excitation force (K_{xy}) than predicted and remain stable) to meet the original equipment manufacturer's guidelines. Thus a damper seal with swirl brakes and shunt holes is prescribed. A cylindrical hole pattern seal, also with swirl brakes and shunt holes, ("Cylindrical HPS") is predicted to improve the stability considerably over the toothed labyrinth seal, with a log dec of 1.72 vs. 0.67.

Once the impact of 76 microns (3 mil) of radial damper seal divergence caused by deformation is incorporated into the analysis, the system is no longer predicted to be stable ("Divergent HPS"). The damper seal divergence stability threshold has been exceeded, analytically shown as the log dec falls to –2.4. In the final analysis case (representing a modified seal), the damper seal has received a 102 micron (4 mil) convergent radial machined taper to counteract the effect of the deformation, resulting in a damper seal with net 25 microns (1 mil) of radial convergence and a predicted log dec of 1.35 ("Convergent HPS").

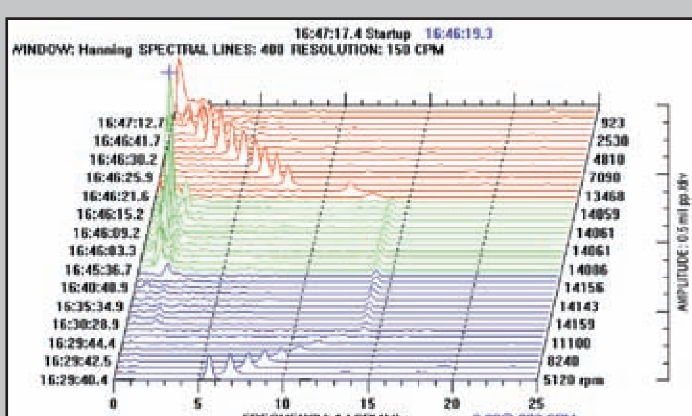

Figure 8 - Waterfall Plot of Six Stage Compressor Experiencing SSV Caused by Rotordynamic Instability

Figure 10 depicts the stability and frequency vs. divergence behavior of this system (similar to Figures 5 and 6 for the arbitrary compressor). It can be observed that the damper seal divergence stability threshold is near 47 microns (1.8 mil) of radial divergence. Also evident in this case is the approximate location of the optimal level of divergence (to produce the maximum log dec) that is located on the divergent side of the graph. The "Cylindrical HPS" and "Convergent HPS" log dec values given in Figure 9, corresponding to 0 and 25 microns (0 and 1 mil) radial convergence, differ from the log dec values given in Figure 10 for the same convergence levels in part because of variation in average clearance associated with the modification of the existing seal.

After machining a 102 micron (4 mil) convergent radial taper into the balance piston hole pattern seal, and re-assembling the compressor, the unit successfully restarted without incident. No evidence of the SSV was found, and the frequency of the first peak response (~5,500 cpm) increased only slightly. This value compares

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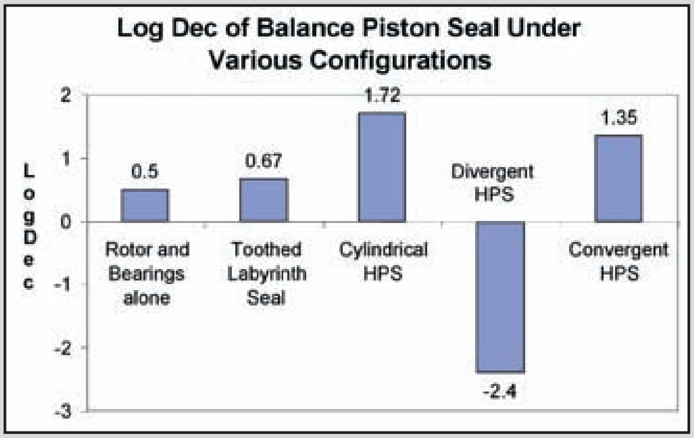

Figure 9 - Predicted Log Dec for Various Balance Piston Seal Configurations Evaluated for Field Instability Example Compressor

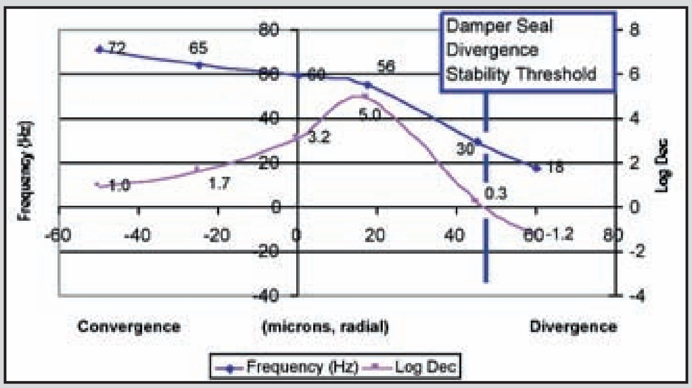

Figure 10 - Frequency and Log Dec (of First Forward Whirling Mode) vs. HPS Radial Divergence for Field Instability Example

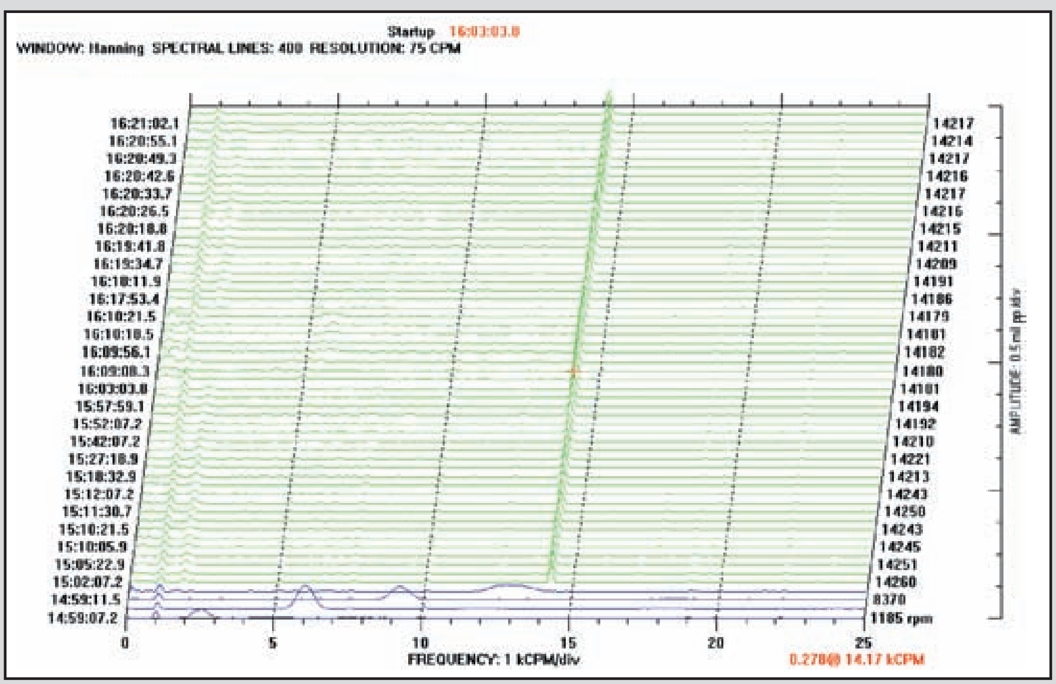

Figure 11 – Final Waterfall Spectrum from Field Instability Example Showing No Evidence of SSV After Installation of Convergent Machined HPS

Mechanism and Impact of Damper Seal...

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favorably with the first critical frequency predicted for this rotor-bearing-seal system of 5,500 rpm. Figure 11 is a waterfall of the vibration spectrum following the application of the convergent taper seal. The machine showed no signs of SSV while being exercised across its entire map. The full analysis and correction process was completed in less than a week.

CONCLUSIONS

The understanding of rotordynamic instability of centrifugal compressors caused by damper seal divergence is progressing. As can be expected with any recently exposed phenomena, numerous perspectives are being offered to define and predict this behavior. This paper has sought to present the first forward whirling mode frequency, stability and effective damping of a rotor-bearing-seal system as a function of the divergence of the damper seal. It is expected that this perspective will assist the reader in gauging the “sensitivity” of machines to this phenomenon relative to the typical magnitude of deformation and manufacturing controls present in turbomachinery internal components.

Pre-machined convergence of a damper seal can be a solution for instances of excessive deformation. However, the negative impacts of excessive convergence include critical speed increase, potentially pushing it up in the speed range, and aerodynamic performance loss because of higher leakage through the damper seal. The use of convergent machine seals must be accompanied by an understanding of what deformations occur in similar seals, and a thorough evaluation of the “damper seal divergence stability threshold” to arrive at an appropriate value of taper.

There can be a predictable, positive effect on stability because of small values of divergence. In some cases the transition to a negative effect, and instability, is sharp. The transition typically occurs over a small change in divergence. The positive damping impact is also over a narrow range of divergence. Careful consideration should be exercised when purposely employing divergent damper seals in an effort to provide stability for an otherwise unstable rotor design. As Tecza [8] describes, assembly and manufacturing tolerances provide uncertain, additional sources of seal divergence that can be analyzed with a statistical evaluation of "worst case" conditions.

Kocur, Tecza [7,8] and the present paper have shown that accurate prediction of stable and unstable rotor behavior is possible using existing rotordynamic tools. Accurate prediction requires the damper seal geometry to be modeled under operational temperature and pressure loads. However, a consistent design of the seal and support structure, accompanied by adequate controls of manufacturing methods and tolerances, can allow the original equipment manufacturer to define an upper bound of seal divergence. This value can then be used in a screening analysis of machines for susceptibility to damper seal divergence driven instability, offering an alternative to extensive analysis on a machine-by-machine basis.

REFERENCES / BIBLIOGRAPHY

A complete list of references and bibliography are available upon request. ■

For additional technical papers, visit our website at: www.dresser-rand.com

Dresser-Rand Expands Ability to Serve Equipment Operators Globally

To better serve its clients and their installed equipment population worldwide, Dresser-Rand Company has opened a new office in Bethlehem, Pennsylvania, as the base for a team of knowledgeable and experienced personnel who will provide additional industry-leading technical capability and capacity to support the rotating equipment needs of D-R® clients.

Equipment to be served includes turbo compressors (axial and centrifugal), hot gas expanders and steam turbines. The office is a part of Dresser-Rand's Product Services organization. It will focus on technical solutions for revamps and upgrades for engineered equipment.

Ken Schoeneck, director of Engineered Solutions at Dresser-Rand, will direct the new team whose members average more than 22 years of global experience working on turbomachinery produced by manufacturers throughout the world. "This team further strengthens Dresser-Rand's offering in engineered solutions for the full range of rotating equipment independent of the original manufacture."

According to Schoeneck, the Bethlehem team includes engineering, drafting, analytical, application and project execution resources, all of which are closely aligned with Dresser-Rand worldwide operations to leverage best practices and technologies. The team is fully staffed to support Dresser-Rand locations globally on a wide variety of projects ranging from product upgrades to revamps and new equipment. "Supporting existing equipment in the field with engineered solutions demands a knowledgeable staff of experienced personnel who can support client requirements," Schoeneck explained.

"Together with the other Dresser-Rand technical centers of excellence, this team will be available to enhance service to our global clients who operate a broad range of rotating equipment. They'll have direct, full access to Dresser-Rand technology, engineering and support services. ■

global visions

Dresser-Rand Announces Product Training Programs

Comprehensive schedule of training programs designed for operations and maintenance personnel

After more than 30 years of training operation and maintenance personnel worldwide, Dresser-Rand Company (NYSE: DRC) continues to provide high-quality product training programs designed to help clients reduce equipment maintenance costs and increase reliability. Product Training is offered for centrifugal compressors, gas turbines, steam turbines, low-speed process gas reciprocating compressors, high-speed separable gas field compressors, and control systems.

D-R courses continue to evolve to keep up with technology advances, making them the most current, flexible, and cost-effective, state-of-the-art courses in the industry. D-R's steam turbine and reciprocating compressor training departments are offering many of their factory course topics in the form of short courses. Related courses are held in succession, allowing students to attend one or all of the courses held in one of many locations across North America. Many of these courses include classroom lecture and hands-on workstations, affording the student the opportunity to fully understand the topic presented.

New this year are individual two-day courses for operators of steam turbines and reciprocating compressors. These courses were designed to help operations personnel with their daily responsibilities of starting, stopping, loading, and troubleshooting the two products. The courses are being offered at locations across North America and more information can be accessed on the company web site.

Dresser-Rand's Web-Based Training (WBT) course library continues to grow. With an emphasis on the practical aspects of machine reliability, repair, and troubleshooting, these intermediate-to-advanced level WBT courses are designed for operators, mechanics, supervisors, and engineers. Dresser-Rand partners with well-established WBT hosting organizations that support the petrochemical industry. These business relationships give clients easy access to D-R's WBT courses and training records through learning management systems (LMS).

"As always, customized programs specific to a client's machinery can be arranged if desired," said Mark Jones, training manager at Dresser-Rand. "If there's a group of people to be trained from a specific facility, we'll research the equipment records and provide a program that is matched to that machinery. Our instructors can travel to a client's site to conduct the course, keeping travel costs to a minimum."

All instructor-led, classroom and hands-on programs are taught by field-experienced, full-time Dresser-Rand instructors, technical engineers and field service representatives. Courses are offered at D-R factory training centers in upstate New York, Houston, and various regional service centers. Clients outside the U.S. can participate in programs offered at training facilities in Le Havre, France; Kongsberg, Norway; Campinas, Brazil; and Kuala Lumpur, Malaysia. Customized programs also are conducted worldwide at client sites. Hands-on, interactive courses using full-size equipment are conducted throughout North America, as well as the Dresser-Rand training center in Le Havre.

If open-registration courses are not held in a location convenient to a particular company, and the company is willing to host the training program, D-R will advertise, market, and conduct the course at the client's facility. This eliminates travel costs and provides other clients in the area with the opportunity to attend and share the reduced travel and living expenses.

For detailed information about any of the classroom, hands-on, or WBT programs, clients can view D-R's 2006 product training

schedule or register for courses by visiting the D-R web site at: www.dresser-rand.com, under "Product Training 06." To receive a copy of Dresser-Rand 2006 training literature by mail, requests may be made by calling (607) 937-2303 or by sending an email to: literature@dresser-rand.com.

Students can register for any Dresser-Rand program by phone, fax, or the company web site. In the United States, credit card payment is accepted.

Dresser-Rand Equipment Helps China Produce Clean Alternative to Petroleum

Dresser-Rand (NYSE: DRC) has secured a $17 million contract for compression equipment with Shenhua Coal Liquefaction Corporation, Inner Mongolia, China.

D-R will provide Shenhua Coal Liquefaction Corporation with four six-throw BDC process reciprocating compressors. The equipment will be used in hydrogen make-up for their coal liquefaction process.

The Shenhua Group began its aggressive coal liquefaction project last year and expects operations to begin in 2007. In the liquefaction process, low-grade coal is used to produce ultra-clean, low-sulfur, synthetic fuel oil. This development is part of China's plans for creating an adequate fuel supply for their rapidly growing economy. China is the world's second-largest oil consumer. With oil prices currently at more than $70 per barrel, China is in need of an economical alternative to petroleum. Coal liquefaction is proving to be a feasible solution.

D-R credits the contract to the team effort on behalf of D-R employees worldwide. "Various people throughout D-R came together to create a successful solution for Shenhua," states Wilson Chiu, project development manager at Dresser-Rand. "We had employees from Beijing, Painted Post, Olean, San Diego, Houston, and Kuala Lumpur collaborating on this project."

Motiva Selects Dresser-Rand for part of Proposed Port Arthur Refinery Expansion Project

Motiva Enterprises LLC is finalizing contracts with Dresser-Rand Company (NYSE: DRC) for the purchase of engineering resources and support relating to the procurement of compression equipment and start-up services for the proposed expansion of its Port Arthur, Texas refinery. The selection is consistent with Motiva's capital investment strategy to increase its refining capacity for transportation fuels in the U.S.

According to Dresser-Rand, the company will be requested to supply assorted equipment, including turbo-compressor trains, reciprocating compressor units, and start-up services. Orders may be released sequentially during the next six to nine months. None of these orders is currently in the company's backlog. If the equipment orders are placed, Dresser-Rand projects delivery of the equipment during the fourth quarter of 2007 and the first quarter of 2008.

The equipment will be used to increase production of gasoline, diesel and aviation fuel. Modern design and advanced technology will help reduce emissions from the refinery on a per-barrel basis.

"We're pleased that Motiva selected Dresser-Rand to supply these services as part of its asset improvement initiative," said James R. Heid, Dresser-Rand's vice president, Global Business Solutions and executive sponsor for the project. "The estimated value of the equipment to be supplied by Dresser-Rand when the orders are released is expected to be approximately $100 million. This order is the culmination of a lot of good work involving project teams at Motiva, Shell and Dresser-Rand, and only illustrates Motiva's positive response to the pressing demand for more refining capacity in the U.S., as well as a concern for protecting the environment."

It is anticipated that Motiva's expansion project will increase the Port Arthur facility's crude throughput from approximately 275,000 barrels to about 600,000 barrels a day. Work is scheduled to begin in 2006. When completed, the project will make the Port Arthur refinery the largest in the country.

Motiva Enterprises LLC, a joint venture between Shell and Saudi Refining Inc., owns and operates refineries capable of refining approximately 780,000 barrels a day, a distribution system that includes ownership interests in 42 product terminals, and a marketing network that supports approximately 9,000 Shell-branded gasoline stations in the Eastern and Southern United States.

insights

DRESSER-RAND®

Paul Clark Drive, P.O. Box 560
Olean, New York 14760 USA
Phone: (716) 375-3000
FAX: (716) 375-3178

www.dresser-rand.com

Editorial Statement:

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Janet Ofano
Communications Coordinator
DRESSER-RAND
insights Editorial Office
P.O. Box 560
Olean, New York 14760 USA
Phone: (716) 375-3000
FAX: (716) 375-3178