S&V OBSERVER

Quelling Excess Vibration in a Large Process Column

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Figure 1. High-displacement, low-frequency vibration developed atop a large process column.

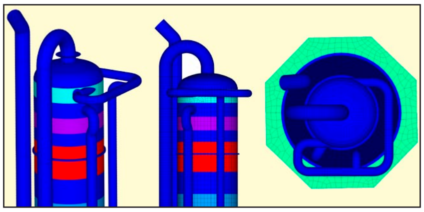

Figure 2. 3D geometry and finite-element models of the 220 foot tall absorber column, which accounted for the main process piping and column's foundation.

Figure 3. Massive foundation of the column was included in the 3-D finite-element model.

Mechanical Solutions, Inc. (MSI) was contracted by a customer to investigate the source of a high-displacement, low-frequency vibration that had been occurring at the top of an absorber column in a large petrochemical plant. The maximum, peak-to-peak, lateral displacement at the top of a 220-foot-tall, 13-foot-diameter column (Figure 1) had been estimated by plant personnel to be roughly six inches. This substantial, undesirable movement of the column was directly responsible for shortfalls that plagued the facility:

- Costly recurring damage to the column's internal components (downcomers, the chimneys, and the trays).
- Additional maintenance during every turn-around, which resulted in approximately 10 days of lost production and increased labor costs.
- Significant reduction in the process efficiency of the unit.

Vibration testing was performed in conjunction with finite-element analysis (FEA) to identify the origin of the excessive vibration, to predict the stress levels in the mechanical components of the absorber column, and to suggest a practical solution to the plant's substantial equipment vibration problem. The overall solution approach was to minimize the unwanted vibration of the column by detuning its natural frequency.

A multichannel spectrum analyzer and a set of accelerometers were used to record the natural excitation response of the vibrating column while it was operated in the customary manner by the chemical plant. These data subsequently were processed through specialized software to create the operating deflection shapes (ODS) of the column, which helped to visualize the motion of the vibrating absorber column accurately. A modal test also was performed by impacting the column on its topmost flange in two orthogonal directions while the responses at locations throughout the column were recorded. The modal test data were used to estimate the natural frequencies and the corresponding mode shapes of the column assembly.

Based on engineering drawings of the column assembly that were provided by the plant, a detailed three dimensional (3D) finite-element model of the column (Figure 2) was created using the ANSYS FEA software package. The model included important structural features, such as the column's foundation (Figure 3), and the significant amount of process piping that was attached to the column. It also accounted for the relevant characteristics of the structural materials from which the column assembly had been constructed.

An FEA of the column model was performed to predict the natural frequencies of vibration and the mode shapes of the structure at each natural frequency (Figure 4). The analytical results were compared with the modal test results, and the comparison revealed that similar vibration modes existed in the frequency range of approximately 0.78 to 0.81 Hz, which corresponded to the first cantilever bending mode of vibration of the column. Further, the consistent close match between the analytical and the test data (Table 1) demonstrated the integrity of the FEA model of the column.

Table 1. Analytical and experimental column vibration data corresponded closely.

	Column Vibration Frequency, HZ	
	Analytical	Experimental
Mode 1	0.81	0.78 to 0.81
Mode 2	4.1	4.0
Mode 3	5.2	5.3

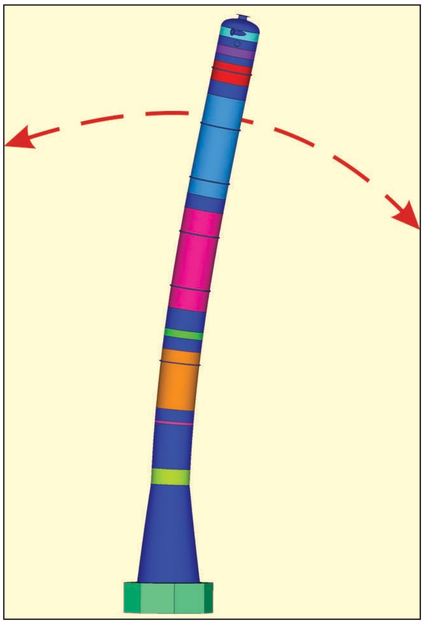

Figure 4. Bending mode of vibration of the absorber column at 0.81 Hz, as predicted by a finite-element model. Arrow emphasizes direction of column motion. Modal test data were used to validate the finite-element model before potential solutions to the vibration problem were considered.

The potential sources of the column's excitation at 0.78 Hz were investigated and included the flow frequency of the fluid that entered the column, the frequency of the air vortexes that were generated by the wind passing around the column's exterior, the thrust loads from the column's internal nozzles, and the wave motion of the process fluid within the trays inside the column. The first three phenomena were found to produce insignificant effects. But the process trend data, that the plant had recorded for the absorber column, revealed a close correlation between the fluid level changes at the top-most internal tray and the response at the top of the column. Each time the fluid level at the internal top tray of the column reached approximately 90% full, the motion of the column increased appreciably.

To efficiently assess the extent of the moving process fluid's influence on the vibration of the column, the column's interior volume at the top tray location was modeled with the standard equation for the natural frequencies of sloshing liquids within tanks and basins. By applying the case of a continuous cylindrical boundary tank with a constant-depth bottom that contained a uniform density fluid, the natural frequency of the moving internal process fluid was estimated to be 0.50 Hz, which was in the neighborhood of the column's first natural bending vibration frequency. The combined contributions of the actual internal geometry of the top section of the column, along with the significant tangential motion of the process solution that entered the tray, increased the fluid wave's natural frequency toward 0.78 Hz when the top tray became approximately 90% filled.

Static FEA also was performed to predict the stresses occurring at the bottom of the column and at the top flange nozzle, both considered critical locations of the structure. A static pressure differential across the column was estimated to generate the 6-inch maximum peak-to-peak lateral displacement that occurred at the top of the column. The response of the column was predicted analytically for the pressure differential load case and in addition due to the acceleration of gravity that acted on the column. The stresses forecast by the FEA to occur at the two critical locations of the column were plotted on a Goodman diagram to evaluate the structure's resistance to fatigue. On the diagram, the stresses that had been caused by the gravitational acceleration represented the steady-state stresses, and the stresses due to the pressure differential represented the alternating stresses.

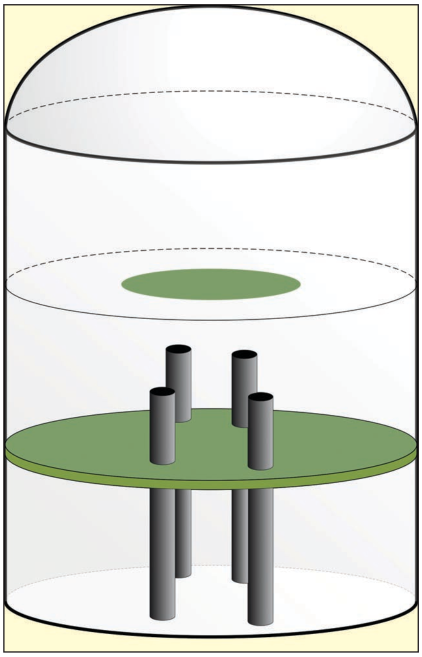

Figure 5. Installation of floating plate inside top section of absorber column.

The predicted state of stress in the column due to the approximate 6-inch peak-to-peak maximum lateral displacement observed by plant personnel exceeded the fatigue limits of the column structure's materials of construction. This would limit the service life of the column, and would result in a mechanical fatigue failure once the column accumulated enough vibration cycles at the 0.78 Hz natural vibration frequency in bending.

To reduce the vibration response and to eliminate the cause of a potential fatigue failure of the absorber column, MSI recommended that the responsible equipment OEM fabricate and install a simple floating plate at the top internal tray inside of the column (Figure 5). The floating plate would serve as a wave breaker that would detune the process fluid wave's natural frequency well away from the column's 0.78 Hz first bending mode of vibration. In turn, this would eliminate the excitation of the structure at that frequency and would prevent the destructive response of the column from occurring. The outlay to resolve the column vibration problem was considered insignificant when compared with the improved production and the reduced maintenance costs that would accrue over the service life of the absorber column.

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Hydraulic Actuators Optimize Wind Turbine Performance

Companies like AVN Energy, a Danish manufacturer of wind power equipment, are creating the technology that now provides 20% of Denmark's electricity production. AVN co-operated with Trelleborg Sealing Solutions to develop seals for its wind turbine actuators (see Figure 1). Wind turbines are dotted all over the green and rolling landscape of Denmark, where the idea for wind power originated. This renewable energy source is now more prevalent here than anywhere else in the world.

AVN Energy's production site is located in Silkeborg, Denmark, which has more than doubled in size over the last year. "We've been involved in wind power since it began back in the 1980s," says Poul Kristensen, AVN's export sales manager. "At first the turbine producers came to us and told us what they wanted, but over time we gained a high level of expertise, which allows us to recommend the optimum hydraulic system for their application."

Wind turbine technology has changed in the last few years. Previously, wind turbines were stall machines and their position would shift only once every 10 minutes. Such turbines have been superseded by continuous-pitch systems, where the pitch (the position of the nacelle and angles of the blades) constantly changes in small amounts once every rotation. That could average 15 times per minute. The nacelle is the structure that houses all the turbine's generating components for the blades.

"While this optimized the production of energy from the turbine for us, the actuator manufacturer, it presented a real challenge," continues Kristensen. "Instead of hydraulics producing six long strokes per hour, they now had to give nine hundred short strokes in the same period. And it's not just the pitch that is continuous, it is also the turbine's operation, with the actuators needing to initiate those strokes 24 hours a day, seven days a week.

"Customers have high expectations from our products, and the number-one requirement of wind turbine manufacturers is reliability. At first, this was not the case. Initial demand for windmills was on a small scale, from farmers with a single turbine powering an individual generator. Then the power distributors became involved. They built relatively small wind farms, and quality needs increased. Nowadays wind power is government backed and expansion is on a huge scale; the power suppliers are making the decisions and the demands. These big investors are not prepared to finance installations unless equipment can be guaranteed for 20 years with only minimum maintenance.

"Maintenance of turbines is difficult and costly," says Kristensen. "On land it is hard enough, but offshore it gets really tough. And when the windmill is switched off for maintenance, it is not producing energy and losing income. On top of that, operators are often penalized if supply targets are not met. So a primary objective for them is to minimize routine downtime, while stoppages due to component failure have to be avoided at all costs."

AVN put a great deal of emphasis on research and development, with more than 20% of the 70 people employed at the Silkeborg site involved in R&D. "Here in R&D, it's not just about knowing the product, it's about thinking about new solutions to the challenges imposed by turbine design and about finding new ways of doing things," says Johnny Fruekilde from AVN's R&D department.

"Meeting the target life of 20 years for an actuator required all our expertise, and initially it seemed almost unfeasible. If you imagine the actuator as a car, it's a bit like saying to its manufacturer that you won't buy his vehicle unless it can travel 500,000 kilometers without replacing the oil filter, brake pads or any other wearing parts. Yet we have tried to accomplish the impossible, and our actuators should provide the 20-year life span stipulated with very little maintenance.

"At the moment though, we are working a little in the dark when it comes to actual performance in application. The continuous-pitch systems have only been around for three years, so we are basing our expectations on extrapolating performance results from older-generation wind turbines. This is combined with virtual modeling and long-term testing on individual elements of the system."

Simulation programs are extensively used by AVN to specify the best hydraulic and actuation system for each design of wind turbine. Following on from this though, automated physical testing is a necessity. The conditions within the wind turbines are very specific to the application. This means that AVN needs to build test rigs to its own designs that can as closely as possible replicate the situation within the nacelle and hub.

"We know that the hydraulic system can only ever be as strong as its weakest link, and early on we realized that the reliability of the sealing configuration was highly dependent upon the quality of its counterparts," continues Fruekilde. "So one area we have focused on is the interaction between the surface finish of the rods and shafts of the actuators and the sealing components. A special rig was constructed specifically to test this and operates around the clock."

The seals within the hydraulics are integral to its performance, and optimizing their life is critical to the long-term effectiveness of the total system. Several other specially built rigs are used to measure sealing characteristics, since the dynamic demands of the application are extreme (see Figure 2).

"The requirements for sealing of the actuator for wind turbine applications were unique," says Per Hvidberg, sales engineer from Trelleborg Sealing Solutions, Denmark. "Never before had I been faced with a demand for a sealing configuration on a cylinder that produced relatively rapid short strokes continuously. And not only was there linear pressure from the rear, there could be side load too."

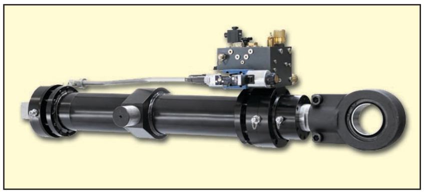

Figure 1. Typical hydraulic actuator.

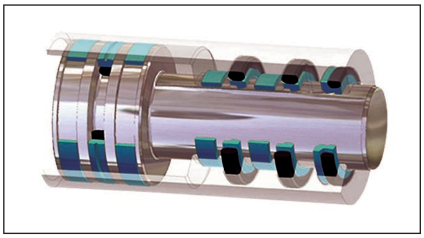

Figure 2. Hydraulic actuator seal configuration.

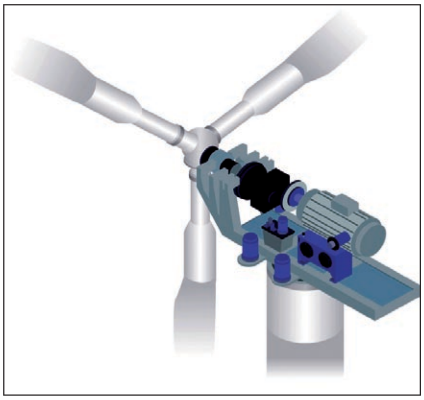

Figure 3. Wind turbine cutaway showing hydraulic actuators in place

"Within the actuators is a complex arrangement of seals ranging from O-Rings to specialist Turcon® PTFE-based geometries and Slydring® in Orkot®," says Hvidberg. "The unique configuration is specially engineered to enhance lubrication, optimize friction characteristics, and maximize service life, while preventing any external leakage. Some of the seals are expected to achieve the 20-year target, but it is impossible to guarantee this."

"Since this was the case," says Fruekilde, "the hydraulics were designed for easy exchange of the seal set. This is mounted in a module that can be quickly bolted on and off. The minimum life expectancy of the sealing configuration, allowing for the seal that has the shortest predicted life, is seven years, but replacement is recommended after five. Other than this and routine rod replacement, the actuators should run without maintenance except for the systematic checking that the operators do for any leakage or loss of pressure. We feel that this arrangement gives the ideal compromise between minimum required maintenance and guaranteed long-term performance. "

"Cleanliness of subcomponents is another important factor," comments Kristensen.

"Before assembly, the system is flushed to ensure there is no metal from machining or other debris like dust or sand within the cylinder."

So what does the future hold for AVN? "Growth and more growth," says Kristensen. "We see the Silkeborg site expanding even further, but we are also supporting the turbine manufacturers as they enter booming wind power markets globally. We already have production facilities in India and are planning expansion in China and the U.S."

Challenging Requirements. The wind power actuator and its sealing system must be capable of operating at 3625 psi (250 bars) with constant pressure on the rod from behind and differential side loads that control positioning. Seals must give minimal wear and facilitate dynamic movement that is continuous in short strokes, on average 900 times per hour.

Temperature resistance is needed down to –22° F (–30° C) as standard and to –40° F (–40° C) in the Arctic. Below these temperatures, the oil within the cylinder cannot function and requires warming with heating elements. Maximum temperature is 60° C/140° F. Beyond this, the system is cooled; otherwise, the oil becomes stressed, its viscosity is too low, and it carbonizes.

In addition, the actuators must withstand high humidity, salt spray and the rigors of wind and rain. Corrosion is prevented with advanced coating technology.

Maintenance a Daring Occupation. It's hard to imagine when you look at a wind turbine that the nacelle is large enough for a man to stand up in. It has to be, because for maintenance, the engineer has to enter this either through the side, but more commonly by climbing to the top of the tower and down into the nacelle from there. That's not easy 330 feet (100 meters) high on land and even more daring when the turbines are up to 60 miles (100 kilometers) out to sea.

Wind Turbine Facts. The wind turbine tower is from 115 to 395 feet (35 to 120 meters) high with blades 40 to 195 feet (12 to 60 meters) long. These are attached to the nacelle, which is more than 7 feet (2 meters) high and that can rotate 360° on top of the tower. Each of the three curved blades of the turbine is positioned by an independently operated actuator with a stroke of 4 to 5 feet (1.2 to 1.5 meters) and can be tilted through 90°.

The higher the turbine and larger the blade, the greater the amount of electricity produced each hour. The smallest turbines are producing 1 megawatt per hour, while the largest yield up to 5 megawatts. In Europe, most turbines are between 1.5 and 2.6 megawatts. The biggest used on land is 3.6 megawatts, with a number installed offshore between 4.5 and 5 megawatts. In Asia, the trend has been for larger wind farms with smaller wattage turbines.

Bigger turbines are not always better; it depends on the size of the wind farm, the stability of the electricity grid it supplies and the promised output. So in some cases it is beneficial to have the option of shutting off a lower production source than a higher one, even though there are economies of scale in running a high-output turbine compared to a smaller one.

On top of a turbine tower are two wind sensors checking wind direction and speed. One is the primary input and the second for backup. At installation, the nacelle of the turbine is positioned in line with the predominant wind direction. Based on complex mathematical calculations, the wind turbine's control system takes the sensor's input and automatically yaws, or turns, the nacelle to the wind, the actuators tilting each blade independently. Positioning is precise, to exacting tolerances, optimizing energy production in the wind condition. The movement is calculated for every rotation, which may be 15 times per minute, continuously for 24 hours, seven days per week.

When choosing a site for a wind farm, analysis must prove it to have 2,500 hours of wind at 39 feet (12 meters) per second over a year to make them viable to utility companies. Wind turbines will normally operate from 10 feet (3 meters) per second to 80 feet (25 meters) per second, with optimum wind speed being between 40 to 50 feet (12 to 15 meters) per second. Though designed to withstand speeds up to 165 feet (50 meters) per second, the control system will counter over-rotation for speeds of higher than 80 feet (25 meters) per second due to safety concerns.

The utility companies target 98% utilization with two percent allowance for maintenance. The turbines can be switched on and off remotely from control rooms anywhere in the world. This is done for maintenance or in response to grid changes.

On the stall turbines, a braking mechanism is employed to stop the windmill. On the new larger turbines, this can stress the tower, so tilting a single blade to 90° normally stops them. In an emergency, this method plus a brake will be employed. In these circumstances, the windmills are stationary in well under a minute. In all cases, the brake, then holds the blades in position.

95% Renewable Energy. A dependable electricity supply finally arrived in February 2008 for residents of the Isle of Eigg, which lies in the Small Isles archipelago off Scotland's west coast. So remote, it previously had to rely on expensive diesel generators to run homes. Now operational, a £1.6 million renewable energy system, which includes hydro, wind and solar power, is expected to generate more than 95% of its annual energy demand.

It has taken a decade for the islanders' green dream to be realized. The idea was first raised after the community of less than 100 people bought the island from its previous owner in 1997. Now, a total of 45 households, 20 businesses and six community buildings are linked together by 6 miles of buried cable that form a high voltage network. This proves the future really can be renewable.

For more information on Trelleborg products, please contact donna.guinivan@trelleborg.com.