Damping of large structures to enable more cost-effective systems has been demonstrated by LORD Corporation's engineering team as they work with the Wind Tower Systems design division of Wasatch Wind (WW). WW is a new development venture based in Heber City, Utah, allied to Brigham Young University and Windward Engineering (an aero-elastic turbine modeller). WW's Wind Tower Systems division has developed a unique space frame tower to support large wind turbines, made up of segments of steel tubes assembled into a 3D matrix. The lighter tower is made possible through the use of proprietary damped struts in specific tower locations. The struts are structural members of the tower, and comprise an outer tube material of lower stiffness than the inner, so that a relative motion is created between them during dynamic loading events from the turbine. For aesthetic reasons, and to prevent bird perching, the frame is covered overall with a non-structural skin, essentially achieving the look of a typical steel tube tower. This new design enables installed-tower cost reductions of 20 to 35%, depending on turbine size.

By Bryan Haltom, Market Development Manager, LORD Corporation, USA

Filling a Need for a New Tower Design

Solutions to Tower Challenges in New Damper Technology

The solution for the damped struts is based on the LORD Fluidlastic damper technology, used in the aerospace industry for more than a decade, specifically for lead-lag dampers on helicopter rotors. It was chosen due to its maintenance-free characteristics and proven use in the field at wide temperature ranges. Particular challenges in this application are that the resonant frequency range is very low (0.25 to 0.45Hz) and there is very little motion to drive the piston of the damper. For comparison, a helicopter would drive the piston several millimetres, whereas this design only allows for a displacement of fractions of a millimetre.

The fluid damper is actuated by the inner member of the WW strut that moves a piston through a fluid to achieve damping losses of greater than 50% for loads up to 300,000 pounds (136,000kg), even though the stroke length is extremely short. The damper is designed for leak-free performance during its 20 or more years of life (hundreds of millions of cycles), and LORD high performance coatings are applied for operation in harsh environments. The damper operating temperature is between -30 and 50°C. The modular design offers ease of assembly in the strut, and a positioning method is included to ensure alignment of the piston in the cylinder. Furthermore, the design eliminates the typical wear components of hydraulic dampers, reducing the need for operational maintenance, a costly proposition in many tower locations such as offshore or in climates with harsh winters.

LORD Corporation's solution also integrates other LORD technology

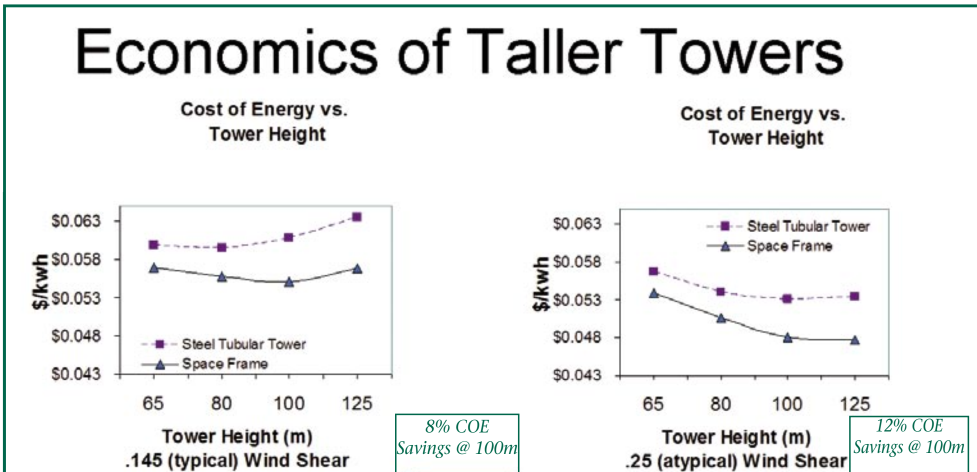

Figure 1. Charts compare Cost of Energy (COE) for a turbine built with a standard tubular steel tower versus a space frame tower from Wasatch Wind, Wind Tower Systems division

Figure 2. A picture of the full damper on its 100 kip (4.5 kN) actuator test rigging

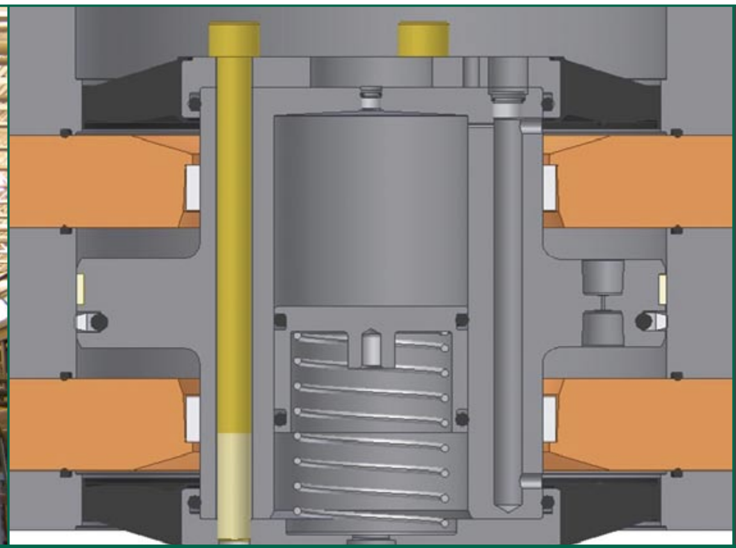

Figure 3. The basic damper layout with elastomer sections, internal accumulator and fluid chambers visible

Figure 4. The dampers incorporated into the struts in the Wasatch Wind tower. Note there are five struts arranged to facilitate both the torsional and bending moments of the tower

Figure 5. Space frame wind tower with Hi-Jack and gin pole

solutions such as LORD adhesives for assembling key components of the damper head. Used in a wide variety of industries, including marine, automotive, truck and industrial applications, LORD structural adhesives simultaneously provide assembly flexibility and a hermetic seal in this damper design.

LORD and WW were first introduced at a United States Department of Energy forum in October 2005. When LORD studied the design and operational requirements for WW's damped struts, significant manufacturing and life challenges were identified. LORD proposed a design that would make the damper modular and permanently sealed.

The new tower model solves transportation issues through its modular design. Incorporating damping allowed for tower weight reductions of 50%, while achieving the same profile as tubular towers. A supplemental lifting system allows turbine and tower erection and heavy-repair operations to be completed without the need for expensive track cranes. The design approach facilitates taller wind towers with hub heights of 125 metres and larger. Combined with linear height/cost scalability, the new tower design will achieve overall reductions in the cost of energy of 5 to 12%.

The first functional damper prototypes have been assembled and are currently being tested in LORD labs. The test protocol consists of both fully assembled damper characterisation and accelerated durability of critical subcomponents subject to potential wear. Multiple actuator rigs and specialised fixtures need to be run in parallel to accomplish this testing in a reasonable time frame in order to bring this solution to market more quickly (see Table 1).

The fluid dynamic modelling used to tune the damper design allows for a certain amount of 'leakage' to occur internally within the damper during the piston stroke, so accurately measuring the wear rate of the bearing surfaces ensures the design will stay within these leak limits over the 20-year design life. Various surface finishes are being tested to establish the most robust and economical solution for the bearings. One of the key challenges in this subcomponent testing was to get multiple bearings on one rig without contaminating the other bearings once wear starts occurring. The solution was to use one actuator, but individual 'chambers', to capture the fluid bath around each piston-bearing test sample. Also, each of the bearings has a side-load applied to represent the gravitational loads present in the installed position on the

Test	Purpose	Acceptance criteria
Bearing wear test	Determine the most cost-effective surface treatment for the piston surface that provides adequate wear rates of the bearing.	Bearing wear amount after initial wear-in period, together with passing a visual inspection for cracks. Wear-in period is defined as the initial 100,000 cycles.
Seal characterisation test	Determine the most durable seal configuration that provides adequate sealing performance.	Sealing performance based upon the pressure measurements and analytical model.
Seal durability test	Gain insight into the seal life under combined axial and radial loading.	No visible cracking or tearing of the seal that would cause seal performance issues.
Characterisation test of elastomeric seals	Understand the axial stiffness of the elastomeric components in the system.	Axial dynamic stiffness must not exceed prescribed amount for any condition.
Dynamic characterisation of damper	Ensure damper is tuned to the correct frequency.	For a frequency range from 0.25 to 0.45Hz for the applicable displacements and temperatures defined, achieve a dashpot coefficient that would yield a minimum Tan of 0.5, using appropriate analytical models for the entire strut configuration.
Accelerated durability test of the elastomeric seals	Validate the elastomer design.	Leaks via elastomer cracks are not permissible. D ynamic stiffness must not change by more than 20% of the original value at a comparable temperature.
Accelerated durability test of the damper	Test the damper head assembly according to the true load and frequency profile for a 20-year life.	Leaks are not permissible. For a frequency range from 0.25 to 0.45Hz for the applicable displacements and temperatures achieve a dashpot coefficient that would yield a minimum Tan € of 0.5, using appropriate analytical models for the entire strut configuration.
Full strut testing	Test the damper as assembled in the full strut under various load conditions.	Dashpot coefficient matches the predicted values from LORD testing.

Table 1. Basic outline of the critical performance tests being conducted to prove the predicted performance and durability of the damper and its subcomponents

tower. Wear patterns are being checked with CNC measuring devices on a regular basis.

The elastomer section of the damper is also being tested for durability. Because a certain amount of fluid pressure will be seen at the elastomer interface during operation, a special fixture has been produced to test the impact of a pressurised fluid on the elastomer. A high frequency block-loading test is applied, and the elastomer is periodically checked via a visual inspection for the formation of any cracks.

Full damper durability is being tested with a worst-case operation in mind. Because the full damper must be tested near its actual operating frequency, a 'Miner's Rule' block-loading is being applied to test the most damaging loads first. Temperature extremes are also being tested, as they affect both the fluid properties and elastic components of the damper. This effect is being tested by cycling between extreme heat and cold conditions on a daily basis using a specially created insulated box with liquid nitrogen and heat gun ports.

The use of damping in this application demonstrates the tremendous benefit of reducing mass through the appropriate use of the technology. LORD believes that as drive-train and nacelle components grow larger, more of this technology will be required to keep the overall mass small in order to minimise transportation and erection costs . For example, a lighter-weight bedplate would certainly be possible. Also, reduction of the loads in the top-head could reduce the need to add mass in the other coupled components of the turbine.

Biography of the Author

Bryan Haltom joined LORD in 1998. Based in Atlanta, Georgia, he supported their automotive business. Haltom moved to LORD Corporation's headquarters in 2005. He manages the portfolio for market expansion ideas and leads commercialisation projects for existing technologies in new markets. Haltom holds a BS from Davidson College in North Carolina.

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