Wind Turbine Noise Reduction

Modeling of a megawatt wind turbine system enabled Xi Engineering Consultants to address a problematic tonal resonance with an innovative solution that minimized the cost of remedial work for their client.

BY JENNIFER HAND

Noise from wind farms falls into two categories: aerodynamic noise is created by the blades of a turbine swishing through the air while mechanical noise is associated with the machinery housed in the nacelle of a turbine. As mechanical noise tends to be tonal, it is this that is most often a nuisance factor for residents living nearby. As a result there are strict regulatory standards throughout Europe and North America and when operators do not meet these requirements they face potentially heavy penalties.

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Wind Farm in the Scottish Southern Uplands.

“People perceive noise, but often what they are really noticing is vibration,” comments Dr. Brett Marmo, Senior Consultant at Xi Engineering Consultants Ltd, an Edinburgh–based company that specializes in complex vibration issues. One of Xi’s recent projects was carried out for the manufacturer of a set of megawatt scale wind turbines emitting excessive noise in the 800-830 Hz frequency band.

The manufacturer had already identified that the most likely source of noise was the meshing of teeth within the gearbox and in a major project had lifted the 15-ton gearbox out of one of the 80 m high towers and replaced the rubber buffers beneath it. This had only exacerbated the problem. It was not at all clear how the continuing noise could be addressed without considerable redesign and remedial work, which would be both expensive and disruptive, given the significant number of turbines involved. As Dr. Brett Marmo explains, “We were brought in to address this vibration by tracking it to the source.”

Seeking the Source

After a thorough study of existing design data and an extensive site survey in which sensors were attached to the turbine towers, Xi Engineering confirmed that the source of the noise was indeed the gearbox. “We were able to ascertain that at normal running speed the teeth on a set of gears make contact around 820 times per second. In other words, we had the sound of 820 clashes each second,” notes Dr. Marmo. “However it was not that simple. The original noise was being amplified somehow and we suspected the involvement of the tower's steel skin. Every structure has a harmonic and in this case the tubular steel tower had a series of resonances between 800-900Hz.”

Xi has extensive experience with simulation and used COMSOL Multiphysics to develop a model of the tower, the rotor blades and the nacelle housing the gearbox (Figure 1). The model incorporated all of the air inside and outside the turbine so that engineers could identify the modal shape of each vibrating element and see exactly how vibration was travelling out of the gearbox. This led them to the tower wall where resonances around 820Hz were clearly visible. The next step was to make an eigenfrequency model of the tower structure and skin. Dr. Marmo again: "Within this complex model we could see that there were certain hotspots near the top of the tower where the tower skin was rippling at resonant frequencies of 800 and 830 Hz. These resonances were amplifying the gearbox vibration and producing the annoying tonal noise."

Keeping it Simple

"Our philosophy is to begin with simple solutions such as buffers and springs that isolate the source of the vibration," comments Xi Operations Manager, Barry Carruthers. "Where we can, we will develop passive correction rather than an active intervention that may require tuning and maintenance. In this case the design solution was to break the vibration pathway between the gearbox and the tower wall and the simplest method would have been to modify the rubber buffers below the gearbox. However engineering constraints meant that it was impractical either to stiffen or soften these. The most effective alternative solution was to coat the inside of the tower with a specialist material that reduces the amplitude of the vibration."

There were two major considerations: the material was expensive and with each tower measuring 2.5m across the top and 4m at the bottom the potential surface area to be covered was extensive. In addition, installation would be costly. The material could only be fitted by Rope Access engineers working inside the tower, but between integral platforms. The big question was exactly how much material would be required to solve the noise problem? The only option was to create a third model in COMSOL Multiphysics to

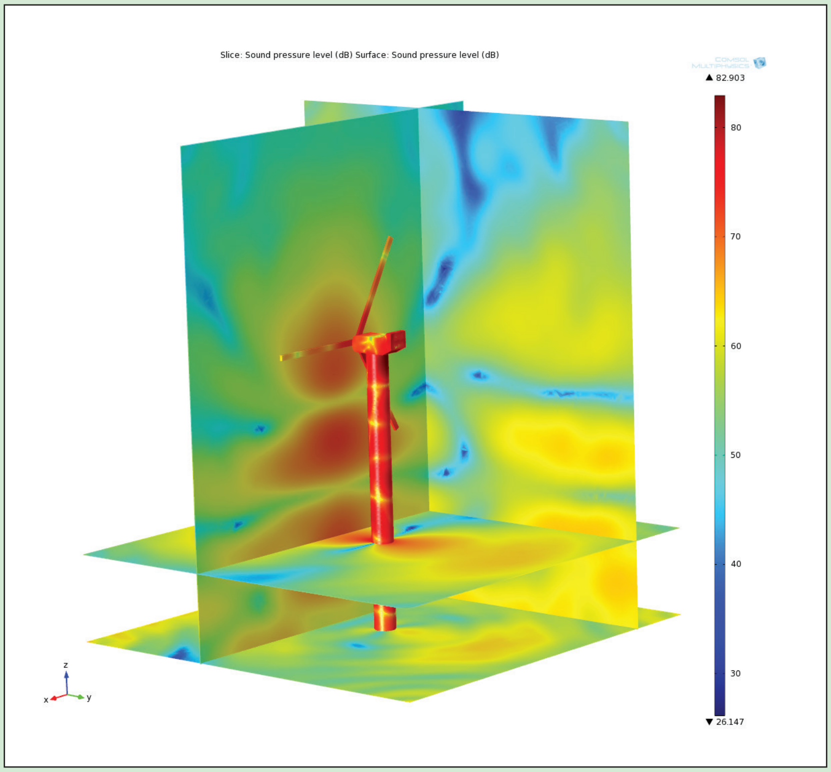

Figure 1. Acoustic-structural interaction model of a wind turbine surrounded by air showing the vibration acceleration amplitude of the turbine and slices through the air showing the resultant sound pressure level. The figure here shows vibration with localized amplification of the noise at the top of the tower (red area).

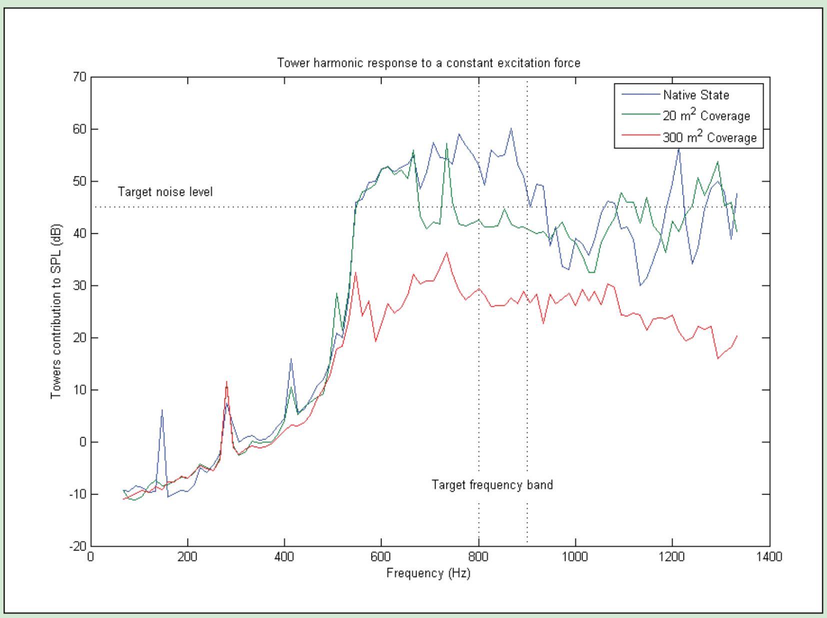

Figure 2. The sound pressure level measured at a virtual microphone outside that tower for: the wind turbine in its native state; when the top 20 m² of the inside wall is covered with the anti-vibration material; and when the top half of the tower (300 m²) is covered in the anti-vibration material.

> "We were able to conduct virtual testing and explore our options without the real-life costs associated with an iterative process."

simulate the effects of the material inside the tower (Figure 2).

"We made an acoustic structural interaction model of the tower walls and the internal and external air. We determined what the sound level was 50m from the tower when different surfaces of the tower were covered in the material, rather like using a virtual microphone. We began with the hotspots identified close to the top of the tower in the eigenfrequency model and experimented with different amounts of material. As we adjusted the amount of material in the wall we reached a point where the noise dropped to a satisfactory level. We continued to adjust the coverage until we had also minimized the amount of material required."

The high costs of the material would have meant that full coverage of the 600 m^2 surface inside the tower would have cost tens of thousands of pounds. Even if material had only been applied to the top part of each tower, 100 m^2 per unit would have been needed. Given the number of turbines, the bill would have been substantial," reports Mr. Carruthers. "Instead, we were able to advise the client that only 20 m^2 of material was required for each tower. One prototype installation confirmed our findings exactly: the noise was sufficiently attenuated and our client was extremely happy."

Brett monitoring vibration of a wind turbine tower with a hand held accelerometer.

The Value of a Virtual Test Bed

According to Dr. Marmo, it is difficult to overestimate the value of being able to simulate in such situations. "From our initial survey we knew that the tower was resonating and without the facility to model within COMSOL Multiphysics we would have had to go back and cover the whole of a 80 m high tower with sensors. Instead, we were able to skip that phase altogether with our first analysis model." Mr. Carruthers continues, "We were able to conduct virtual testing and explore our options without the real-life costs associated with an iterative process. Trial and error on-site, with expensive materials and labor, is more than 30 times the cost of additional simulation and analysis — the key is to investigate virtually, but solve in reality only once."

Barry (left) and Brett (right) in a turbine tower during the southern upland project.

Xi has been using COMSOL Multiphysics since 2006 when it was commissioned to solve a complicated seismic vibration issue in the Southern Uplands of Scotland. "It is unusual to be able to conduct different types of analysis within one single engineering application. As vibration experts we are particularly interested in how structures interact with acoustic waves or fluid flow and COMSOL Multiphysics allows us to plot dynamic relationships; get an overview of what is going on; play around and do complex multifaceted things more easily. Vibration issues within systems can be very complex and while many companies can identify a problem, they cannot solve it. Our value comes from providing a solution and COMSOL Multiphysics assists us in what can be an extensive and difficult process." ■

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