Vibration Testing

The National Wind Technology Center offers modal and vibration testing as part of its comprehensive structural-testing program. A fully equipped mobile test van allows engineers to conduct vibration testing on wind turbines anywhere in the United States.

The wind industry can also take advantage of advanced modal-testing equipment, software, and trained engineering specialists at the Center, located near Golden, Colorado. Modal testing allows engineers to identify the natural vibration frequencies of turbine components such as blades and towers. It is performed by shaking a wind turbine that is not operating, then measuring the structural vibrations with accelerometers attached to the structure at key positions. Vibration testing uses the same instruments to measure operating deflections of the turbine that occur during normal or abnormal operation.

Uses of Modal and Vibration Testing

The wind industry can use modal and vibration testing to validate and update computer models, to troubleshoot operational problems, to understand operational loads, to detect interactions between turbine components that cause unwanted vibrations, and to evaluate the impacts of design changes.

Validation of Analytical Models

Modal testing has become an integral part of computer-aided product design and development. It provides important feedback to designers on the modal characteristics of new components and systems. The modal test data allows designers to validate and refine the analytical models used in turbine design.

Troubleshooting Operational Problems

Modal testing can identify potential or existing problems with operating wind turbines. An operating turbine can experience a resonant (and potentially damaging) vibration if the turbine operates near one of its natural vibration frequencies. To identify problems, a modal test is performed in the field. Results can be obtained immediately by graphing the data to produce a plot known as a Campbell diagram, which compares the machine's natural vibration frequencies with the operating speeds of the turbine.

The coincidence of a natural frequency with a per revolution forcing frequency of the rotor identifies a potential resonance condition.

Warren Gretz, NREL PIX 00213

Researchers perform vibration tests on a newly designed wind turbine blade in the high bay at the National Wind Technology Center.

Understanding Operational Loads

Engineers use vibration testing to help them understand operational loads on a wind turbine. Most turbine manufacturers gather information on operational loads, such as the blade flap bending moment and the tower bending moment, by attaching strain gauges to the machine and measuring deflections as a function of time. Often, this data is used to produce a power spectrum, a graph of the amplitude of a response versus frequency. This power spectrum is the sum of the machine's natural vibration responses and responses due to machine operation, known as forced responses. Forced responses result from non random problems such as blade pitch and mass imbalances. Natural responses result from random excitation caused by turbulence in the wind.

Modal tests help engineers sort out the forced and natural responses and understand the loads in terms of their origin. Modal tests also provide information on how natural and forced responses interact. This information helps wind turbine designers avoid resonances, which occur when forced responses coincide with natural responses.

Analysis of Complex Vibrational Patterns

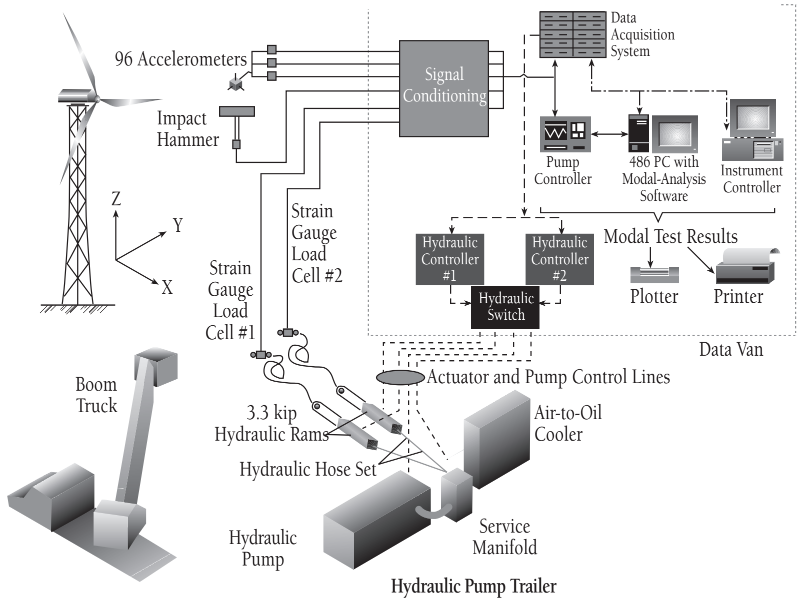
When modal tests are done in the field, engineers often conduct vibration tests at the same time. Because the machines are already instrumented with accelerometers from the modal testing, it is relatively easy to gather data on the deflection of key structures during operation. This experimental information is then used to animate a model of the structure at a given frequency on the computer. Analytical models such as ADAMS (a powerful turbine design code) or a finite element analysis code can also be used to create the animation.

The animated structures allow design engineers to look at turbine operation from the perspective of an outside observer. It is particularly useful to create an animated wind turbine at frequencies in which large peaks in the power spectrum occur. Often, coupled vibration responses such as a nacelle pitch and tower bending show up. Once a complex vibration pattern has been identified, design engineers can use their analytic software to develop ideas for design changes to remedy the problem. Specialists in vibration testing at the National Wind Technology Center use modal and vibration test data to analyze the turbine's response to proposed design solutions.

Control System Modeling and Design

Modern control systems for flexible, dynamic mechanical structures such as wind turbines are designed with the structure's modal response in mind. Typically, a turbine designer will model a turbine design's natural vibration responses and system dynamics before designing a smart control system. This information allows the control system designer to predict the turbine's controlled behavior in many different environments.

Modal Test Setup



Modal Test Equipment

Component	Rating/Size
Dual Hydraulic Actuators	3.3 kip
Air-Cooled Hydraulic Pump	23 gal/min; 3000 psi
2 Pump Controllers	
Data Acquisition System, UNIX Instrument Controller	96 channels
Low-Frequency, High-Resolution Accelerometers	96 (21 triax or 31 biax)
Low-Noise Conditioning System	
Structural Testing and Modal Analysis Software	CADA-X
Strain Gauges	
GM/Itasca Van, Hydraulic Pump Trailer	

Vibration Testing Capabilities

Because the wind industry often needs vibration tests done in the field, the National Renewable Energy Laboratory developed a mobile testing laboratory. A specially designed van houses a computer system and test equipment. A trailer carries a hydraulic pump and associated equipment. Test equipment includes a dual hydraulic shaker system controlled by a computerized data acquisition system. The shaker system consists of hydraulic actuators powered by an air-cooled hydraulic pump.

Ninety-six low-frequency, high-resolution accelerometers placed on the wind turbine measure the machine's response to the shaker. Signals from the accelerometers pass through a low-noise conditioning system into the data acquisition system. The low-noise signal-conditioning system is necessary to measure the low-frequency natural vibration characteristics of a wind turbine. The data acquisition system is controlled by a high-speed, UNIX-based instrument controller. Special modal analysis software automatically determines natural vibration modes and turbine operating loads.

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