BOXBORO
systems

DEFLECTION AND TWIST MEASUREMENT DEVICE FOR LARGE STRUCTURES

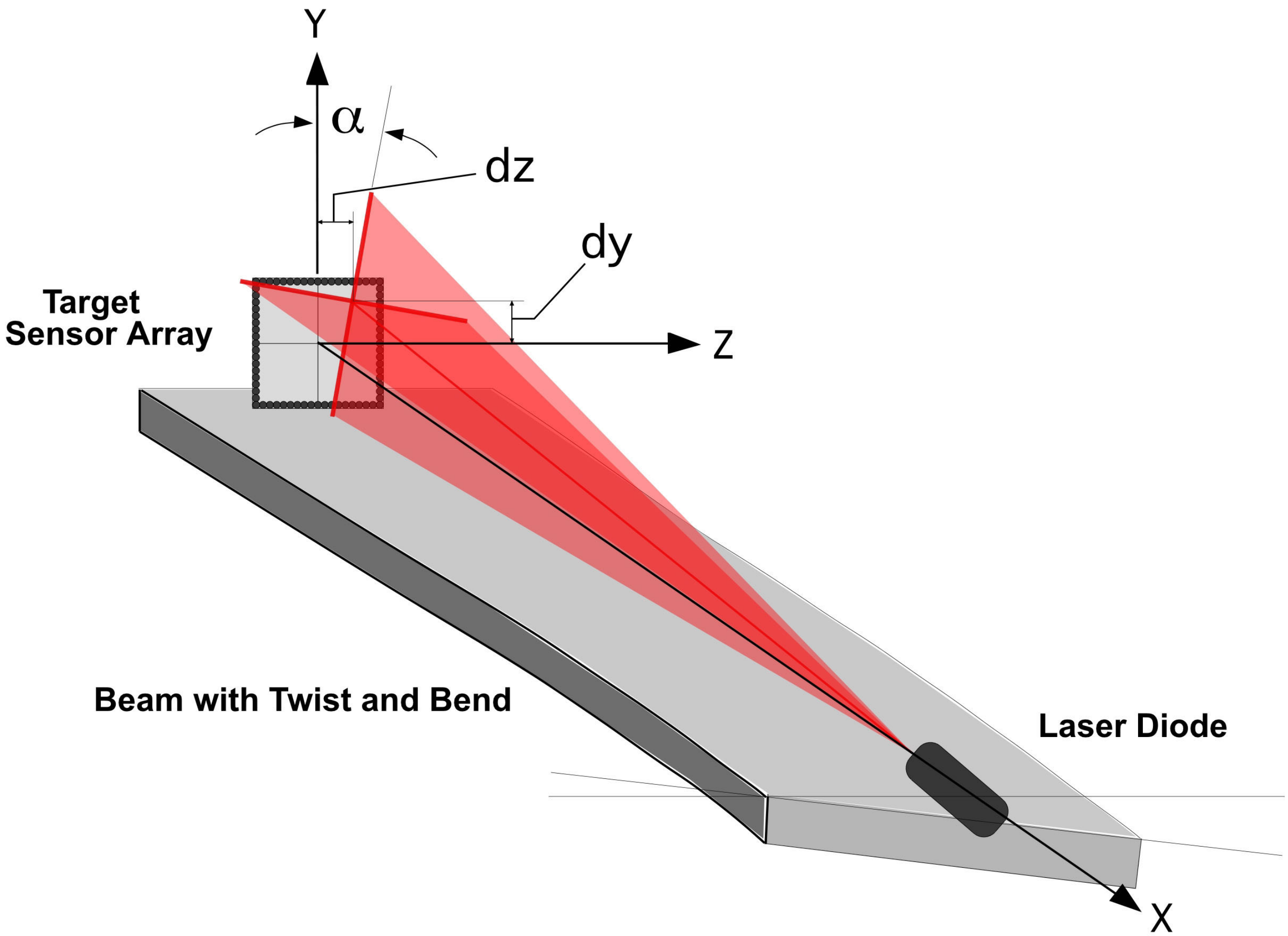
Long or tall structures like bridges and buildings are subject to seismic movement, weight, and wind gusts, potentially compromising their structural integrity. Aircraft wings, fuselages, tail booms and vertical stabilizers are subject to deflection and twist during flight. Wind turbine rotor blades can strike their supporting towers when they are subject to large flap-wise bending due to wind shear, yaw motions, turbulence, and other extreme conditions. Masts on large sailboats can break when overloaded during a race. The result of these catastrophic events can be not only costly but fatal.

Regardless of the application, a device that measures deflection and twist directly in real time is a cost-effective tool for avoiding damage or performing structural health monitoring. Accelerometers, strain gauges, and GPS have been used alone and in combination to measure deflection and twist, but each has limitations. Strain gauges need to be calibrated versus deflection and twist on the structure, or a model of the structure is required to convert strains to deflections and twist. With accelerometers it can be difficult to determine the motion of a component when the whole structure is in motion, such as trying to determine the deflections of an airplane wing relative to the fuselage when the plane is executing complex maneuvers. Both strain gauges and accelerometers are analog devices, subject to noise and zero drift. Differential GPS units can be used to measure deflection on stationary objects but require an expensive base station located near the object to be measured, the coordinates of the base station must be known exactly, and every measurement point requires an antenna and GPS receiver networked to the base station.

Measuring Deflection and Twist Directly

The DTMS (Deflection and Twist Measurement System) is a patent-pending electro-optical system that measures bending in two axes and twist of long live beams. It provides the deflection and twist data at multiple stations with respect to one end of the structure, not with respect to a fixed ground. Therefore it can be used for a variety of bending and twist measurements on structures where conventional instrumentation won't work. It can be used either as a real-time monitoring device to signal potentially dangerous situations, or as a test tool to verify the performance of a system.

The DTMS consists of several laser-diode/photo sensor pairs, each pair making up a measurement segment. A simplified 3-axis measurement segment is shown below. The laser generates a cross-hair pattern on a rectangular array of photo-sensors. From the coordinates where the cross hair intersects the photo sensor array, the deflections in the Z and Y axes (dz and dy) and the twist along the x-axis (α) can be calculated. The accuracy is proportional to the spacing of the photo sensor elements. We use linear photosensor arrays with spacing ranging from 150 to 400 sensors per inch.

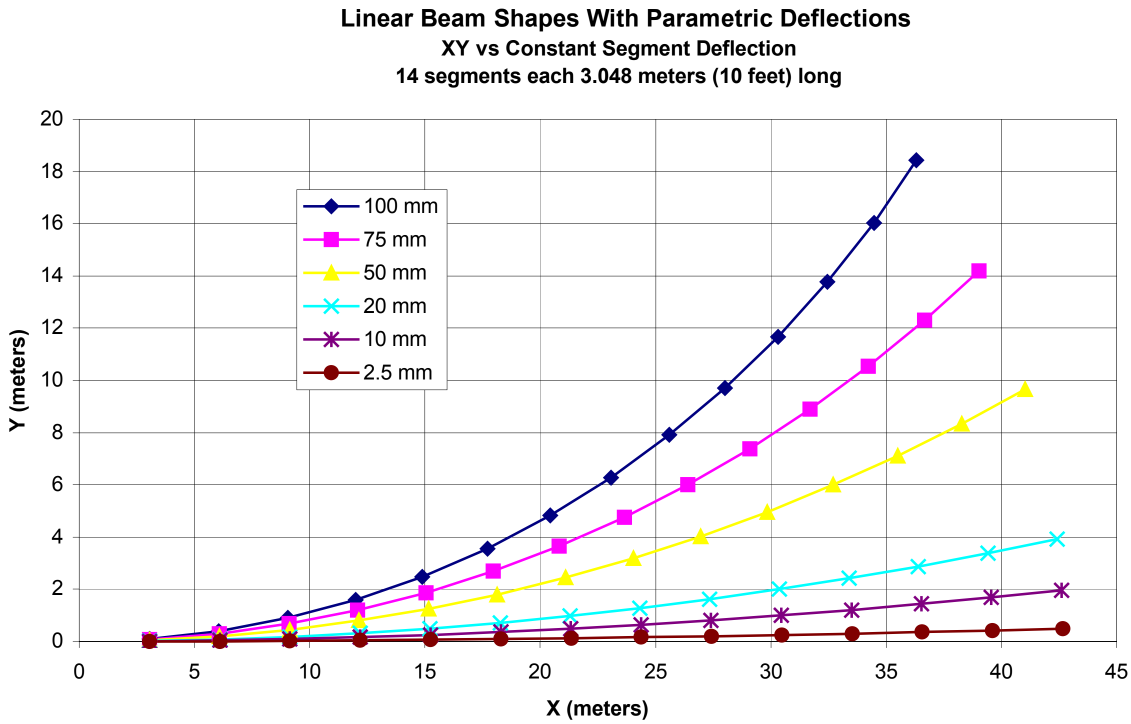


A single segment system can be used to measure deflection and twist between two points on a structure. The maximum deflection that can be measured is equal to the size of the sides of the sensor array.

With a multi-segment DTMS the deflections of each segment can be added vectorially. Therefore the system can measure large deflections, where the total deflection measurable is greater than the combined sensor array length. The graph below shows the amount of deflection that can be measured with 14 segments spaced 3.048 meters apart, with a range of sensor array sizes from 2.5 mm to 100 mm. Note that the 14 segment DTMS with 100 mm sensor arrays can measure over 18 meters of deflection on a 42.5 meter beam. Note that the deflection and twist data is available at the end of each segment, allowing the mode shape of the structure to be measured.

Customizing and Optimizing the System

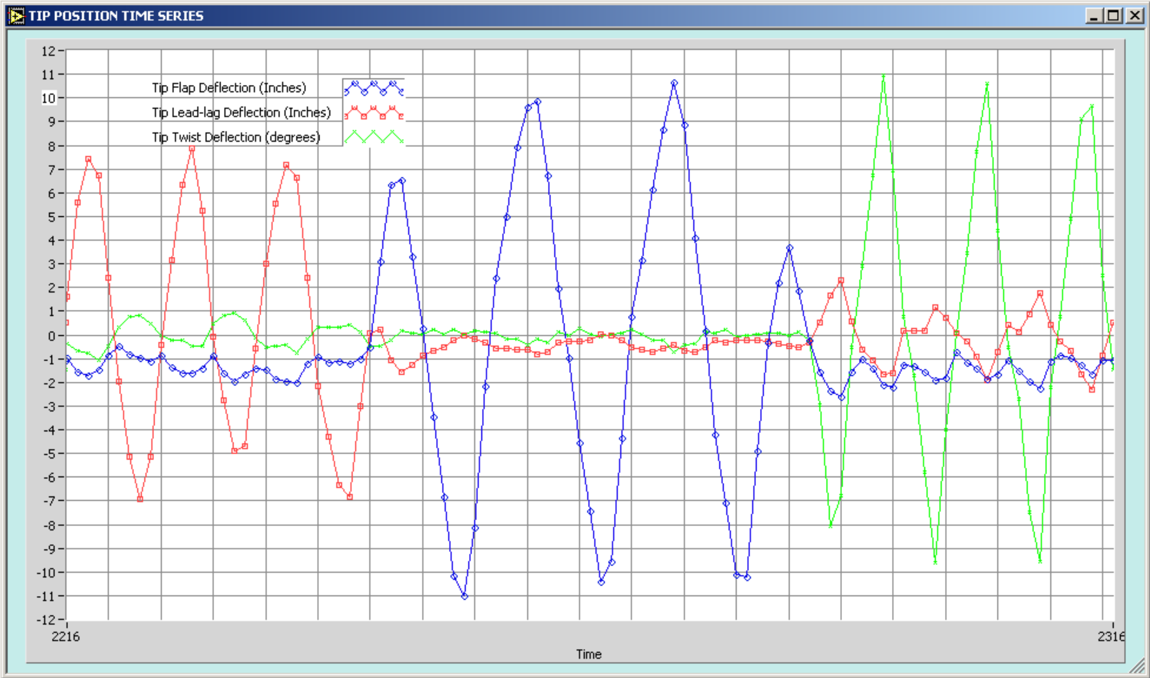
The size of the sensor arrays, and the length of the segments, can be adjusted to optimize the DTMS for a particular application. Where space is constrained, smaller diameter, shorter segments can be used. Longer segments can be used where less deflection is expected, and shorter segments used in areas of high deflections.



The packaging of the DTMS depends on what it will be used to measure. In a clean environment only mounts for lasers/sensor boards need to be attached to the structure. For environments where the optical path may be corrupted by fog, dirt, or other environmental hazards, then flexible tubing can be used between the mounts for the lasers/sensors to protect the optical path. For bridges, buildings, and tall towers the DTMS can be packaged inside standard trade size conduits, and mounted to the structure using standard conduit mounts.

Microprocessors on the sensor boards determine where the cross-hair lasers intersect with the sensor arrays and transmit the information to a PC via an RS485 multi-drop network. A PC program calculates and displays the actual deflected shape of the beam and tracks tip position as shown below. In addition, the PC program displays time history of bending (flap- and edge-wise) and dynamic twist.

The screen grab below shows the time series display of the DTMS monitoring a 12 foot long cantilevered beam with three segments. During the first section, a beam was deflected in the edge-wise direction (red trace); next, the beam was deflected in the flap direction (blue trace); and finally, the beam was twisted (green trace).



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