NI Solutions and Techniques for Structural Test

Overview

National Instruments defines structural test as the mechanical study of materials, components, or systems in response to an applied stimulus. Structural tests are typically performed during research, prototype, and validation phases. Structural health monitoring involves damage detection of structures in-service under normal operating conditions. National Instruments provides solutions for both structural test and structural health monitoring applications. Because the applications can have very different requirements, this paper focuses on solutions specific to structural test. To learn more about NI solutions for structural health monitoring, visit ni.com/shm.

National Instruments hardware and software tools help you to quickly develop and customize systems to perform structural tests, including static, fatigue, aerodynamic, vibration, impact, blast, and ballistics testing. NI combines its instrumentation, industrial control expertise with the NI LabVIEW graphical programming environment to deliver the industry’s easiest to use and highest performance solutions for structural test. Benefits from NI tools and measurement techniques are applicable to a wide variety of industries including military, aerospace, naval, automotive, and renewable energy.

Features

Modular, Flexible, Accurate Measurement Instrumentation

The PXI platform, introduced by National Instruments, is a rugged PC-based platform that provides a modular approach to high-performance instrumentation. Modularity provides the flexibility needed to adapt a test system to changing structures, with commercial off-the-shelf parts and availability. The PXI architecture provides the industry’s highest bandwidth and lowest latency with advanced features,
including integrated timing and synchronization buses. With more than 1,500 products from more than 70 vendors, the PXI platform delivers a complete, high-performance and high-channel-count system for modern structural test applications.

Figure 2. Example PXI Structural Test System

Structural tests take advantage of the modularity and flexibility of PXI because they require a variety of sensor types – strain and vibration measurements are the most common. Strain measurements are usually made with resistive foil strain gages that are set up in full-, half-, or quarter-bridge configurations. Piezoelectric accelerometers with a built-in charge amplifier are often used for dynamic vibration acquisition. The NI PXI platform offers strain and vibration specific modules designed for high-channel-count systems with up to 204.8 kS/s/ch sample rates, 24-bit resolution, and 0.02 percent accuracy. Other sensors often incorporated in structural systems include linear-voltage differential transformers (LVDTs) and string potentiometers for displacement or tilt measurements, as well as load and torque sensors. In structural test applications, these measurement types are typically used as feedback to control an input stimulus.

Dynamic tests, such as aerodynamic and impact tests, require high sample rate and high-resolution measurement hardware to capture fast events. This approach requires large amounts of data to be transferred to disk at once. Dynamic events are not easily reproduced so they contain valuable information. Dedicated bandwidth per device and low latency ensure all of the data is captured reliably before offline processing. Using a high-performance platform such as PXI Express with dedicated throughput ensures the fidelity of your test system for dynamic tests.

In contrast, static tests typically suffice with sample rates below 1 kHz but have increased accuracy requirements. Load bearing structures must be tested for absolute strength as well as fatigue life. Both tests require precise measurements to ensure that the correct stress/strain is being applied to the material. Structural engineers commonly perform multiple test runs with slightly different loads. These tests benefit from a high-accuracy system that removes the hysteresis. This is crucial to understanding complex mechanical interactions as well as the affect that a controlled stimulus pattern has on a structure. Fatigue load cycles rarely go beyond hundreds of cycles per second and sampling 10 times faster than this rate yields a good illustration of the material behavior. National Instruments provides tools to measure a variety of sensor types and meet requirements specific to the various structural tests.
Scalable Platform With Best-in-Class Synchronization

The PXI platform offers a variety of chassis with 4- to 18-slot 3U and 6U sizes. The chassis contains the high-performance PXI backplane, which includes the PCI bus and timing and triggering buses. PXI Express provides the additional timing and synchronization features of a 100 MHz differential system clock, differential signaling, and differential star triggers. By using differential clocking and synchronization, PXI Express systems benefit from increased noise immunity and the ability to transmit at higher frequencies. Ultimately this leads to tighter synchronization across longer distances. Using these timing and triggering buses, you can develop structural test systems for applications requiring precise synchronization within a single chassis and across multiple chassis for high-channel-count systems.

Static and dynamic structural tests take advantage of different aspects of the PXI synchronization features. Static tests usually require many channels to characterize the principal strain on a structure because complex material properties make it difficult to predict. In addition, distributed systems are common when testing full-scale structures because they can be enormous in size such as those in the aerospace and defense industry. Due to cable complexity, installation, and maintenance costs, it is often impractical to connect sensors to a central measurement system. Platforms that easily and transparently expand to multiple distributed systems can save time and cost. With the PXI platform, measurement hardware can be distributed using signal-based or time-based synchronization methods using existing Ethernet backbones or even GPS.

Figure 3. High-Channel-Count Multichassis PXI System

Timing and triggering capabilities are especially critical in dynamic structural tests, such as impact, blast, and ballistics testing. These tests result in large amounts of data to capture such a rapid event. One way to reduce this burden is to trigger acquisition to start only when a specific event has occurred. Dynamic tests are typically initiated in this fashion, which prompts the DAQ module to start acquisition. The PXI
Express bridge and vibration modules can be triggered from analog or digital signals using fast, reliable, built-in triggering.

As sample rates increase, channel skew begins to introduce more error because the data is changing very quickly. National Instruments uses PXI Express to deliver tight synchronization between devices in one chassis or multiple chassis. For example, the NI PXIe-4330 bridge sensor input module has a channel-to-channel skew of less than 100 ns on a single module or different modules within a single chassis. National Instruments offers powerful and flexible solutions to synchronize across channels, modules, and chassis to meet structural application requirements.

**Reliable, Deterministic Control to Apply Stimulus**

Synchronized, high-performance control is essential for static and fatigue structural tests. In many cases, the input stimulus used for fatigue testing can be just as important as the instrumentation. For this reason a deterministic real-time system is needed to consistently repeat the same load pattern up to millions of iterations without disruption. To do this, a stimulus signal is usually sent to a hydraulic control valve, known as a servo valve, that regulates a hydraulic actuator applying force to the structure. This force is measured and fed back to create a control loop. This loop can be run on deterministic systems that include the instrumentation or on advanced digital servo valves themselves.

To serve these needs, National Instruments provides a new class of industrial controllers known as programmable automation controllers (PACs). PACs combine features and capabilities from the traditional programmable logic controllers (PLCs) and PC-based control systems.

**Figure 4. Example CompactRIO System**

NI PACs are based on highly reliable and rugged platforms such as NI CompactRIO and PXI. These modular platforms provide advanced analysis and signal processing capabilities that can run on standard OSs such as Windows, real-time OSs for more reliability and determinism, or field-programmable gate arrays (FPGAs) for the highest performance available. With FPGAs, you can run control algorithms, perform analysis, and make decisions at the chip level, delivering the highest performance control over your structural tests. Although very powerful, you can easily program these devices using LabVIEW, a graphical development environment. LabVIEW abstracts all the complexity of real-time OSs and FPGAs while providing drag-and-drop control algorithms, allowing you to focus on your area of structural expertise.

**Graphical Development Environment**
Thousands of engineers use the LabVIEW graphical programming environment to develop sophisticated tests, and control systems for structural testing using intuitive graphical icons and wires that resemble a flowchart. LabVIEW offers seamless integration with thousands of hardware devices, such as digital hydraulic servo valves using fieldbuses such as CAN and EtherCAT. LabVIEW provides hundreds of built-in libraries for advanced analysis and visualization for fatigue and modal testing. The LabVIEW platform is scalable across multiple targets that span your structural needs, from a desktop computer running Windows to a PXI test rack running a real-time OS to a hydraulic control system using CompactRIO and FPGAs. The flexibility of LabVIEW makes it ideal for advanced structural test needs.

Figure 5. LabVIEW Graphical Programming

Benefits of LabVIEW for Structural Test:
- Fast Programming – Program with drag-and-drop graphical blocks to create a flowchart representation.
- Hardware Integration – Connect to any instruments or sensor with built-in libraries and drivers.
- Multiple Targets – Develop and reuse code on Windows, Mac, Linux, real-time OSs, and FPGAs.
- Multiple Programming Architectures – Integrate text-based code or other models of computation.
- Professional User Interfaces – Interact with data using hundreds of drag-and-drop controls and graphs.

Configuration-Based Real-Time Testing and Simulation Software

NI VeriStand makes programming real-time targets even easier by adding configuration-based closed-loop control and stimulus capabilities for real-time testing and simulation. NI VeriStand also easily integrates with hardware to provide deterministic I/O. NI VeriStand is well-suited for an out-of-the-box software architecture that can be used to build static and fatigue test and control systems.
Figure 6. NI VeriStand Real-Time Testing and Simulation Software

Benefits of NI VeriStand for Structural Test:
- Closed-loop control, stimulus generation, and model execution
- Deterministic single-point I/O, data logging, and alarming
- Run-time editable user interface

Advanced Analysis and Signal Processing

LabVIEW, NI Sound and Vibration Measurement Suite, and NI DIAdem software feature hundreds of built-in signal processing and analysis functions that provide the specific algorithms you need for your applications. A few of the analysis algorithms for structural measurements include the following:

- Full- and fractional-octave analysis
- Modal analysis
- Rainflow
- Peak and root-mean-square (RMS) detection
- Fast Fourier transform (FFT), power spectrum, zoom power spectrum, and frequency response
- Averaging, filtering, and windowing

A subset of these functions can run on a real-time OS and FPGA, providing real-time, inline analysis. Additionally, NI software includes advanced visualization techniques to quickly display and analyze advanced processing techniques.

Powerful Data Management Techniques

Too often, structural test engineers produce large amounts of technical data with limited consideration to its storage and future use. Data is expensive, especially in the case of structural test applications where a transient event that needs to be recorded cannot easily, if at all, be replicated. Useful data is all too often lost, buried in unsorted, difficult-to-mine data files. Useful data might not even be known to exist because of a lack of proper visualization tools. National Instruments offers a three-staged data management solution that provides flexible and organized file storage, comprehensive search capabilities, and an interactive post-processing environment.
To map to the three requirements, the NI Technical Data Management (TDM) solution consists of three components: the TDM data model for storing descriptive information with your test files, NI DataFinder for searching and mining your test data regardless of file format, and DIAdem software for analysis, visualization, and reporting.

Figure 7. DIAdem Visualization

Professional Consulting and System Integration Services

The National Instruments professional services team consists of NI applications and systems engineers and the worldwide National Instruments Alliance Partner program, a network of more than 600 independent consultants and integrators. From design and specification to application development, project management, and integration of third-party software and hardware, take advantage of the team’s in-depth knowledge of NI products and applications when developing and deploying your structural test solution.

The NI services team can serve as part of your design and development team with an emphasis on design review, knowledge transfer, and collaborative development. Whether you are working on a single project, standardizing your development on the National Instruments software and hardware platform, or designing NI into your OEM product, the NI services team can work with your team to integrate NI software and hardware products into your application.

Alliance Partners have in-depth expertise in delivering complete solutions using NI products. From system design and architecture to coding, optimization, integration of third-party software and hardware, and deployment, the NI services team tailors each system to meet your company’s specific needs. The Alliance Partner program is a worldwide network of consultants, system integrators, developers, channel partners, and industry experts who partner with NI to provide complete, high-quality virtual instrumentation solutions to customers.

Conclusion

With modular instrumentation, deterministic control, customizable software, and professional integration services, structural test solutions from National Instruments can perform any test on any
structure, ranging from static load to aerodynamic test. NI structural test solutions provide unrivaled software and hardware integration, customizability, embedded intelligence, and value.