BEYOND ACCELERATION: DYNAMIC TESTING FOR HIGH-VALUE TEST ARTICLES

Complex spacecraft demand a vibration test system with multifaceted capabilities to reduce risk and ensure accurate and reliable data acquisition

// DALE A. SCHICK

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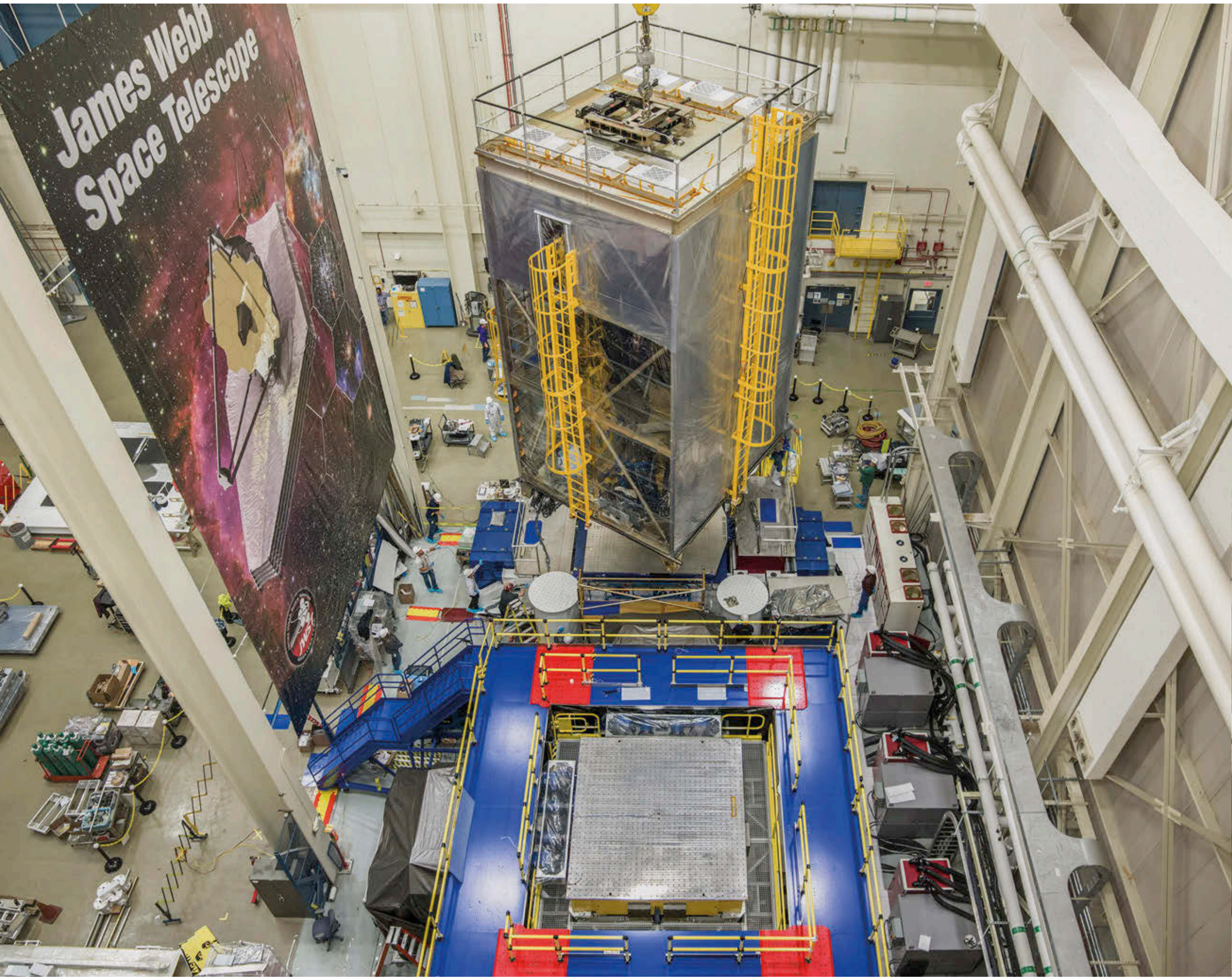


Spacecraft require dynamic testing to guarantee that their sensitive components are assembled properly and will withstand rather rigorous journeys to their final destination among the stars. Be it Low Earth Orbit (LEO) satellites for critical scientific missions, Geosynchronous (GEO) satellites for telecommunications, or more experimental deep space spacecraft, each has a specific set of dynamic testing to undergo in order to reduce risk and to ensure mission success.

THE EVOLUTION OF VIBRATION CONTROL

In the early days of dynamic testing, a shaker and a simple signal generator with variable gain were used to excite a structure with discrete frequencies or broadband random signals. The results of these manual sine burst or sinusoidal sweep methods were inconsistent at best and dangerous if not used properly. As a result, the primitive signal generators were soon replaced by significantly more reliable closed-loop vibration control systems.

Modern test systems are now arguably in the third generation and require more than just a control system and a shaker. Many major manufacturers in the aerospace industry now use a complete dynamic testing package including independent vibration overtest protection systems, advanced safety interlocks and large channel-count data acquisition systems. Some laboratories have even adopted built-in analysis software as part of their vibration control system, which allows dynamicists to process data while test technicians prepare for the next test.

m+p international is at the forefront of these developments and provide comprehensive dynamic testing packages that enable even the most advanced tests to be run safely and efficiently. To understand the complete system presented here, it is important to first examine each component and its individual contributions before viewing the system as a whole.

VIBRATION OVERTEST PROTECTION SYSTEM

Vibration overtest protection systems (monitors) are simple devices - an accelerometer or force transducer is fed into a basic limiting system wherein limits are entered in either peak or root mean square. Should one of these limits be reached, the system compresses the drive signal to ensure a soft shutdown of the shaker system. Alternatively, a relay-driven enable loop opens, signaling the vibration controller to end the test. The importance of a monitor system cannot be understated, as it can prevent unwanted physical movement of the shaker table even if all other systems fail.

But what about overtest situations that do not involve control system? There are many circumstances in standard Failure Modes and Effects Analysis (FMEA) of vibration systems that are not caused by a controller-gone-rogue or miscalculated sensitivity setting. These many and varied possibilities call for a more robust solution than a standard monitoring system can offer.

Recently, a major aerospace corporation discovered a transient pulse with almost infinite amplitude and frequency content was fed into their amplifier while the control system was inactive. After investigation, the root cause of the failure was found to be a frayed three-inch cable. The cable, which patched the drive signal from a single control system to several shakers, had been situated in a cabinet located in an area with a lot of human traffic. The simple act of someone leaning on the cabinet or grazing the cable while the shaker's amplifier was 'on' caused a relatively large shock pulse to resonate through the US$40,000,000 structure sitting atop the shaker table. The magnitude of this pulse? Unknown.

This scenario demonstrates the profound importance of a monitor system which has evolved to do much more than simply clamp a signal whenever a value is reached.

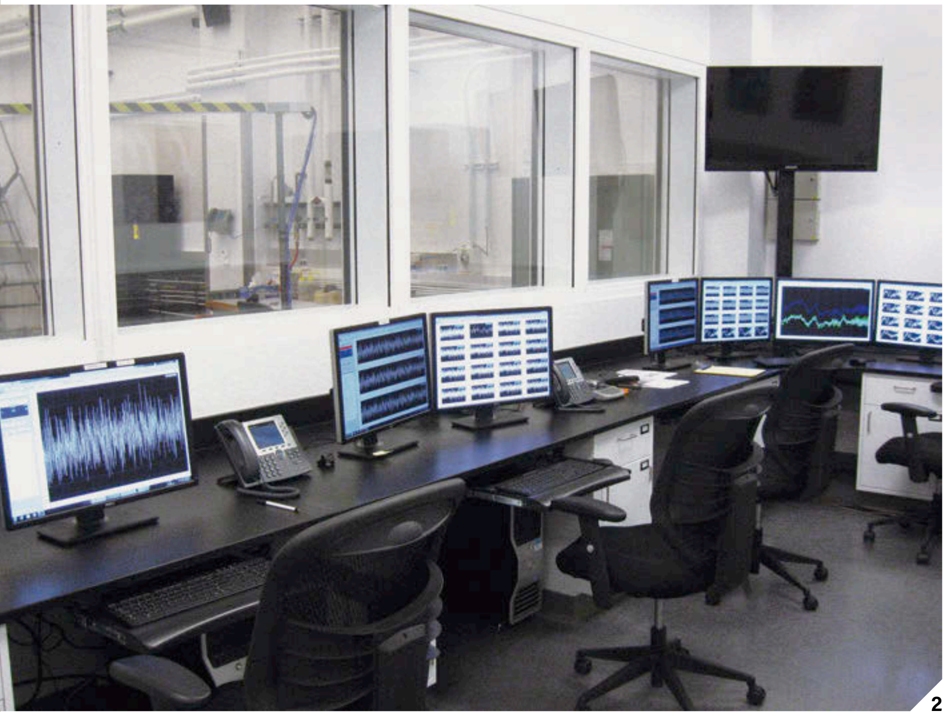
m+p Coda (Continuous online data acquisition) is an advanced system which actively monitors tens or even hundreds of channels, including amplifier current and voltage, strain, stress, and pressure while recording time domain data for post-anomaly analysis should any signal reach predefined levels. In the case of the frayed patch cable, the transient pulse would have immediately put the m+p Coda system into transient capture mode. The acceleration of the table, the amplifier current and voltage, and even the drive signal itself would be recorded. With this data, a review board determining the anomaly's impact on the test article could accurately asses the risk said anomaly imposed on the system and determine a path forward.

The protection offered by advanced monitoring systems is not limited to the context of amplifiers, shakers and vibration control systems. Pressurized tanks, battery voltages, critical structures and more can all be monitored and equipped with automated shutdown circuitry for safety. It is not only overtest protection anymore, it is simply protection.

1 // Positioning the James Webb Space Telescope onto the shaker table (*Photo: NASA)*

2 // m+p international's high-channel count systems used for large-scale spacecraft testing *(Photo: Johns Hopkins University APL)*

3 // Monitoring large structures from workstations



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VIBRATION CONTROL SYSTEM

Early closed-loop vibration control systems, though an improvement over the first generation signal generators, could only afford the end-user a handful of channels and test modes. Modern ones, like m+p VibControl, offer over one hundred channels in the active control loop and almost unlimited testing capability.

Due to the increasing complexity of spacecraft and the shakers that test them, it is sometimes necessary to have many accelerometers in the primary control loop average, which produces single or multiple drive signals. A secondary control loop can also be used for 'watchdog' channels that can notch or limit the drive signal within specific frequencies in order to protect sensitive optics, instruments, or even the spacecraft's composite structure itself.

The m+p VibControl system can have up to 128 channels in both the primary and secondary control loops all while performing calculations on pseudo-channels (which can also be limited) to monitor overturning moment, force and even geometric vector-RSS calculations for off-axis accelerometers. While controlling the vibration test, this system can also store high-frequency time domain data for advanced post-test analysis for a subset or for all the channels, including notch or limit channels. Built-in bridge modules can now provide dynamic notching for stress/strain gauges and pressure sensors for an added layer of control.

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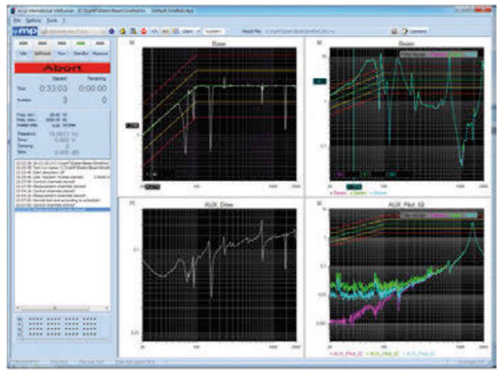

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4 // Online data reduction during closed-loop sine vibration test

5 // Rack mounted high-channel count hardware

DATA ACQUISITION SYSTEM

Most large structures require frequency and time domain recorded data in addition to the channels acquired by the control system. These additional channels can be useful for many things from determining the quality of workmanship of a component to characterizing the operating deflection shapes or even validating a systems Finite Element Model. A modern systems can provide a nearly unlimited number of channels for which to acquire this data. And more.

For example, the James Webb Space Telescope (JWST) recently utilized a 256-channel system from m+p international to not only record acceleration in sinusoidal sweep harmonic plots and time domain data during vibration testing but also as a 'watchdog' system to abort a vibration test should any of the aforementioned channels reach their limits. In this case, a test was aborted during a sine sweep when one of the spacecraft's critical components saw acceleration levels above the prescribed limit by opening an enable-loop that signaled a safe shutdown of the control system. The analysis team responsible for the JWST was able to use the recorded data to determine a safe path forward and ultimately completed the test successfully.

POST-TEST ANALYSIS SYSTEM

Just as critical as acquiring the data from a dynamic test, is analyzing the data to determine the test's efficacy and comprehensiveness. While every major spacecraft manufacturer and agency has a viable way to process their data, some are more efficient than others and have been able to bypass the typical report-then-analyze system of the past in favor of a more synergistic system.

One manufacturer, in particular, has employed the use of an offline version of m+p international's control software on several workstations networked to both the vibration control system and data acquisition systems. This configuration makes it possible to instantaneously deliver all data acquired during testing directly to the analysis group for post-processing.

Whenever time domain processing or more advanced calculations are needed, the group employs the use of m+p Analyzer software to complete the task. This configuration saves hours of single-line-flow in between the graduated testing levels and axes and frees the test engineers to perform concurrent tasks like making test preparations, repairing instrumentation and checking the health of their shaker system.

THE COMPLETE SYSTEM

At its worst, technology can be used to react to the errors of the past. At its best, it can predict and prevent future failures, working together elegantly to assist our most advanced endeavors. The spacecraft that are sent to the cosmos can do everything from providing information to remote parts of the world to hopefully providing answers to the myriad questions about the origins of our universe. Whatever the mission, the spacecraft manufacturers are primarily concerned with efficiency and risk. Increasing efficiency. Reducing risk.

With respect to just one small part of the monumental task that is testing a spacecraft, m+p international has made enormous strides to increase the efficiency and reduce the risk of vibration testing. This has been done by combining a revolutionary, standalone Monitor System with both a reliable Vibration Controller and extensive Data Acquisition System and finally networking all three to an extremely capable Post-Processing and Analysis system.

Though some of the aforementioned features are forward-looking, most are aerospace community requests, special developments, or ideas incorporated from the end-users of the systems. m+p international as one of the premier providers of these types of systems remains so precisely because they continue to listen to their customers. This community-driven spirit produces systems that are robust but easy to use. Powerful yet personal. \\

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