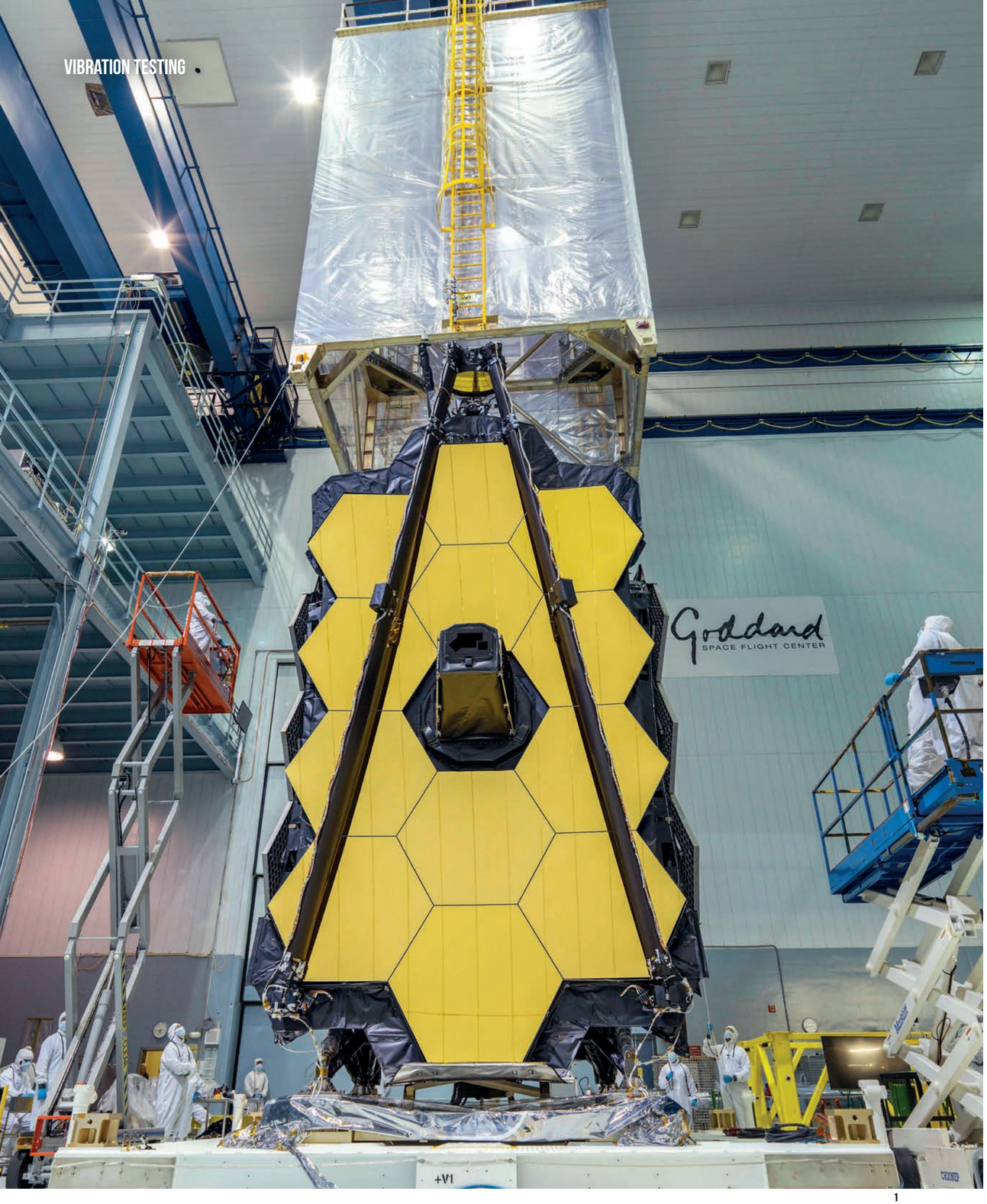

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SAFETY FIRST FOR SATELLITE AND SPACECRAFT TESTS

A solution that provides the smooth ramp-down of vibration testing has helped to safely test the world's most advanced space telescope

// THOMAS REILLY

The primary objective of satellite and spacecraft vibration testing is to ensure a high level of confidence in the survivability of flight hardware during launch. Unfortunately vibration testing is risky and the industry is full of examples where satellites and spacecraft were damaged during test.

Data Physics and Team Corporation combined resources to integrate advanced safety features into vibration test systems. These features detect and potentially eliminate anomalies that might otherwise cause damage to flight hardware during test. While it is standard practice to monitor for over-test conditions on the test article, the solution also monitors the entire test system environment, including the vibration test system itself and facility resources such as supplied power. This approach tightly links the health of the entire test environment to automatic and safe shutdown of the test. If a shutdown event is detected, the vibration test controller will deploy a user-configurable controlled ramp-down to prevent damage to the satellite or spacecraft – after the trip.

SWEPT SINE VIBRATION TESTING

Vibration qualification of satellites and spacecraft requires swept sine vibration testing of actual flight hardware. Swept sine qualification tests consist of subjecting the test article to sine vibration, typically in the range of 5-100 Hz. This is normally done at very high sweep rates to minimize the number of cycles at resonant frequencies. Test levels are selected to keep exposure of the test article within acceptable levels. Force and acceleration limiting prevent over-test. Notching, or reducing the vibration amplitude over specific frequency ranges, also prevents excessive loading of the satellite or spacecraft structure.

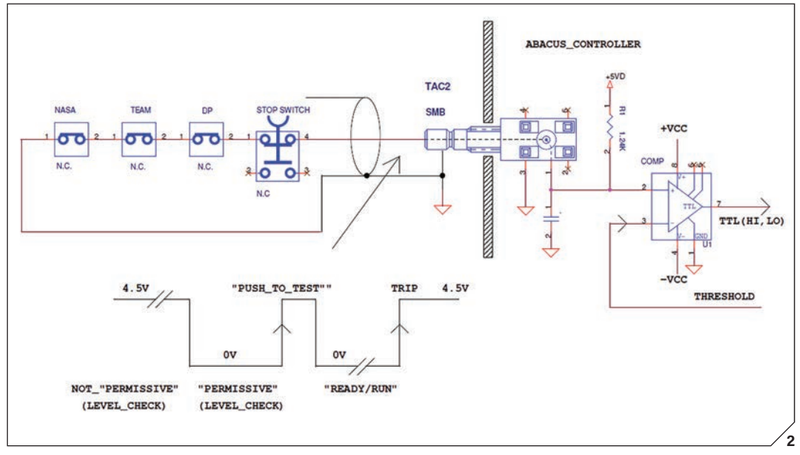
Testing starts with a low-level sweep and is repeated at increasing levels until the full-level sweep is completed. Between each sweep, data is analyzed, and changes can be made to control and limit profile levels to ensure maximum allowable levels are not exceeded. After the full-level sweep is completed, the low-level sweep is repeated and compared with the previous one to ensure there are no changes in the dynamic response of the test article. This sweep test sequence is performed for the three orthogonal axes.

SHAKING A SPACE TELESCOPE

NASA Goddard Space Flight Center recently completed vibration testing of the Optical Telescope Element/Integrated Science Instrument Module for the James Webb Space Telescope (JWST). The JWST test article weighed around 15,000 lb (6,800kg), with a high center of gravity that generated significant overturning moments when subjected to excitation during test. These complex dynamics, in addition to the extremely high value of the test article, further elevated the need for a vibration testing solution that integrated advanced safety features with sophisticated vibration test control.

The Data Physics and Team Corporation vibration test system used for the JWST testing consists of a 50,000 lbf (220,000N) electrodynamic shaker with a large slip table for the horizontal plane, and a guided head expander configurable for one or two 50,000 lbf shakers in the vertical plane. The shakers are controlled with the Data Physics Matrix Vibration Controller.

There are several critical systems which ensure the safe operation of the test. The slip table and guided head expander include linear variable differential transformer (LVDT) sensors to detect over-travel of the tables. The hydraulic power supply provides monitoring of hydraulic pressure and can provide a signal to shut down the test if the pressure is not within acceptable levels. The shakers also have an LVDT to detect armature overtravel and can provide a signal to shut down the test. The amplifier has settings for maximum



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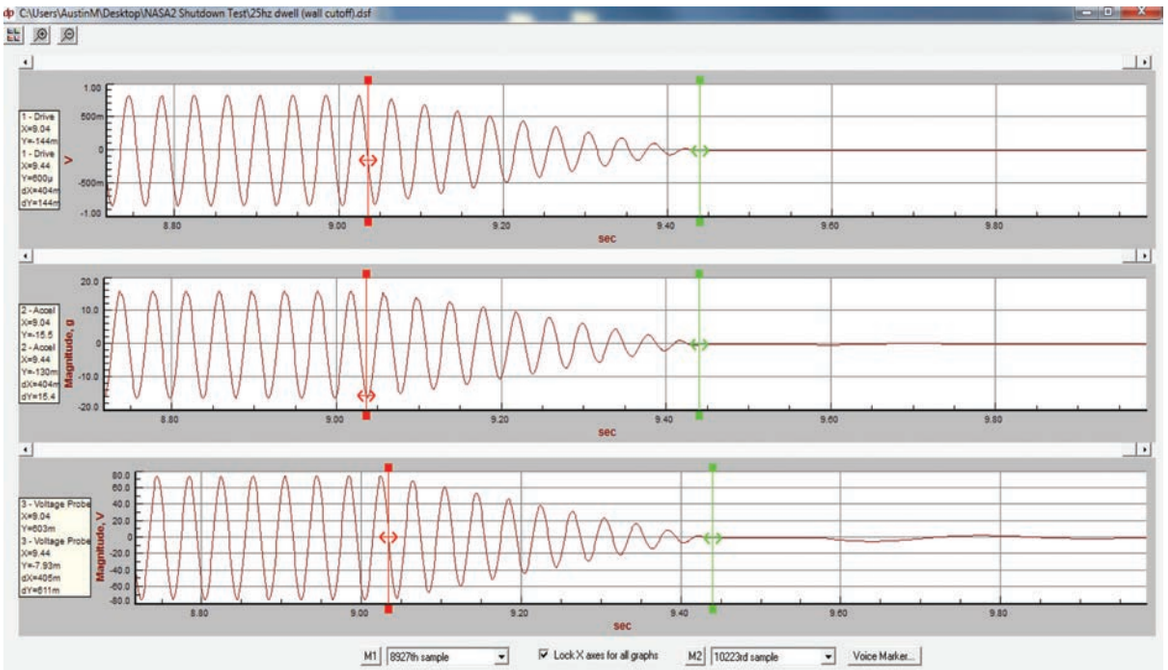
1 // Preparing the James Webb Space Telescope for testing at NASA Goddard (Photo: NASA/Chris Gunn)

2 // Shutdown relay schematic



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3 // Shaker drive voltage shutdown profile after complete loss of facility power

voltage and current. All these measurements are linked to the control system. Exceeding any of these levels will shut down the test.

As further backup protection, an independent measurement system monitors vibration at locations not measured by the vibration control system. This measurement system can assign abort profiles to any measurement channel. If levels exceed limits defined in these profiles, the independent measurement system can send a signal to the vibration controller to shut down the test.

"SOPHISTICATED MONITORING AND CONTROL PROTECTED THE SPACE TELESCOPE FROM POTENTIAL DAMAGE"

SAFE SHUTDOWN SYSTEM

The safety systems described above detect an over-test condition and trigger an immediate hard shutdown. While this quickly stops vibration from the shakers, the instantaneous stopping of excitation can create transients – rapid deceleration up to hundreds of *g*. This can be more harmful to the flight hardware being tested than the over-test condition that caused the shutdown.

Data Physics and Team Corporation have created a comprehensive system for managing all the safety systems and ensuring a smooth, safe, soft shutdown of the shaker system given a shutdown event and trip. The safe shutdown system used at NASA for testing of the JWST had several major components – the Table Health Control System, an advanced vibration control system, as well as a specially designed amplifier.

TABLE HEALTH CONTROL SYSTEM

This is a computer and sensor system that protected the JWST from potential damage due to unexpected vibrations, should failure of the vibration test system have occurred during testing. JWST tests required that no unexpected vibrations should be introduced during sine testing, such as from the failure of a bearing that supports the vibration table.

The Table Health Control System monitors various subsystems including overall hydraulic supply pressure, hydrostatic supply pressure locally at each bearing, and pneumatic pressure and position of the air isolation system. It also provides communication between the interlocks and the vibration controller. It must provide a 'permissive' signal, indicating that all systems and the table are working and in the proper state, for the vibration controller to start a test. Upon detection of a fault condition, the Table Health Control System will stop the vibration test at a user-definable ramp-down rate. It also controls the startup operations for the shaker systems, bringing the vibration test system from park to the operate state in a controlled manner. At the end of testing, the Table Health Control System turns off the hydrostatic bearing and air isolator.

VIBRATION CONTROL SYSTEM

The vibration controller has modifications to the sine signal generation code to ensure that all shutdowns from the controller include a 400ms ramp-down. The sine signal generation code runs in the digital signal processor hardware on the controller front-end and receives instructions from the control loop processing code. A watchdog feature looks for instructions from the control loop. If the control loop does not issue a command to the drive generation within the expected time, a soft shutdown is initiated. This mitigates risk of over-test due to controller malfunction.

All interlocks are connected to the tachometer input channel of the controller hardware front-end. The tachometer channel is continuously monitored to detect a trip of one of the interlocks. Trip of an interlock will initiate a soft shutdown within a few milliseconds.

An uninterruptible power supply (UPS) provides the ability to continue operation of the vibration controller instrumentation after loss of power. Should power loss occur, the UPS signals the controller to initiate a soft shutdown.

MODIFIED AMPLIFIERS

The amplifiers that deliver power to the electrodynamic shakers are designed to support a soft shutdown after complete loss of power.

Modifications to the amplifier include larger capacitors and a UPS that supplies power to IO modulators. Given a power loss event, these features enable continued operation long enough for the controller to smoothly shut down the test. \\

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