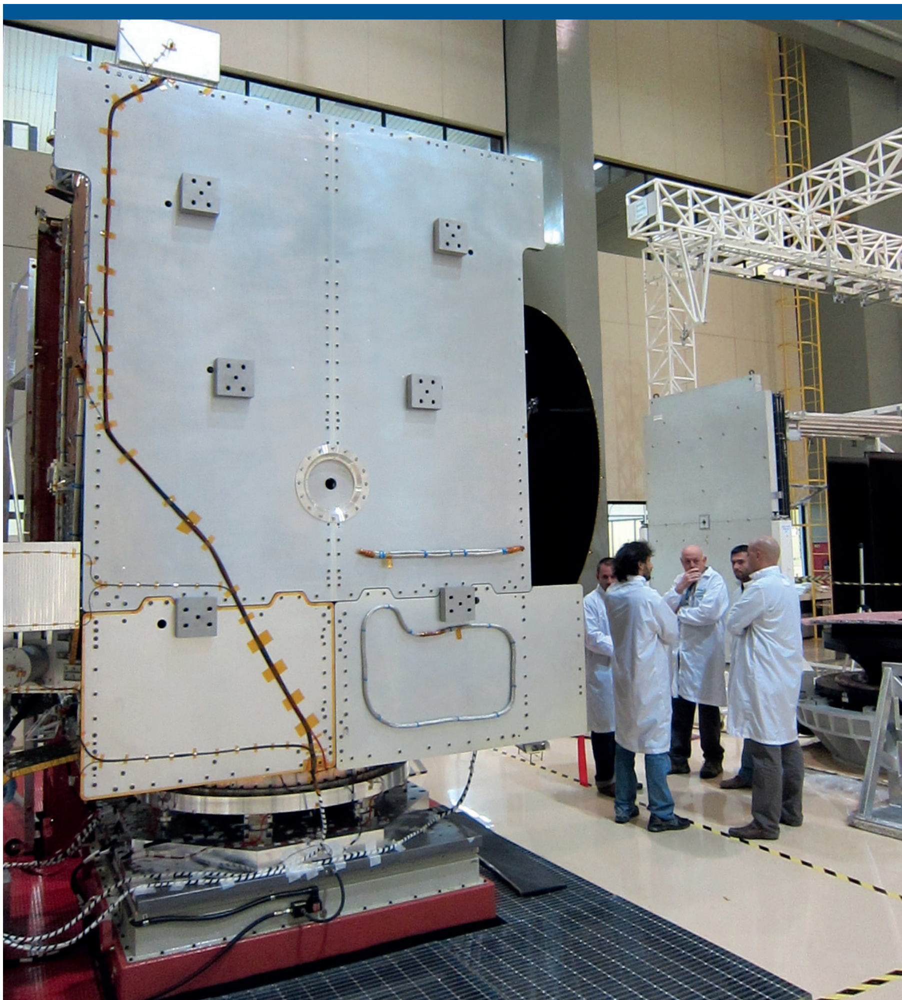
CASE STUDY

Brüel & Kjær
BEYOND MEASURE

SATELLITE QUALIFICATION TESTING AT INPE

For Brazil's space research organisation, safe tests with first-time data capture are vital when shaking precious satellites. Their vibration test system features advanced data acquisition, recording and analysis, with multiple user-interfaces for separate, specialized roles. Brüel & Kjær also provides servicing, updating and local calibration.



CHALLENGE

Provide safe qualification and acceptance vibration tests on high-value satellites, with extensive monitoring and customer observation facilities

SOLUTION

A large shaker combined with a 324-channel data recording system, and multiple tailored interfaces featuring workflow-driven test and analysis applications

RESULTS

- Post-processed results delivered to customers ten minutes after testing
- Multiple tests and analyses per day enabled
- Consistently safe, reliable and efficient vibration testing

INPE's Integration and Tests Laboratory (LIT) facilities provide extensive services for testing and qualification of space systems and components

BACKGROUND

The National Space Research Institute of Brazil (Portuguese: Instituto Nacional de Pesquisas Espaciais; INPE), is a research unit of the Brazilian Ministry of Science and Technology. INPE is the civilian research centre for aerospace activities, and offers testing services to other satellite manufacturers.

INPE's Integration and Tests Laboratory (LIT) has complete satellite test facilities, including EMC/EMI test chambers, thermal test chambers, and highly specialized acoustic, vibration and shock test facilities for evaluating the vibration behaviour, fatigue strength and structural integrity of satellites, sub-systems and components.

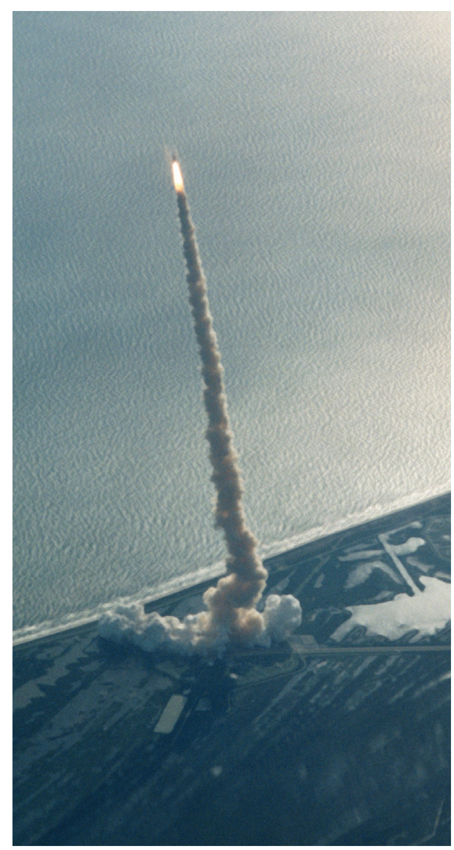
INPE's Integration and Tests Laboratory (LIT) is located in the city of São José dos Campos, São Paulo, has been in operation for some 20 years.

In this case study, test setups and results are highlighted and explained from vibration testing of Argentina's INVAP's ARSAT 1 satellite. INVAP S.E. is an Argentine high-technology company – the only company in Latin America certified by NASA to supply space technologies. INVAP's ARSAT1 satellite is a geostationary telecommunications satellite, the first of three intended to provide Argentina and surrounding countries with extensive telecoms services.

THE CHALLENGE

Satellites are inherently delicate and very costly structures. And as they glide serenely through space, they must be able to work under extreme operating conditions. They experience a near-vacuum, high electromagnetic radiation, and violent temperature transients – with one minute in darkness and intense cold, and the next in direct sunlight. And in addition to these tough requirements on operational integrity, during launch they experience extremely high levels of vibration and acoustical sound pressure which can severely damage or even destroy components. So it is vital that the whole satellite is thoroughly tested before the launch into space, including its sub-systems. There are no easy repair options.

INPE needed a data acquisition and analysis system to complement their vibration test systems, and enable mechanical qualification and



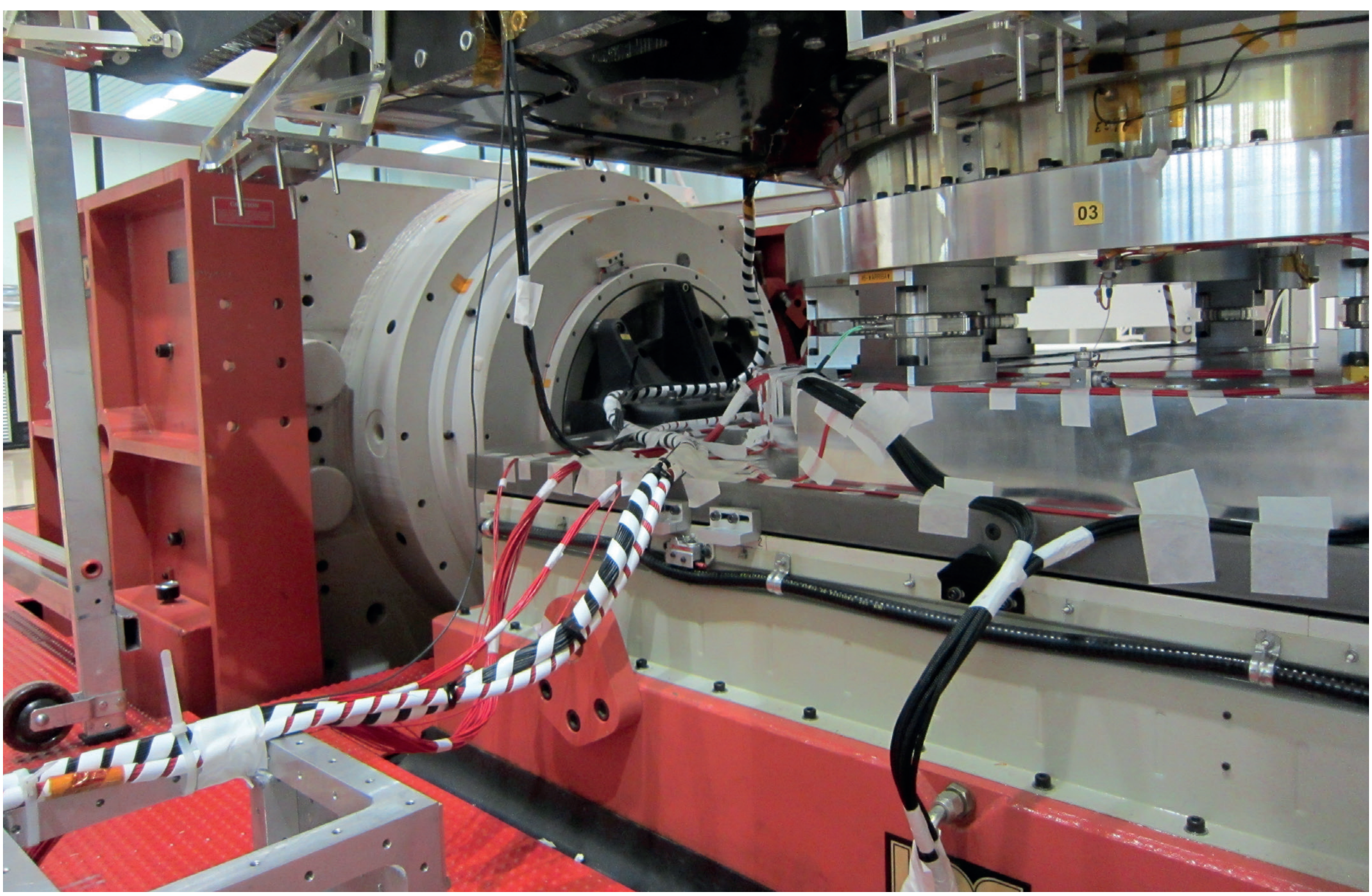
During launch, extremely high levels of vibration and sound pressure can severely damage or even destroy components acceptance testing of satellites - both their own satellites and for external clients. As with all satellite testers, INPE's main concerns were test safety, measurement reliability and efficient data processing. Such large, expensive tests of heavy and very expensive objects call for focused attention to detail from a large team. Satellite test engineers must ensure that over-testing with too much vibration or shock never occurs, and they must be sure to get quality test data recorded first time.

Test systems

The vibration test systems at INPE comprise two customer-specified electro-dynamic shakers designed to be able to handle specific payload requirements. A powerful water-cooled V984 applies the high force levels needed for satellites that can weigh several tonnes, while preventing over-testing through excessive vibration levels. A V964 is used for testing smaller objects and sub-components.

Acoustic fatigue testing excites the structure, simulating the launch conditions. It is performed in a large acoustic chamber.

A satellite in the acoustic test chamber as preparations are made to bombard the structure with acoustic energy



A custom adapter fixing the satellite to the slip table reproduces how the satellite is attached in 'real-life' inside the launch vehicle. This allows the satellite to be quickly removed and repositioned for testing in the x-, y-, and z-directions. Built-in force transducers measure the vibration exposure of the satellite and the force interaction between the launcher and the satellite. Argentina's ARSAT1 satellite was equipped with 300 accelerometers, strain gauges, and force transducers on the slip table

“SAFETY, DATA QUALITY AND TEST RELIABILITY ARE THE ESSENTIAL CRITERIA THAT THE SYSTEM PROVIDES.”

Heyder Hey, Head of Data Acquisition Department at INPE

Measurements and requirements are discussed by INPE’s Heyder Hey, Head of Data Acquisition Department, Nicole Silva, and Brüel & Kjær’s Harry Zaveri (seated)

Data acquisition and analysis requirements

Safety dictates a data acquisition system with a hundreds of channels that can show how the structure is behaving at every possible point during testing. Typically, a test lasts between one and three minutes, during which time the test operator’s only concern is for overloaded test points – if a point exceeds a maximum designated level, the test is aborted.

A traditional 300+ channel system can easily require over 15 km of sensor cabling, which would necessitate lengthy and exacting setup procedures. It must also then follow the test object through its various procedures around the lab. However, long cabling is expensive, decreases the signal quality, and increases the risk of cable failure – so an alternative solution needed to be found.

Hundreds of channels also generate an enormous amount of data. For example, recording 320 channels at 131 kHz sampling frequency for 10 minutes will produce a file of 96 GB.

Such large systems can be very heavy to handle in terms of setup, calibration, recording, and analysis. This has to be efficiently handled and presented to the user in such a way that users can easily choose the data to be viewed, while maintaining an effective overview.

At INPE, many different people must be able to view proceedings in different locations and for different purposes. Roles such as vibration test control require a different focus than data acquisition and recording. As a test house that sells its services, clients are often present during the testing of their satellites, and wish to monitor tests and quickly receive reports and the relevant data, in order to make their own analyses.

Guaranteeing ease throughout all these roles and uses is a challenge requiring an advanced and complex infrastructure that is easy to interact with at the different levels required and gives a simple overview.

> A traditional 300+ channel system could easily require over 15 km of sensor cabling. However, long cabling is expensive, decreases the signal quality, and increases the risk of cable failure. So a solution putting the data acquisition units as close to the sensors as possible was needed.

Accelerometer mounted on a satellite’s solar panel. Vibration levels as high as 60g were measured on the solar panels from just 1g measured at the shaker table. The maximum for a flight test is 80g

OUR SOLUTION

INPE's data acquisition and analysis system comprises a range of response and feedback control sensors, a 324-channel data recording system and workflow-driven acoustic fatigue, transient, random and swept-sine vibration test and analysis applications.

Test setup and data handling is performed by dedicated software that simplifies task-specific user-interfaces. These integrate and configure different aspects of the PULSE analysis platform in tightly defined workflows. Post-processing and data analysis takes place in the PULSE Reflex post-processing environment.

The real-time test data is then shared via LAN throughout the facility to specific rooms for different uses including customer test monitoring, control and recording.

INPE's data acquisition system undergoing testing prior to delivery. The distributed system architecture is shown here collected together, but each workstation is now established in different locations at INPE's facility. At left is the recording control station, the middle three screens show the remote monitoring screens, and right is the post-processing workstation

Multi-channel data acquisition

Like all satellite test systems, INPE needs many hundreds of response measurement channels, each being sampled at a high rate to capture all events in real time. Response sensors (accelerometers) are mounted over the complete structure, and wired to the data-acquisition system, to validate the satellite's structural behaviour and ensure that no part or component will experience excessive vibration during launch.

The 324-channel LAN-XI data acquisition system is mounted in mobile racks that can be wheeled around the test-bay locations together with the satellite for the different tests. This allows the use of short analogue cabling between satellite and data acquisition system ensuring optimal signal quality, and allowing the sensors to be left on the satellite between tests, even as the satellite is moved – so lengthy accelerometer setups only need to be done once. The system dramatically reduces cabling costs and setup time.

Test workflow

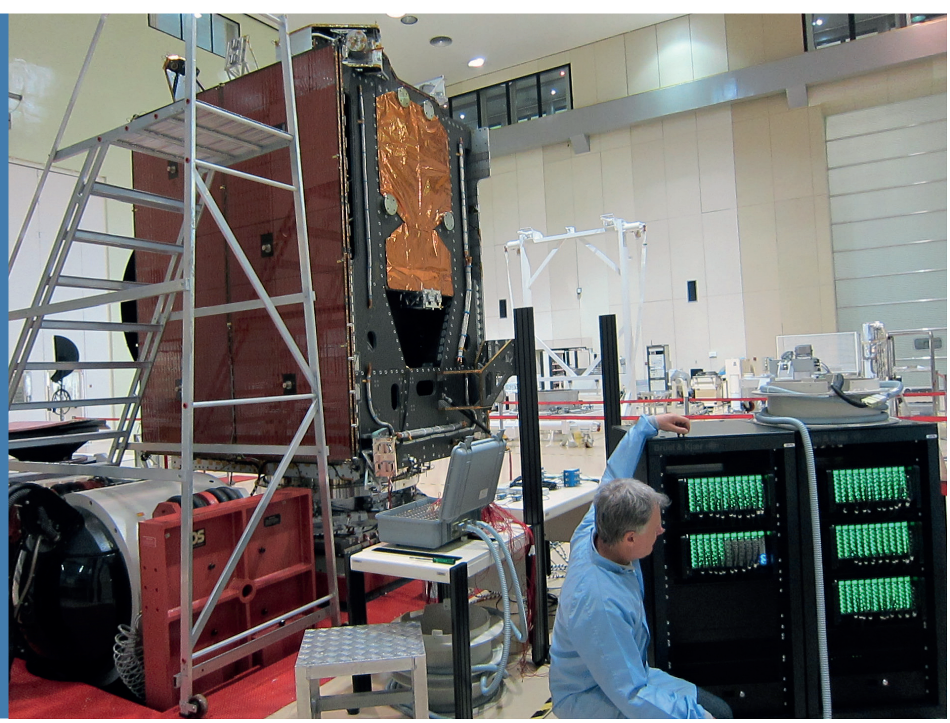
With so much data to handle, efficiency is vital and requires effective overview control software. The overall test sequence is organised through the data handling application DAQ-H.

DAQ-H unites all PULSE applications to give a dedicated user-interface that efficiently manages all setup, calibration, measurement,

Automatic input ranging

LAN-XI's Dyn-X technology eliminates the need for input ranging and removes the risk of over-ranges. This is thanks to dual, parallel analogue-to-digital convertors that seamlessly switch to cover the entire dynamic range, so that when one nears its limit, the other automatically takes over – producing an effective dynamic range over 160 dB.

INPE's system consists of 54 individual LAN-XI data acquisition modules, each with 6 channels. These are configured in five frames that hold 11 modules each. The frames are held in secure cabinets that enable them to be wheeled around the test area, along with the satellite



analysis, data management and reporting. This is configured for specific test types to ensure mistake-free, repeatable testing.

The complete test workflow is organised from a dedicated control console where the test engineers pre-plan the test, set up the data acquisition and the required analyses, calibrate the system, initiate and monitor the recording, initiate post-processing, visualise the results, create reports, and archive the data.

Setup

To set up tests, INPE's engineers simply use a Microsoft® Excel® file to pre-define channel setups, sensor sensitivity, and other specific front-end setup parameters. The data recording length and bandwidth is also setup here. All this information is then automatically incorporated in the DAQ-H control software, which sets up the PULSE system in seconds.

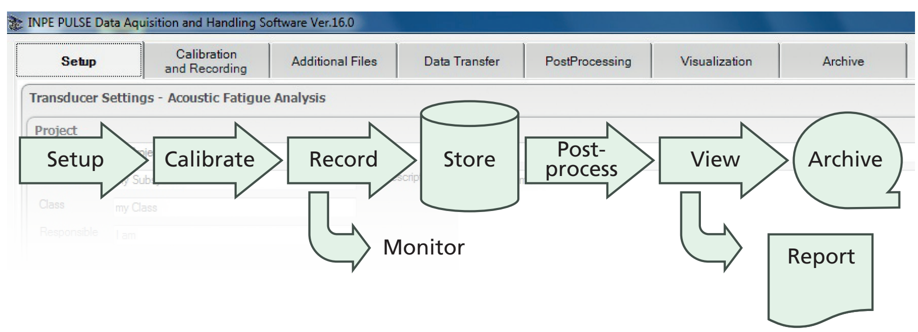
Data input is intelligently automated wherever possible to minimise manual inputs and their potential errors. Input channels can be grouped and organised, and meta-data labels added.

Recording and monitoring

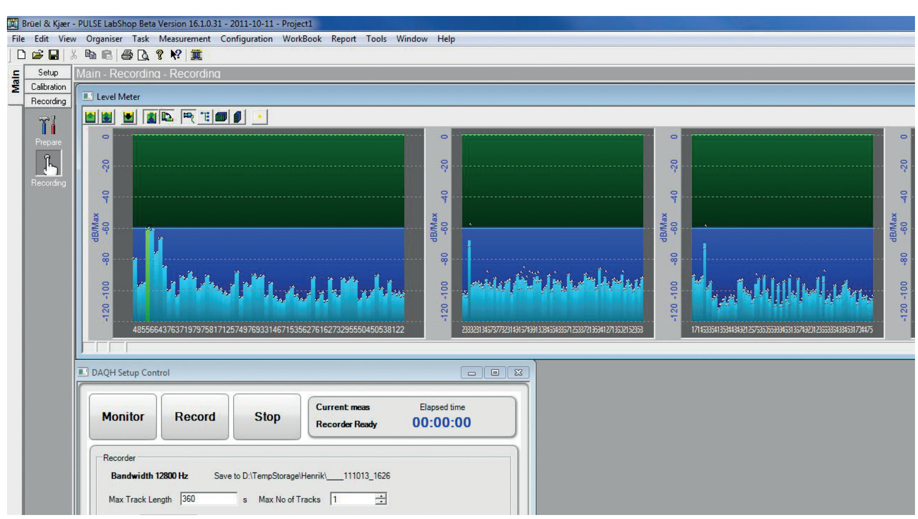
Even before recording begins, measurements start so that unplanned events such as tools being dropped can be tracked (line test). If for some reason testing has to be stopped, it can be restarted at precisely the same point.

Data recording is initiated by a single button and the remote monitor in DAQ-H displays chosen measurement channels, with colour coded level indicators. Real-time FFT, time, and nth octave analysis is performed on all channels during recording.

The main control console gives a complete overview, and also sets the display parameters for the remote monitor PCs. The left screen displays overall levels for all channels, plus recorder start/stop control. The right screen shows a remote monitor display – the same that can be seen in other locations. The display for every channel can be customised to show the desired real-time analysis as histogram level, time, FFT and CPB

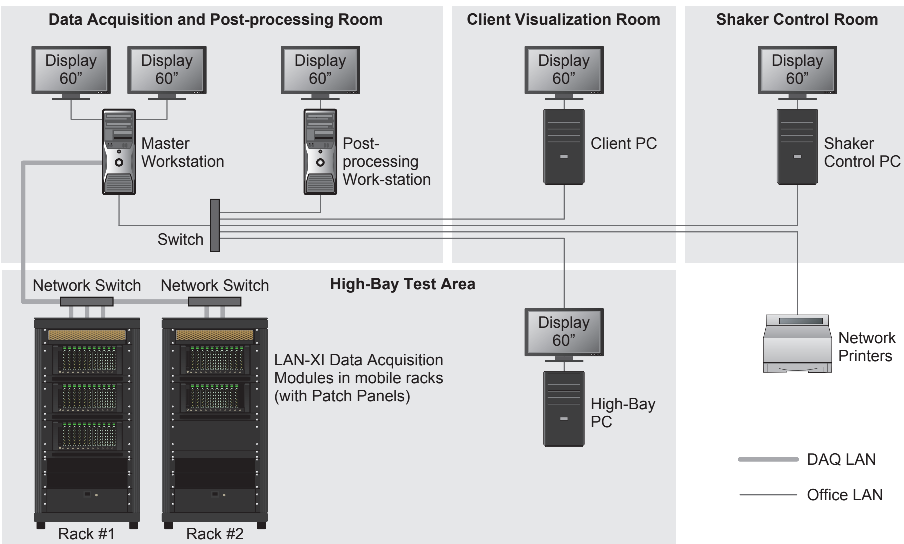


DAQ-H gives a very simple interface, with tabs at the top corresponding to each stage of the workflow. The client room only has the post-processing and reporting tabs available



Real-time monitoring of all 320 channels during testing, with simple test control buttons. All remote monitor users can select some or all of the measurement channels to monitor in real-time during recording

> Processed data is made available through the LAN network for the client to review and export elsewhere as required. Results are available within 10 minutes after testing is finished.



Viewing

Data is distributed by LAN to the various locations. All display parameters are controlled from the control console. Local, real-time monitoring of the test progress is performed on large screens in the test area, right next to the test object

Storing data

Data is stored automatically in a standard Windows® folder tree, and is searchable according to test, date and other meta-data parameters.

A tab at the top of the DAQ-H screen gives access to the data transfer function. It is simply a matter of copying folders to the desired network destination.

Post-processing

As soon as a test is finished and data safely recorded, post-processing can begin. A range of analysis functions exist for the different tests:

- Acoustic fatigue testing - (nth) octave analysis and FFT
- Random vibration testing - FFT analysis
- Swept-sine testing - transfer functions, over, fundamental and harmonic analysis, Total Harmonic Distortion (THD)
- Transient testing - shock response analysis

The satellite owners monitor the test progress in the comfort of a dedicated client room. Here the post-processed data is also made available through the LAN network for the client to review and export elsewhere as required. Results are available 10 minutes after testing is finished.

The client's view and report generation is driven by the Reflex viewer that gives a structured view to compare the tests and data in many different ways, and includes smart features to assist with data handling efficiency like colour coding etc. Access control ensures that their DAQ-H interface shows only the post-processing and reporting functions, so test operation is reserved for the control console alone.

RESULTS

Analysis of recorded test data takes place immediately after test completion. A suite of test applications are at hand to accurately determine the structural properties of the test object.

Comparisons between tests are a major part of satellite testing, as test engineers assess structural changes by comparing low vibration-level signature tests with higher level vibration testing. The extensive visualisation package vastly simplifies this process for INPE.

During testing of the ARSAT1 satellite, typical vibration test plans involve running a series of swept-sine load tests at increasing vibration levels. To check the structure's integrity between these tests, the same low-level signature test was repeated after each load test as a reference. Comparing results from the signature test with the load tests effectively identifies any structural changes induced by the testing.

System performance

In the words of Heyder Hey, the Head of Data Acquisition Department at INPE, "Safety, data quality and test reliability are the essential criteria that the system provides."

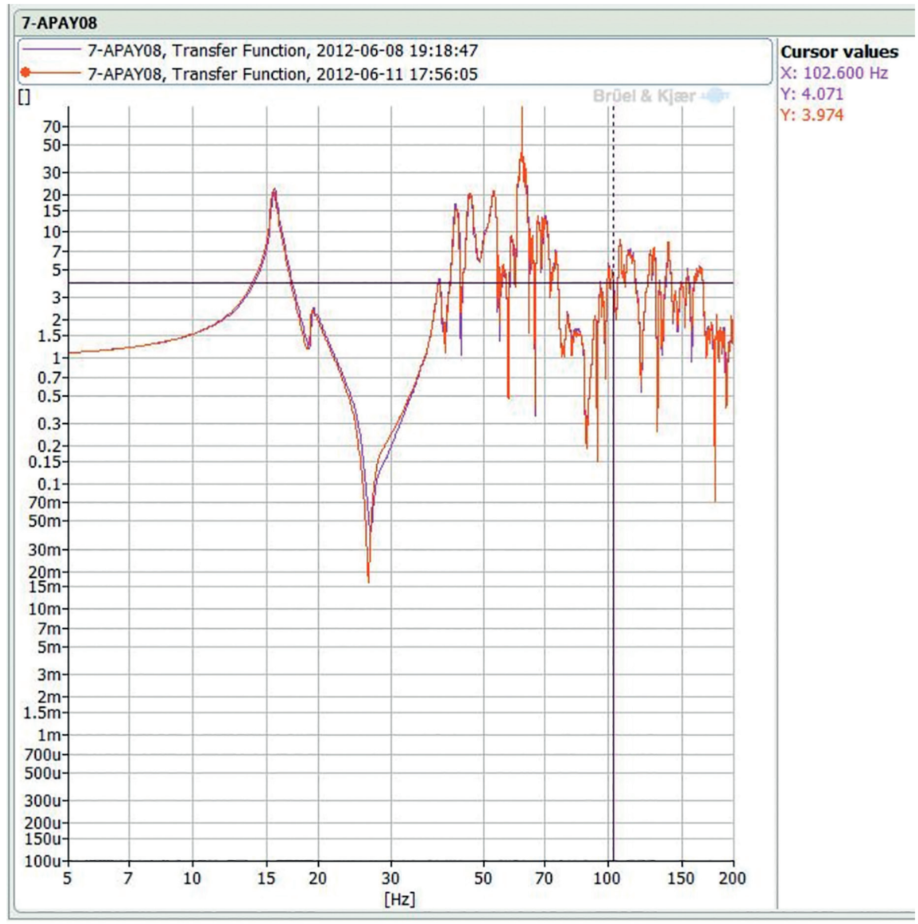
> "DATA RECORDING AND PROCESSING, AND DISPLAY/ANALYSIS OF PROCESSED DATA IS SO FAST THAT ONE CAN EASILY MAKE, ANALYSE AND REPORT THE RESULTS FROM MANY SATELLITE TESTS PER DAY."
>
> *Heyder Hey, Head of Data Acquisition Department at INPE*

Satellite testing systems are so bespoke they need precise solutions. The configurability of the DAQ-H system and the solutions experience that Brüel & Kjær is able to deliver is precisely what INPE needed in a user-centric way. The system allows both test engineers and clients to witness and validate the relevant recording data in real-time, and to get quick and precise access to the results that need investigating. As Heyder Hey says, "Clients only need top quality data, and this delivers it reliably."

Data throughput is fast, and test efficiency exceeds INPE's expectations. Results (data) can be quickly processed and sent elsewhere for specific analysis. "Processing and display/ analysis of processed data is so fast that one can easily make and analyse the results from many satellite tests per day," says Heyder Hey. "The ease of use features come from the specific expertise of Brüel & Kjær's people, and take the system over and above what we were hoping for."

Installation has been smooth. "We are very pleased with the level of service we have received, and with how receptive to our requirements Brüel & Kjær has been. They respond rapidly to any requests," says Heyder Hay.

Being modular and highly versatile, the LAN-XI system is ready for simple future developments including higher sampling and frequency rates and doubling the channel capacity to over 600 channels, by simply adding more modules.



Comparison of test signature data before/ after a load test during testing of the ARSAT1 satellite. Recorded data is analysed using Brüel & Kjær's PULSE Reflex sine reduction application software

Analysed results from a swept-sine test, comparing two measurement channels. Top–left is the COLA reference signal; top-middle are the overall levels; top-right is total harmonic distortion (THD); bottom-left is the fundamental level; and bottom-right the transfer function

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