REALTIME
Update

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A Newsletter
for Noise,
Vibration and
Electromechanical
Test Professionals

Satellite Testing With State-of-the-Art Vibration Control

by Josef Fritz
Deutsche Aerospace AG
Space Transportation and
Propulsion Systems

When the products you're designing are destined to spend their lives in space, you spend a lot of time and energy on reliability issues. After all, you can't call your customer service people and ask them to send a repair truck up to your satellite.

Aerospace manufacturers often turn to specialized testing and consulting laboratories to make sure their products can survive in the intended operating environments. The products range from small instruments to entire satellites, and it's our job to subject them to the kinds of forces they'll encounter once they're put into use.

Also in this issue:

HEWLETT PACKARD

Every day is a hard day at the office

If you think you have a stressful work environment, consider what a satellite has to endure. Among other things, it is subjected to extreme stress during the launch phase. Engines and launchers can produce tremendous oscillations and firing propulsion systems (such as pyrotechnic separation devices) create sharp shock waves through the structure.

Once in orbit, mechanical systems must perform as expected, even in the absence of gravity. Outside of Earth's atmosphere, extreme thermal loads, such as the temperature differential resulting from exposure to the hot sun on one side and cold space on the other, can lead to damage and early component failure if not addressed in the design stage. And the trial-and-error approach won't work up here in space; you need to be sure before you hit the launch button that the product will survive and do its job.

The solution is to simulate these internal and environmental conditions and to make sure the product can withstand all foreseeable circumstances. These conditions include climate (temperature, humidity, and pressure, for products intended for use inside Earth's atmosphere), heat transfer in a vacuum, and a wide variety of mechanical shocks and vibrations.

Simulating space on earth

As you can imagine, simulating these conditions is not a simple task. Deutsche Aerospace's test facility near Munich, Germany, has installed state-of-the-art systems for measuring both physical properties and responses to climate, thermal vacuums, and mechanical vibration. Our goal is to expose the product to all relevant influencing factors in its intended operating environment.

The tests we perform fall into two general categories. The first involves qualification tests for recently completed products (see figure 1). The goal here is to simulate the real environment as closely as possible to see whether the product meets its design criteria. In other words, we confirm or reject the calculations made during the design modeling stage. The second category involves acceptance tests, which represent the final check-out prior to launch (for complete systems) or to integration (for subsystems). We check the instrumentation and physical systems one last time to ensure that no potential assembly failures or product defects—or the disturbances these defects could cause—remain undetected.

Figure 1
Subsystem Tests
A Deustche Aerospace specialist prepares a test of the AESTUS engine for the European launch rocket ARIANE V.

For vibration simulations, our customers (both internal departments and external clients) generally define a vibration test profile that we then apply to the specimen. The vibrations can be sine, random, transient signals, or combinations of all three. The vibration is set up to expose the specimen to the type and level of vibration it will face while in use, without exposing it to irrelevant vibrations that may damage it during testing. For aviation products, for instace, we have to know exactly what kind of loads will occur during take-off, while in flight, and during landing. We also need to know when material fatigue will require parts to be replaced.

These vibration profiles can present quite a challenge when it comes to dynamic range throughout the test loop. Amplitude levels can be as low as ±0.2 g during a sine test or as high as ±250 g during a shock test.

High-performance measurement and analysis system

The centerpiece of our vibration test lab is a modular, digital vibration control and analysis system, the m+p VCP9000, developed by Mahrenholtz + Partner (m+p). This system is built around the HP 3565S measurement hardware, with m+p VibControl software running on an HP 9000 Series graphical workstation (see figure 2).

For data acquisition and signal conditioning, the HP 3565S front end is equipped with a signal processor module, 48 input A/D channels with 12.8 kHz frequency range and 72 dB dynamic range, and a programmable D/A output module with 16-bit resolution. The processing power built into the HP 3565S hardware provides very high performance vibration control with fast reaction times because it handles all vibration control functions, including abort checking and notching.

A fast control loop is an absolute necessity for the types of tests we run. Without this intelligent front end, we would've been forced to transfer raw data to the host computer, and performance would've been unacceptably slow. Not only does the measurement hardware provide real-time, on-line processing, it frees the computer for other tasks we want to run simultaneously (such as analyzing test data).

Figure 2: The m+p VCP9000 System
The m+p VCP9000 vibration control system is built around HP 3565S measurement hardware with m+p VibControl software.

The HP workstation runs the UNIX operating system with the X-Windows/OSF Motif Run Time Environment. Because the test software is fully integrated in X-Windows, the system is much simpler to operate than previous vibration control systems. The graphical user interface makes it easy to display signals of interest, including any number of active measurement channels, the control error, and the output signal sent to the shaker.

Taking vibration control to the next level

One of our requests to m+p during design of the system software was to go beyond traditional vibration control capabilities. We wanted to analyze measurement data in a variety of different ways. As a result, the m+p VCP9000 provides extensive analysis functions, including PSD, auto and cross correlations, transfer functions, and waterfall displays.

In terms of setting vibration limits, traditional vibration control systems allowed the user to define only a single amplitude level inside a specified part of the frequency band. In contrast, our m+p VCP9000 system lets us define up to 50 different limit levels for each of the 48 channels. We can even define slopes inside each of the 50 bands, not just fixed levels, providing unparalleled ability to shape the control signal to the customer's specifications. This greatly expanded shaping ability is representative of the flexibility the system offers (see figure 3).

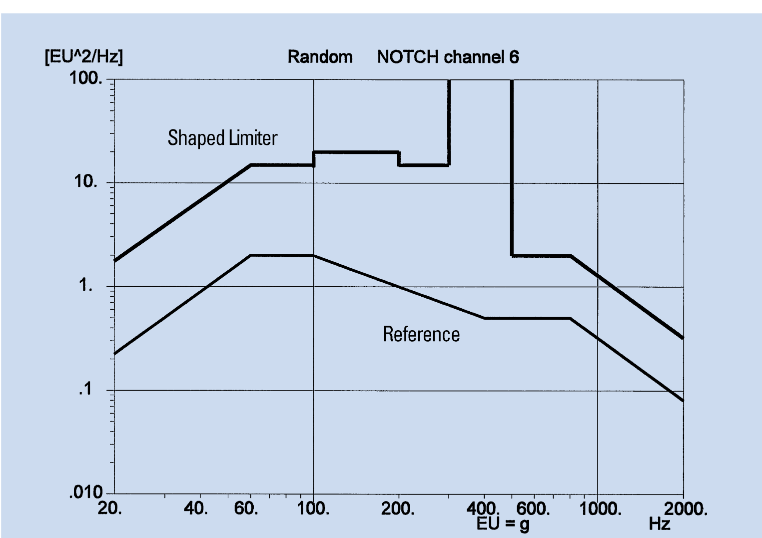

Figure 3: Advanced Limit Capabilities
This limit spectrum shows the m+p VCP9000's ability to include both fixed levels and slopes.

Safety and data integrity are also prominent concerns in vibration control. Innovative self-checking features reduce the risk of specimen damage or erroneous results.
All numerical inputs are checked for plausibility, and the system will draw the operator's attention to any numbers that seem inconsistent. The self-check also examines the control loop and measures system gain, displaying the results in a separate window for the operator's verfication.

Searching for resonance frequencies is another step we take to keep the control within safe mechanical limits.

The m+p VCP9000 system presents both a numerical listing and a graphical analysis of the frequencies that have the potential to cause structural damage.

The automatic notching function significantly reduces pretest preparation of complicated structures and protects specimens from excessive vibration. This notching is available in both sine and random excitation modes.

Putting the system to work

A typical application of our vibration control system is conducting the qualification and acceptance tests for the titanium propellant tanks used in satellites. These tanks are usually on the order of 1 meter in diameter, with empty weights of 30 kg and filled weights of perhaps 600 kg (see figure 4).

The instrumentation for such a test includes four control accelerometers on the test fixture holding the tank and a minimum of eight measurement accelerometers on the tank, along with strain gauges on particularly sensitive parts of the tank.

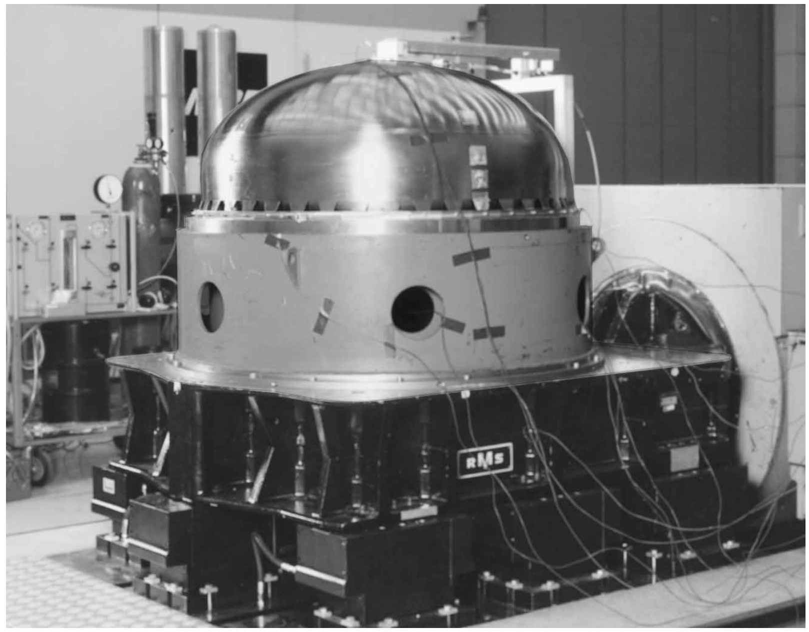

Figure 4:
Testing a Propellant Tank
This titanium propellant tank is instrumented and ready for a random noise vibration test.

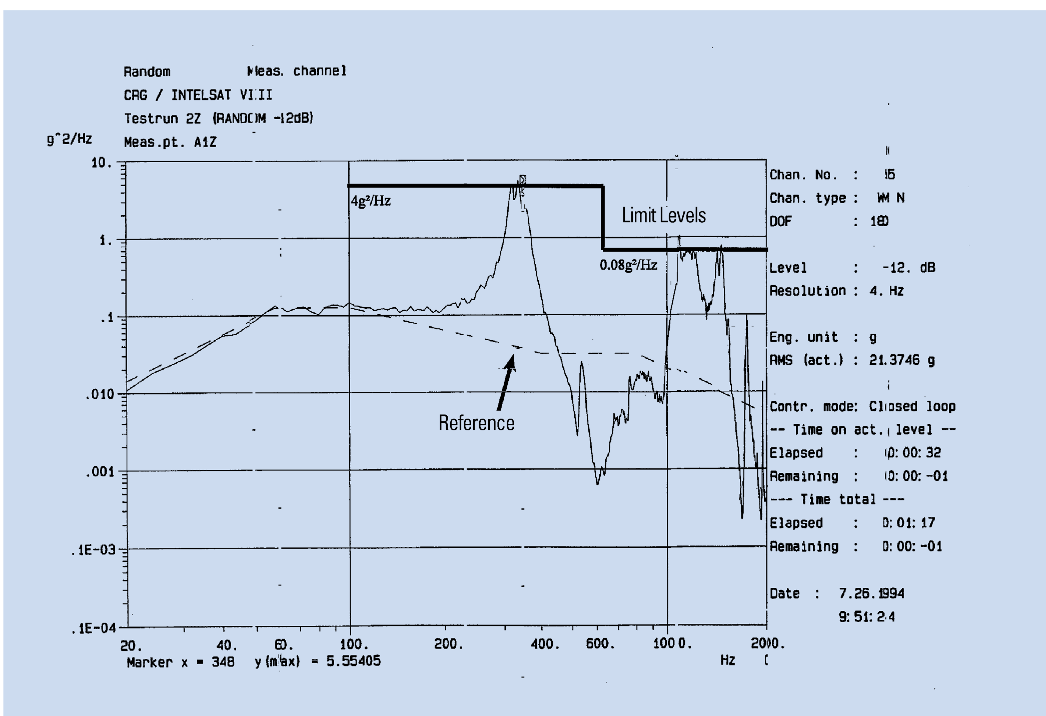

Figure 5
Limit Checking on the Response Signal
You can see the three points at which this response spectrum exceeded the preset limit levels. Figure 6 shows how the control signal was correspondingly notched.

For acceptance tests, we examine specimens on each of the three axes in the following sequence:

1. Search for resonances, using a 0.5 g sine excitation, over the range of 5 to 2000 Hz at a rate of 2 octaves/ minute.

2. A run using random noise at -12 db for 20 seconds; this run and the -6 dB run are done to verify calculations and check for proper system function.

3. Another check run using random noise at -6 db, also for 20 seconds.

4. The main run, with random at 0 dB (approximately 8 g_{RMS}) for 60 seconds.

5. A final resonance search, again with 0.5 g over 5-2000 Hz at 2 octaves/ minute.

As a safety backup, we employ limiters that take control if the response vibrations exceed a pre-determined limit.

Figures 5 and 6 show the results of a typical test, using random excitation with automatic notching engaged. In figure 5, you can see the frequencies at which the limiters took control. In figure 6, you see the corresponding responses and limits.

Keeping up with our customers

As our customers demand increasingly rigorous tests with specialized requirements, we need to stay one step ahead with systems that can make the necessary measurements. With high-performance measurement hardware and computers, innovative software, and years of experience with a wide range of test articles, we're ready for anything our customers can throw at us. ■

Josef Fritz manages Deutsche Aerospace's Environmental Test Laboratory in Munich, Germany, which provides both product testing and consulting on technical matters related to environmental labs and environmental testing procedures. He can be reached at (089) 607-23604.

For more information on the m+p VCP9000 vibration control system, check 1 on the Reply Card.

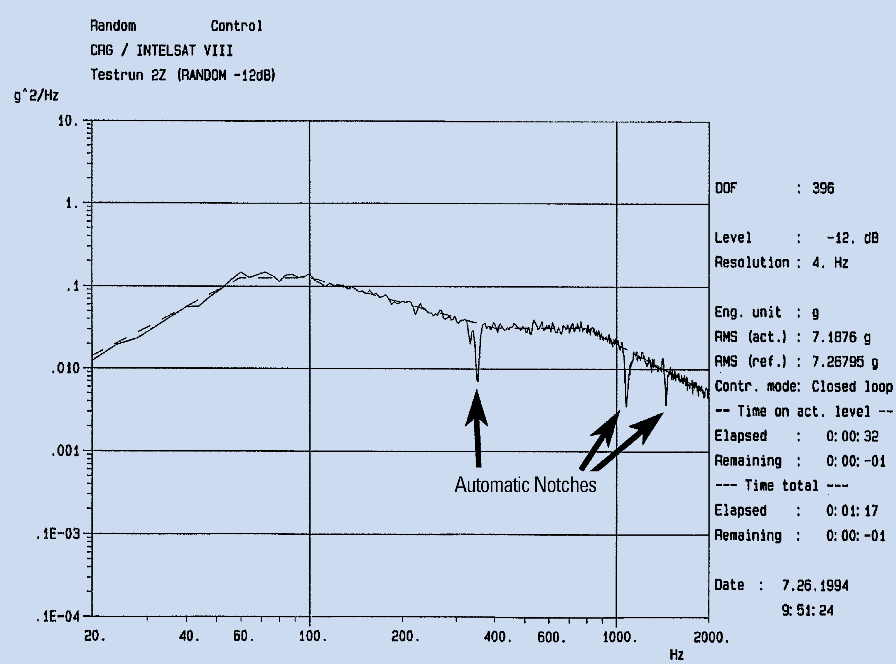

Figure 6
Automatic Notching on the Control Signal
This example of automatic notching shows three points in the control spectrum at which notching was applied (corresponding to the three points in the response signal that exceeded the preset limit as shown in figure 5).

Vibration Control Testing

by Al Prosuk and Guido Bossaert
m+p international

The vibration control measurements described in the cover story are one of the more intriguing and important applications of signal analysis technology. Engineers who work in product design and development, quality assurance, and qualification and acceptance testing put vibration control to work on products ranging from small consumer goods to space vehicles. This article provides an overview of the most common vibration control techniques.

Figure 1 shows a block diagram of a vibration control setup. As you can see, it's a basic control loop. On the excitation side of the loop, a drive signal generated by the vibration control system is amplified and fed to an electromechanical shaker. The shaker generates the vibration that is applied to the test article, which is usually contained in some sort of test fixture. On the feedback side, a control transducer measures the test article's vibration response. This signal is conditioned as needed, then measured by an input channel on the vibration control system. The controller in the system then compares this response vibration with the test specification, then adjusts the drive signal amplitude until the test article is vibrating at the required level.

Overview of the Major Test Approaches

Vibration control techniques are distinguished primarily by the type of signal used as the drive signal in the control loop. The type of signal then determines the type of measurements you need to make on the response. The most commonly used excitations are random noise, swept sine and transients (shocks).

Random noise is defined by a spectrum, typically power spectral density (PSD) versus frequency. The phase of the output spectrum is randomized so that the test article experiences the specified excitation in a random sequence. Random noise is a common choice in aerospace and military applications, where engineers attempt to duplicate such events as aircraft take-offs, rocket launchs, or driving over rough terrain. Random excitation is also popular as an environmental screening tool.

Swept sine, a technique that predates random noise, uses a flexible oscillator to provide the drive signals. You can control the start and stop frequencies, sweep rates, excitation levels and the breakpoints at which the output level is adjusted. Many specifications written around sine sweeps remain in force today, but random noise techniques are proving to be faster and more representative of real-world environments. As a result, random is increasingly replacing sine in new specifications.

The third commonly used excitation uses some sort of transient as the driving signal. Commonly known as shock testing, this approach can employ basic waveforms such as a half sine, triangle and square wave, or it can use previously recorded events as the drive signal. The last part of this article covers a special application of shock testing, the shock response spectrum test. Whatever the approach, shock testing with transient excitations attempts to duplicate pyrotechnic events (explosions, gunshots, rocket blasts, space craft stage separations, etc.), drops, crashes, and other real-life situations in which the test article is subjected to mechanical shocks.

Many of the capabilities and features of today's advanced vibration control systems are refinements of techniques devised as far back as the 1930s. These original systems used a variety of mechanical and analog electronic approaches that may be easier to conceptualize than the digital systems in use today. The following sections, therefore, start by describing the traditional approaches then contrast these with the benefits offered by today's leading-edge digital approaches.

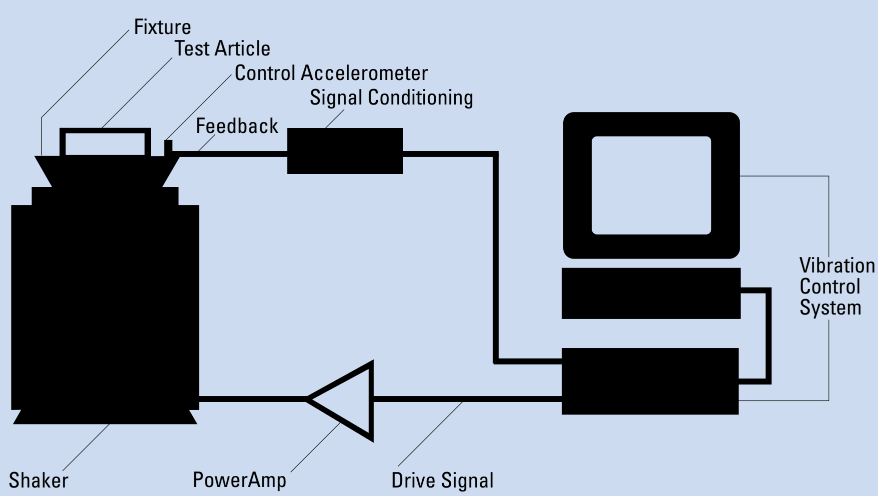

Figure 1
A basic vibration control setup is a control loop that includes the drive signal, the test article, vibration sensors on the feedback side of the loop, and a vibration control system for measuring the response and shaping the drive signal.

Random Vibration Testing

Random vibration control systems originally used banks of fixed analog filters, with 40 to 100 of them in a rack (see figure 2). Having a number of filters let engineers shape the amplitude of the drive spectrum, much like an audio equalizer shapes sound over various frequency bands. You could consider each filter equivalent to a line of frequency resolution in a digital system. A tracking filter sweeping through the frequencies provided the response spectrum measured at the test article.

These systems were relatively inexpensive and easy to understand: you simply adjusted the gain of each filter until the overall response was at the desired level. However, getting one of these tests to equalize (the point at which the test article is vibrating at the desired level, in a controlled, stable manner) could take as long as eight hours. In some cases, these systems were unable to achieve stable control loops, making testing impossible.

Today's digital systems use techniques such as the FFT to simulate those banks of filters, only with far more frequency resolution and greater dynamic range. High-speed computer workstations can achieve equalization in seconds and can ensure control across a wider range of test situations.

Swept Sine Testing

Swept sine testing is perhaps the easiest approach to understand: you simply sweep an oscillator across the frequency range of interest, apply this drive signal to the test article, and measure the results. In addition to continuous sweeps, the swept sine approach offers low cost and good dynamic range.

A complete system requires an array of gear, however: the oscillator for the drive signal, tracking filters and servos to control the response, level controllers to shape the reference spectrum and usually, human controllers to watch the test and to keep track of the test time (see figure 3).

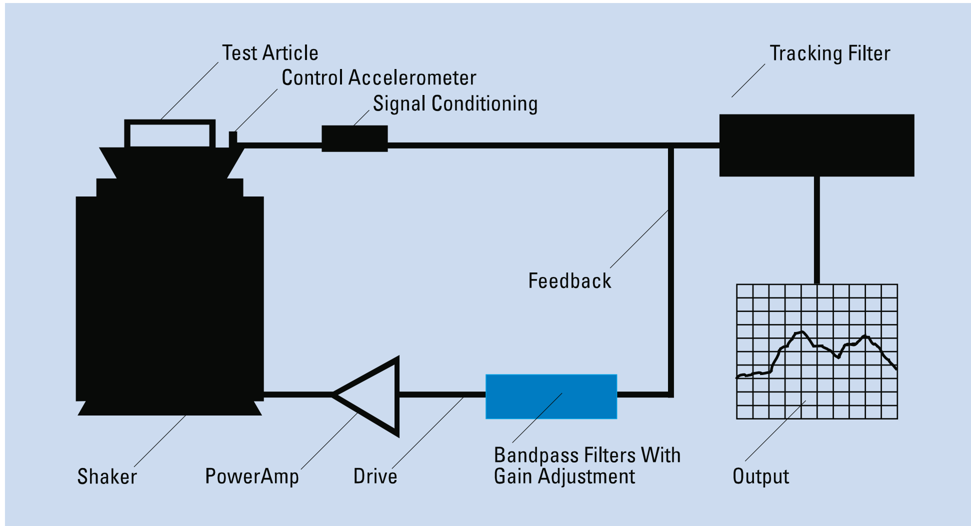

Figure 2
Analog systems using random noise relied on a bank of bandpass filters to shape the drive signal; today's digital systems use the FFT and other techniques to emulate the bank of filters.

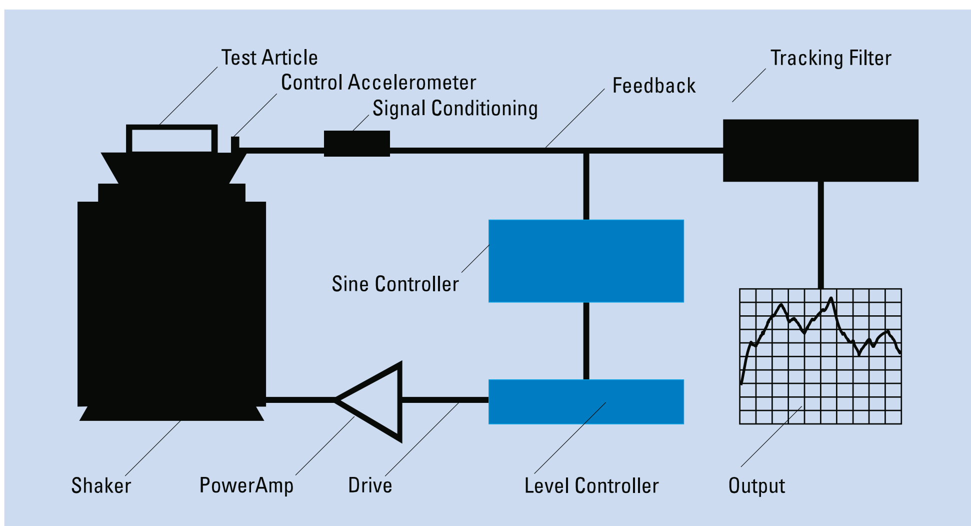

Figure 3
Digital hardware and software routines replace much of the analog equipment used in traditional swept sine systems.

Even with its operational complexity, swept sine's long history means that many vibration test specifications (particularly in military applications) involve variations of sine profiles as the testing technique.

Digital systems provide swept sine testing by using a digital-to-analog converter to create the sine waves. Although this approach doesn't produce the purely continuous sweep of a traditional swept sine system, it can generate sine waves that meet the needs of most swept sine tests. Moreover, the numerous advantages of today's digital approach usually outweigh swept sine's few advantages. Digital benefits include greater system flexibility, more opportunities for data analysis and reporting (since the data are in digital, computer-readable format), increased reliability in terms of both system uptime and control loop tracking accuracy, and faster (and therefore less expensive) tests. Perhaps most importantly in many cases, random excitation is more representative of the real-world environment. As a result, new test specifications increasingly involve random vibration or a combination of random and sine.

Shock Testing

Shock testing is based on the simplest model of all: basically smacking the test article abruptly. The earliest approach used a drop table, which consisted of a pair of stiff columns, a good heavy base and an adjustable drop plate to hold the test article (see figure 4). A transducer on the drop plate recorded the event on a chart recorder or oscilloscope.

By varying the number and shape of lead energy absorbers placed under the drop plate, engineers could determine the shape of the shock. As you can imagine, shaping these absorbers was something of an art. Each new test setup — and sometimes even each new test article — required repeated trial drops to get the right combination.

Digital systems with their electrodynamic shakers and amplifiers have replaced many drop tables. The new systems can generate preprogrammed waveforms or pulses, either one at a time or in a series. With today's systems, you can also use recorded data as the control pulse, a useful test not at all possible with a drop table.

In addition to great flexibility, digital shock testing also offers improved repeatability from test to test.

Drop table tests will not disappear, however. Some shock tests require very high displacements, short durations or very high energy levels that shakers can't provide. Even in these situations, however, digital systems with general-purpose vibration measurement capabilities can save time in documentation and data reduction.

Shock Response Spectrum Testing

One of the oldest techniques for defining a shock or large transient is the shock response spectrum (SRS) method. This technology evolved from efforts in the 1930s to quantify the energy put into a ship when firing a battery of large caliber guns. A group of clever engineers devised banks of mechanical filters to measure the shocks generated throughout the ship.

Current techniques use one transducer at each test location and FFT analyzers to process the data, either

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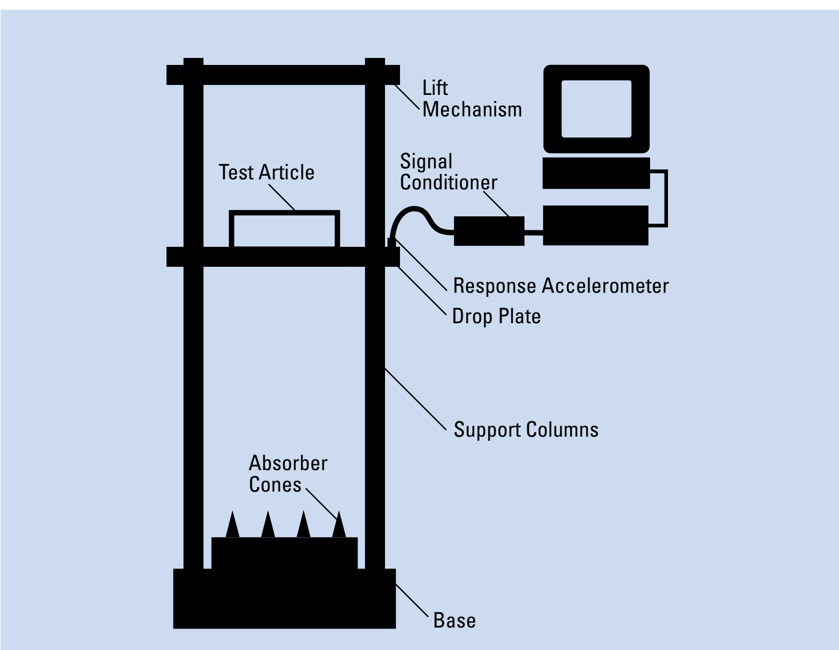


Figure 4
Electrodynamic shakers and digital test systems have replaced the traditional drop table in many shock test applications.

on-line or from data recorded to disk or tape. SRS applications have grown to characterize shocks from such events as stage separations of rockets, explosive separation of bolts holding payloads onto rockets, tank cannon firings and earthquakes.

One of the biggest advantages of SRS testing is the enormous body of accumulated knowledge that helps engineers correlate the measurement results with the potential for damage to equipment mounted in the vicinity. This correlation of damage potential and measurement values has not been as well developed for the other techniques.

Some engineers question SRS, however, particularly in light of current measurement capabilities. The biggest potential problem with SRS is that an infinite number of time waveforms can be found to generate a particular measured spectrum. In other words, a powerful and potentially damaging pulse can have the same SRS as a much less damaging one. Moreover, two testers synthesizing pulses for the same SRS can arrive at different results.

In spite of these arguments, SRS will continue to be used in vibration testing, simply because no other technique is as yet as useful at correlating measurements to damage potential. ■

m+p international is an HP Channel Partner focused on data acquisition and control applications in the fields of vibration, noise and fatigue. The telephone number at the company's Cedar Grove, NJ, office is (201) 256-5282.

Realtime Answers

Question: I want to make hard copies in the field with an HP 3560A but am unable to find a portable graphics printer with a serial input. What do you recommend?

Answer: We recently tested a solution that works with both the HP 3560A and HP 3569A. It uses a special intelligent cable assembly that converts from serial to parallel. The device is the Model 2029 manufactured by Patton Electronics.

The interface needs to be connected to the analyzer's RS-232 port before the analyzer turned on. Connection to the printer needs to be the last step to ensure correct interface operation. Our test used both the HP 3560A and the HP 3569A with a Portable DeskJet. Before printing, the DeskJet needs to be set to a resolution of 75 dpi. This is done automatically by the HP 3569A. HP 3560As with firmware of A.00.02 or lower do not set the printer resolution. You can set the printer resolution with a PC by sending the following command to the printer:

Ec *t75R. (Ec = Escape)

We believe the adapter will work with many other parallel printers. The interface is plug-compatible with both the HP 3560A and HP 3569A. Power to drive the conversion circuitry is supplied by the RS-232 interface.

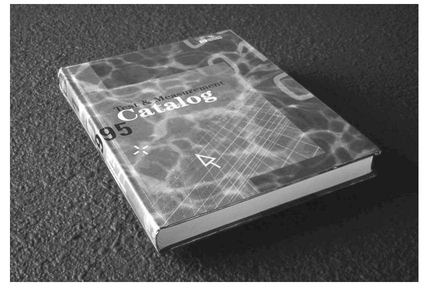
The product is available as the Patton Model 2029 Parallel to Serial/ Serial to Parallel Interface Converter. For more information, contact Patton Electronics directly at (301) 975-1000, from 9 AM to 5 PM Eastern Time.

Question: Do the new HP 3565 Digital Signal Processing modules offer any improvements in the real-time rate of my HP 3565 system?

Answer: HP recently upgraded the HP 35651B and HP 35654A DSP modules to the HP 35651C and HP 35654B. The older modules use the Motorola DSP 56001 and the newer modules use the Motorola DSP 56002.

The newer modules do provide slightly higher real-time rates. For most users the real-time improvement is seen as an increase in the number of channels that can stay in real time. Typically, you will be able to double the number of channels you currently can keep in real time.

The HP 35651C and HP 35654B with a 16 MB memory option offer the maximum performance for time capture, display maps and order tracking. The HP 3566/67A revision A.03.03 uses the memory and faster DSP to provide order tracking of fast machinery run-ups or run-downs. ■



Sign up for the 1995 HP Test & Measurement Catalog

The HP Test & Measurement Catalog is the one place you can find descriptions and specifications for HP's entire line of instruments and accessories. The 1995 edition will be printed in December, and we'll be happy to send you a copy when it's ready.

Check 5 on the Reply Card.

REALTIME Update

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