REALTIME
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A Newsletter for Noise, Vibration and Electromechanical Test Professionals

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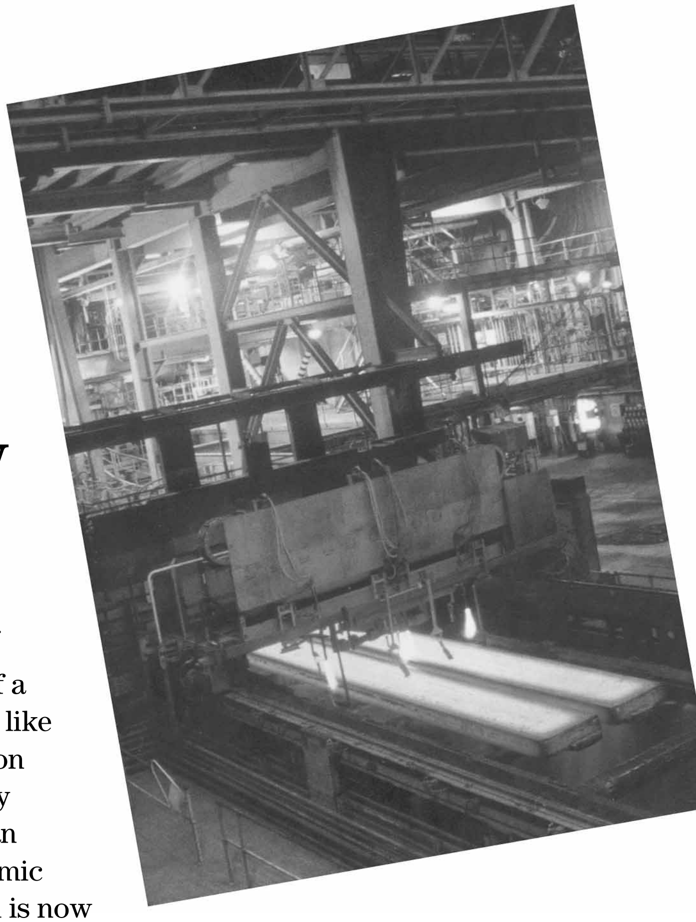

Boosting Product Quality *and* Machinery Lifespan

by Andre Szczepanik and Mathew Boek, Vimac Pty. Ltd.

The harsh environment of a steelworks may not seem like a place you'd find precision signal analyzers, but many aspects of steelmaking can benefit greatly from dynamic signal analysis. BHP Steel is now introducing a system combining Vimac custom software and Hewlett-Packard analysis equipment at its Slab and Plate Products Division in Port Kembla, New South Wales, Australia. This installation is unique to BHP's facility, but the basic concepts apply to a wide range of industries.

Machine condition monitoring is a well-known technique for early machine failure prediction and maintenance schedule streamlining. We've employed MCM in a PC-based system for on-line monitoring of the slab caster mold oscillator system, part of the continuous steel casting process.

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A machine designed for smooth oscillations

One interesting aspect of continuous steel casting is that, unlike most process equipment, the machinery in question is designed to oscillate. The continuous casting process essentially involves the pouring of liquid steel into a mold from which partially solidified steel is continually withdrawn from below.

One continuous slab of steel can be cast during a long period because the process does not need to stop when a ladle of molten steel runs out. It uses the steel in the tundish (a holding tank that supplies a continuous stream of liquid steel into the mold) until the next full ladle of steel is in position. To give you an idea of the size involved, the cross-section of a slab measures 300 mm × 2500 mm (roughly 12 inches × 98 inches).

To prevent the moving steel slab from sticking to the mold, the mold oscillates. Also, a lubricant is applied from the top of the mold, and the oscillation helps distribute the lubricant properly throughout the mold.

Keeping a close eye on oscillation

The mechanism controlling the mold is quite complex, as you can see in figure 1. The equipment includes a motor, gearbox, eccentrics and eccentric arms and an elaborate bearing system. The motor drives the eccentrics, which in turn move the eccentric arms up and down. This movement is transmitted to the mold table by the oscillator bearings.

BHP asked us to design a monitoring system for the mold oscillator. Monitoring the oscillation and other aspects of the process is important from both the process and maintenance points of view.

A key reason for monitoring is to provide accurate information to the process controller to warn of increasing friction between the mold and the steel slab. Reduced friction diminishes the possibility of "breakout." This is a condition in which high surface friction in the mold tears the solidified skin of the slab, releasing molten steel from its core. If breakout occurs, the caster must be shut down (sometimes for as long as several days) while the spilled steel is removed and necessary repairs made. Breakout is extremely costly since it involves extra labor charges, repair or replacement of parts and significant lost production time. Breakout can also be hazardous to plant personnel.

How the monitoring system helps

The primary aim of the monitoring system (called *MOCMS* for mold oscillator condition monitoring system) is to reduce the maintenance down time of the oscillator through the use of condition monitoring to accurately predict maintenance requirements. The system facilitates condition-based maintenance and failure avoidance or prediction. The savings resulting from these alone cover the cost of system.

Indirect benefits come from more accurate control of the oscillator, leading to better product surface quality and less chance of breakout caused by undesirable mold movement. The system also helps optimize mold lubricant performance.

Designing a PC-based monitoring system

MOCMS uses custom Vimac software and the HP 3566A PC-based spectrum analyzer. To gather the necessary input data, we installed eight vibration transducers on the mold oscillator assembly. There are also two strain gauges and two proximity switch sensors. Together, these

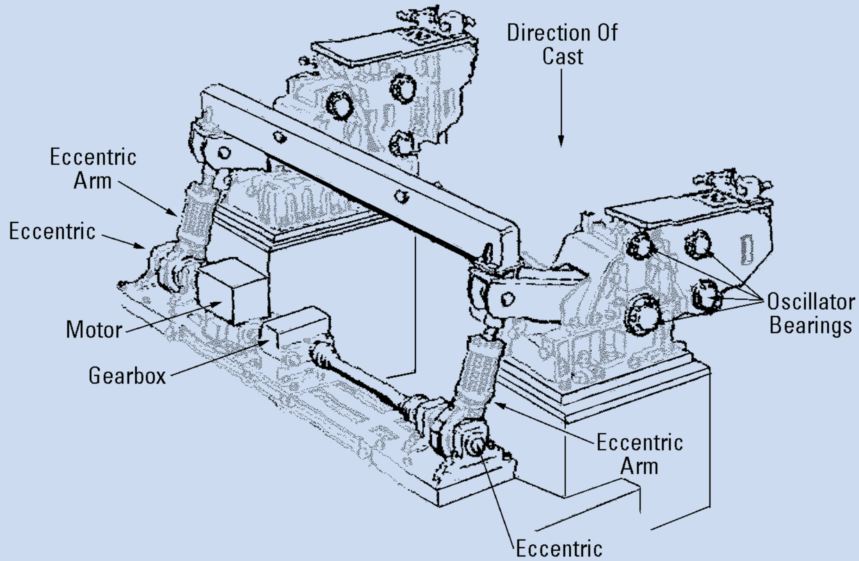

Figure 1
The mold oscillator mechanism.

transducers track the vertical and horizontal movement of the mold table and provide strain readings on the eccentric arms.

The system also monitors process parameters, such as casting speed and drive motor current, using dedicated lines. The current meter that monitors line current drawn by the oscillator's motor points out increased loading, which can indicate bearing wear or other mechanical problems. All signals are connected to a Colorado Data Systems multiplexer, and from there into the HP 3566A mainframe (see figure 2).

The key monitored parameters include:

- *Friction*, which reveals the amount of friction between the shell of the cooling slab and the mold.
- *Phase*, which provides a measure of the phase shift between the sinusoidal movements of the drive and nondrive sides of the mold oscillator. The phase values allow maintenance engineers to monitor the mechanical integrity of the oscillator. When phase parameters exceed preset limits, an alarm triggers to warn operators (as would happen, for example, if the oscillator bearings are damaged).
- *Negative strip time*, which indicates the time the downward speed of the mold exceeds the downward speed of the slab. This data point highlights problems with lubricant flow.

Other parameters of interest include peak stroke of the mold oscillator movement, oscillation frequency, speed of the steel slab, total harmonic distortion of drive and nondrive sides of the mold oscillator, and relative differences between the two distortion measurements.

The heart of the measurement hardware is the Hewlett-Packard 3566A PC-based spectrum analyzer. We chose the HP 3566A for two important reasons: measurement horsepower and the ease of transferring data to our MOCMS software.

Measured parameters are calculated directly, using the analyzer's built-in measurements. This saves much PC time and speeds system response.

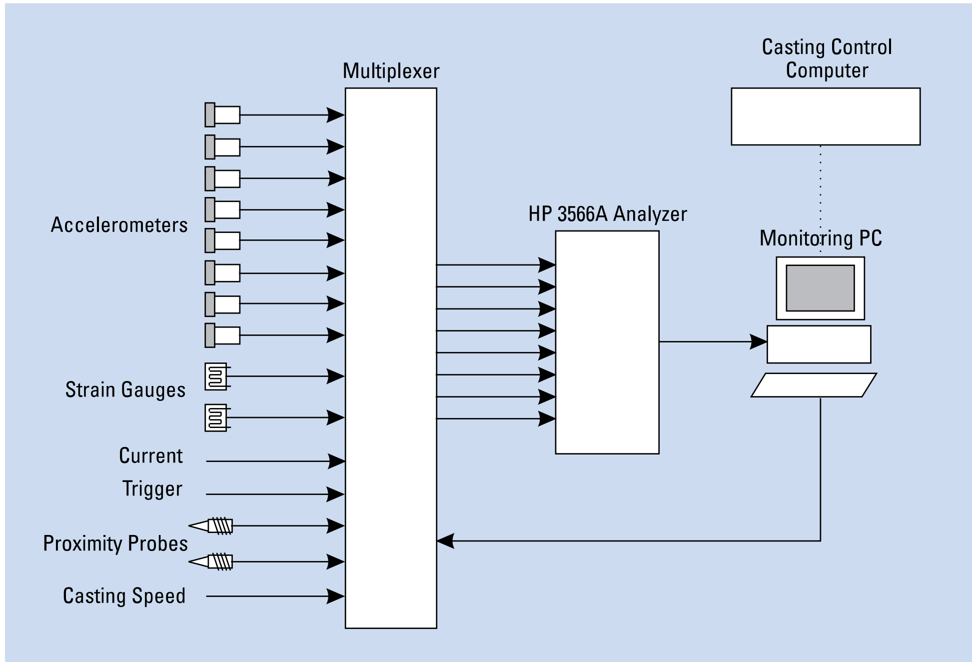

Figure 2
The MOCMS system multiplexes a variety of signals into the HP 3566A PC-based spectrum analyzer.

This powerful measurement capability also provides room for expansion of Vimac's monitoring software.

Working in Windows lets us take advantage of dynamic data exchange (DDE) to speed data transfer from the HP 3566A to the MOCMS software.

Delivering the right information at the right time

The key to successful process software is providing each user with timely decision-making information—and hiding irrelevant information. MOCMS provides several levels of information display, each tuned to the needs of a particular system user.

At Level 1, MOCMS includes a simplified drawing of the mold oscillator assembly and critical parameter values on the same screen to help process controllers effectively monitor mold oscillator performance (see figure 3). MOCMS monitors both system and process parameters continually, comparing them against preset alarm limits and issuing warnings if a parameter goes into an alarm state. It logs parameter values and any system events, such as when alarms are triggered.

For more in-depth analysis at Level 2, MOCMS displays parameter history to provide information about the current and previous condition of the mold table oscillator mechanism and relationships between its condition and process characteristics (see figure 4). These advanced trend features provide the kind of information that metallurgists and process engineers need to determine subtle interactions between the

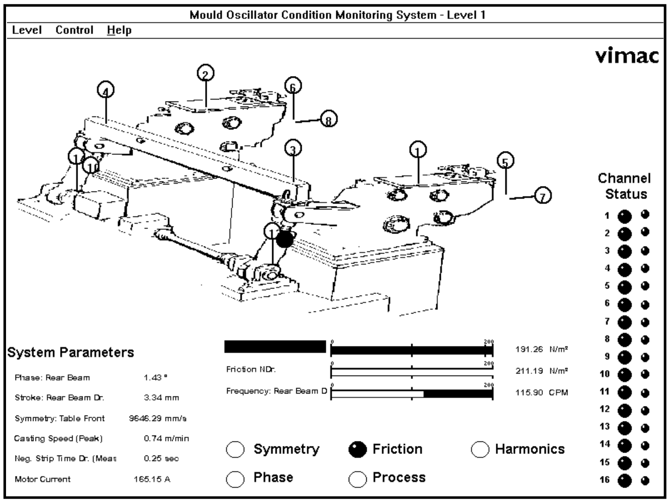

Figure 3
The Level 1 screen provides quick overview information, including the location of sensors and the status of monitored signals.

oscillator mechanism's performance, process parameters and the quality of the finished steel.

At Level 3, MOCMS provides access to the time- and frequency-domain signals from which the derived parameters are calculated (see figure 5). The signal displays are linked to recorded events and parameter trend lines, making it easy to explore and troubleshoot whenever necessary.

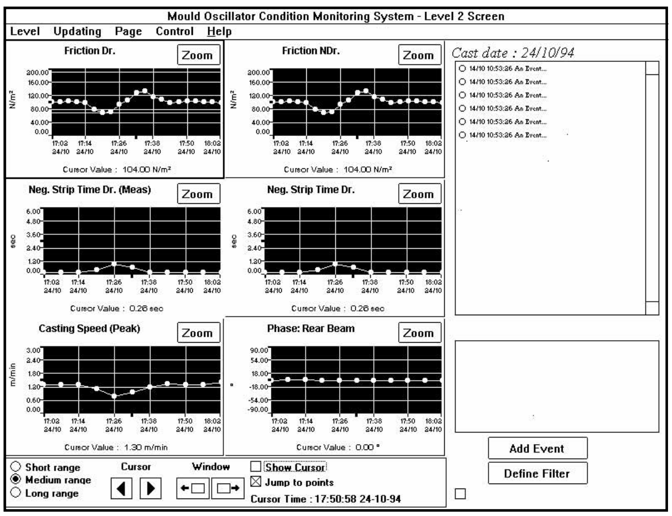

Figure 4
The Level 2 screen provides trending information to help process specialists analyze system performance and product quality.

Other applications

MOCMS is one application of a more general set of software and hardware tools that we have developed. This generic toolset (known as M++) provides the core functionality of an on-line monitoring and diagnostic system:

- The ability to calculate and set alarms on a group of high-level system parameters (such as the development of internal fault mechanisms) from data acquired from measurement devices
- A graphical representation (mimic) of the monitored machine and/or process, together with an instantaneous view of all parameters and alarms
- On-line trending, with the possibility of viewing multiple trends simultaneously together with a table of system events
- Signal analysis, allowing the "raw" data that is used to calculate parameter values to be inspected
- A powerful off-line analysis module that allows a wide range of data manipulation and analysis from all data (parameters, signals and events) that are produced by the system

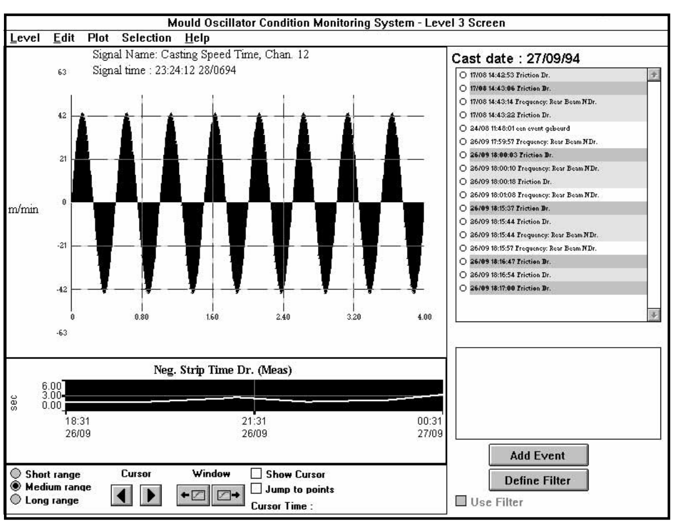

Figure 5
The Level 3 screen gives access to the underlying time and frequency measurements.

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Realtime Letters

Please note: We welcome your feedback and suggestions. Letters may be edited for purposes of clarity or space.

I'd like to present some additional background information on the development of the SRS technique discussed by Al Prosuk and Guido Bossaert in the Fall '94 issue of *Realtime Update.* The present day SRS concept arose in a Ph.D. thesis filed by Maurice A. Biot at the California Institute of Technology in 1932. It was in 1942 that one of the early Navy applications of Biot's work came on the scene. Dr. Bernard Miller of the David Taylor Model Basin developed the reed gauge, an elegantly simple device that embodied Biot's SRS concept.

While the reed gage devices were used to "quantify" the shock levels at various points around a ship, they are not capable of "quantifying the energy put into a ship," as the article stated. The reed gages provided a measure of the peak-to-peak deflection experienced by reeds tuned to different frequencies when exposed to a certain shock motion. Although one can convert the displacements to velocity, acceleration, or other useful units, energy cannot be determined without a good deal more data than that provided by the reed gages.

One remarkable feature of the reed gages for SRS determination is that measurements made with those devices are still valid today. Modern techniques can perhaps provide better information at frequencies above 300 or 500 Hz, but most of what we need for shock design lies below 300 Hz. I keep one of the old Navy reed gages on top of my book case to remind me that in engineering, simplicity is elegance.

There was one last little flaw in the article. While there is a lot of smoke and fury when large naval guns are fired, shock levels on the ship are relatively low. Recoil mechanisms have been refined to soak up the energy and release it slowly enough that there is no appreciable shock from this source. Muzzle blast does cause oscillatory motion of decks and bulkheads near the guns, but, perhaps because of the air coupling, this type of shock is also relatively low level. By far, the most difficult shock problem encountered by combat ships is underwater blast. Sea water is a marvelous shock coupling medium — near-miss explosions or a ship's own depth charges create shock levels that are of much higher level than those created by firing her own guns. While the reed gages may have found some employment in documenting gunfire shock, I am certain that most of their use had to do with underwater blast, both in hardening the ships and in hardening the equipment installed in the ships.

Sincerely,
Richard H. Chalmers

Jim Taylor's article in the Winter '95 issue is interesting and makes some valid points about the value of examining the vibration waveform when diagnosing machine problems. However, he errs in some of his comments regarding the use of demodulation as a diagnostic tool.

The article states that certain conditions existing in a machine can cause amplitude modulation that will produce only one sideband in the spectrum. Moreover, he states that the relative phase of the modulating signal compared to the carrier determines what sideband is present. However, the only way to produce a single sideband spectrum is to eliminate one of the modulation sidebands by filtering after the modulation process is complete.

The reason that some vibration spectra exhibit upper and lower sidebands at different levels is the existence of both amplitude and frequency modulation at the same time. The upper sideband of an AM signal and an FM signal with the same modulating frequency are in phase with one another, and in the presence of simultaneous AM and FM, they will add together. The lower sidebands of the same two modulated signals are in phase opposition, and they subtract if both types of modulation are present.

I also disagree with his statement that demodulation techniques are essentially useless for diagnosing machine faults because the demodulation only extracts information that is already visible in the spectral sidebands or vibration waveform. This ignores the fact that a proper demodulation scheme involves high-pass or bandpass filtering of the raw signal to eliminate low-frequency noise that confounds the vibration spectrum and masks the sidebands. A correctly executed demodulated spectrum has a greatly increased signal-to-noise ratio compared to a standard vibration spectrum, and especially so when compared to looking at the waveform.

Glenn White
PREDICT/DLI
Bainbridge Island, WA

My paper clearly states that single-sideband modulation is theoretically possible, but is extremely unlikely in rotating machinery. Our current thinking is that machines generate some forms of amplitude and phase modulation.

James Taylor
Vibration Consultants, Inc.
Tampa, FL

Careful Planning Improves Impact Testing

Dave Forrest, Seattle Sound and Vibration

Successful modal analysis requires both sensible test preparation and good measurement technique. And while many of us have good measurement technique, sometimes we start making measurements without an adequate test plan. All too often, that means spending too much time fiddling with transducers, gathering unnecessary data and re-evaluating the measurement process as we go along. The result? A lot of wasted time, money and effort. Taking the time up front to plan your test and collect the right equipment will improve both the quality and the efficiency of your impact tests (see figure 1).

Start with a clear objective

Without a clearly written, comprehensive test objective, your chances of making clean, accurate modal measurements are rather slim. So do your homework. Put together a good test plan and set realistic goals for the measurement process.

In what frequency range do you expect to find trouble? How many points should you measure? How long do you need your test structure? Answer these questions in the test objective. Don't wait until you start making measurements to define these issues. Modal testing is difficult enough without the added burden of designing a measurement procedure "on the fly."

Moreover, a good test objective saves money. Modal testing is often done on prototypes or scale models that are in high demand elsewhere in the manufacturing facility. If you know ahead of time how long you'll need the device-under-test, appropriate scheduling will minimize time conflicts. And a well-written test objective helps to focus the measurement process and lets you better estimate measurement time. (Don't forget to allow extra time to verify transducer placement and to fix any last-minute problems before testing begins.)

Where appropriate, include hardcopy of preliminary measurements in the test objective. For example, if a noisy brake mechanism is the problem, be sure to include SPL plots (both narrowband and 1/3-octave) to outline the frequency range for the modal test.

On the other hand, if you have a more general test objective (such as determining the first five torsional modes of vibration) or are less certain about the cause of a noise or vibration problem, you're going to need a lot more time with the device. At a minimum, expect test time to increase in proportion to the number of measurement points and frequency spans required for the test.

Select the right accelerometers

To select the right accelerometers for each test, you need to consider mass, sensitivity and frequency response.

Mass and sensitivity

A good accelerometer is lightweight, with a mass low enough to avoid affecting the structural modes being measured. But it must also be sensitive enough to measure the structure's response decay and to take full advantage of the analyzer's dynamic range.

Paradoxically, a sensitive accelerometer is usually heavy. This might seem like a problem, but the laws of physics are working in your favor. Smaller, lighter structures have modes at higher frequencies, where acceleration levels are higher. That means you can use lightweight, less-sensitive accelerometers because there is more signal to compensate for their low sensitivity.

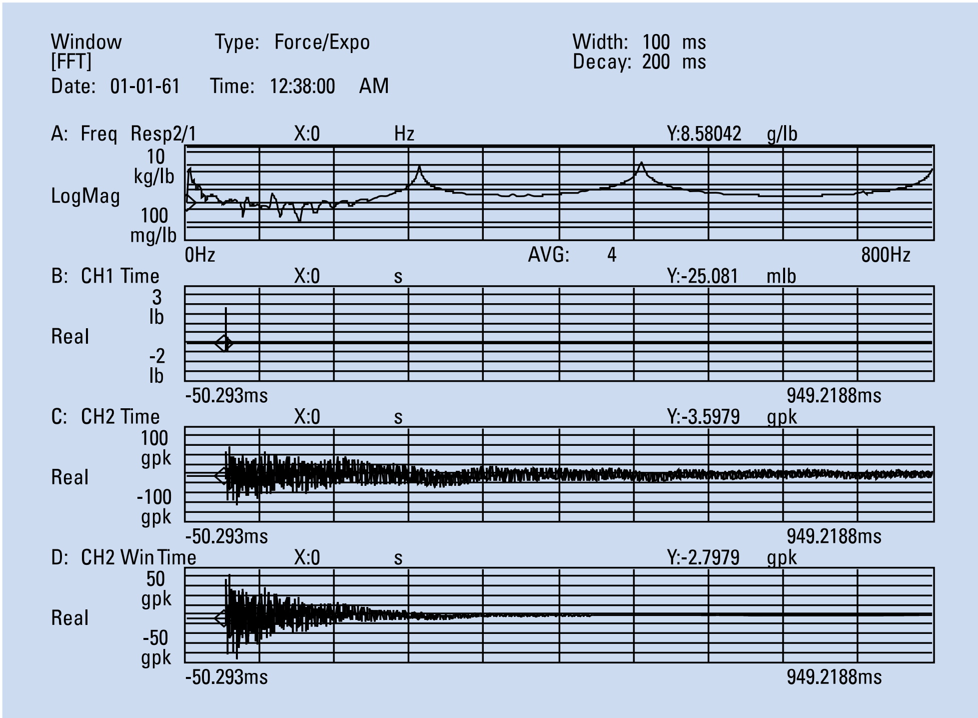


Figure 1
You can improve your test results with thoughtful planning and consistent pretesting to make sure you're getting the signals you expect to get.

In contrast, larger, heavier structures have modes at lower frequencies, where acceleration levels tend to be very faint. Therefore, heavier (but more sensitive) accelerometers can be used because their increased mass is relatively insignificant on heavy structures.

You should be aware that several manufacturers have recently introduced lightweight accelerometers with built-in, high-gain preamplifiers. Such accelerometers weigh only five or ten grams yet feature sensitivities on the order of 100 mV/g. With that kind of sensitivity, a peak response of 0.5 g would deliver 50 mV to the spectrum analyzer—a signal strong enough to take full advantage of the analyzer's dynamic range.

Minimum frequency

Most accelerometers used for modal analysis cannot measure phase consistently below 10 Hz. Response below this is possible only with special accelerometers and preamplifiers that are tailored for low-frequency testing.

For example, if you are measuring flexible modes of vibration below 5 Hz, you should be aware of the limitations of standard accelerometers and expect to pay more for the specialized transducers you'll need.

Attach the accelerometer correctly

Petroleum wax is the traditional means of attaching accelerometers. It's fast, clean, easy to use, lightweight and safe on painted surfaces. However, wax can affect frequency response above 3 kHz, particularly if it's applied too thickly. Cyanoacrylate adhesive is another excellent mounting material, although the surface finish of the test structure can be marred when the accelerometer is removed.

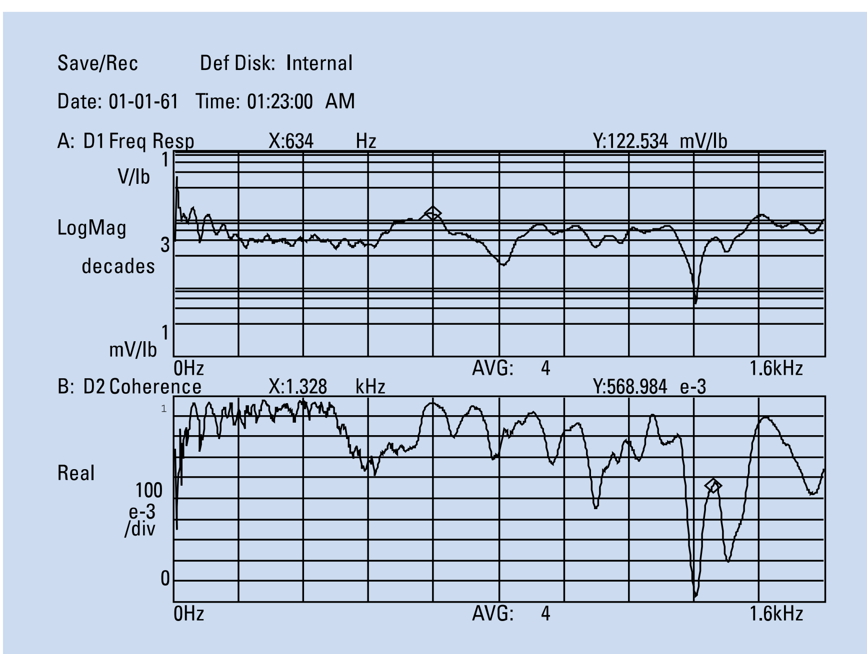
There's also electrical isolation to consider. In some cases, you need to isolate an accelerometer from the test structure to reduce ground loops. Certain preamplifiers provide their own isolation. Some accelerometers have insulated cases (anodized aluminum, for example) but others may require a non-metallic mounting surface.

Select the right impact hammer

Most hammers are selected based on the size and weight of the test structure. For testing lighter structures (tennis racquets or mirror-mounting brackets, for instance), a hammer with a 0.2 pound head would be appropriate. For testing machinery and other heavy structures, a hammer with a 1.0 pound head might be the answer.

Generally, sensitivity is proportional to the weight of the hammer head. For example, a head that weighs 1.0 pound might have a sensitivity of 1 mV/pound and a peak-force rating of 5000 pounds. In contrast, a head that weighs 0.2 pounds might have a sensitivity of 50 mV/pound and a peak-force rating of 100 pounds.

Figure 2
This FRF measurement on a noisy structure shows how the rattle from some loose structural components resulted in low coherence.



Tip composition

The striking end of most impact hammers is threaded to accept different tips. The softness of the tip material determines the impact characteristic and must be appropriate for the range of desired excitation frequencies.

Very soft tips (plastic or rubber) produce lower peak force levels for a given impact but have a longer impact duration. This provides good energy at low frequencies but rather poor excitation for higher frequencies.

Conversely, a hard tip, such as solid aluminum, creates a short impulse with a high peak acceleration. This provides sufficient energy for high-frequency modes but a lower excitation of low-frequency modes.

Make sure the tip corresponds to the frequencies of the modes you need to excite. If all modes are lower than 200 Hz, then use a very soft tip to maximize the force. But if your test structure has high-frequency modes (for example, a solid metal structure such as a disc-brake rotor), you should use a hard tip.

Before you test, listen to the structure

Before you make any measurements or attach any accelerometers, make some test hits with the hammer at various measurement points. Listen carefully for any buzzes or rattles. Nonlinear noises such as these will contaminate the frequency response and invalidate your measurements.

If you detect any looseness, fix it with an appropriate adhesive such as wax, glue or putty. Don't use too much adhesive—the goal here is to stop the noise but not add appreciable mass or stiffness. Figures 2 and 3 show before and after measurements on a structure that needed some carefully placed wax to calm it down.

Now you're ready to fire away

If you've done your homework, the actual measurements should be fairly straightforward. With a clear test objective, careful transducer selection, and strict attention to silencing buzzes or rattles in the test structure, you can expect much-improved frequency response measurements.

Dave Forrest is president of Seattle Sound and Vibration, Inc., a supplier of measurement and analysis software for shock, vibration, and acoustic applications. The company's HAMMER and SHAKER software packages are available worldwide from Hewlett-Packard or directly from SS&V (contact them by phone at (206) 867-9133 or by e-mail at 73023.3103@compuserve.com).

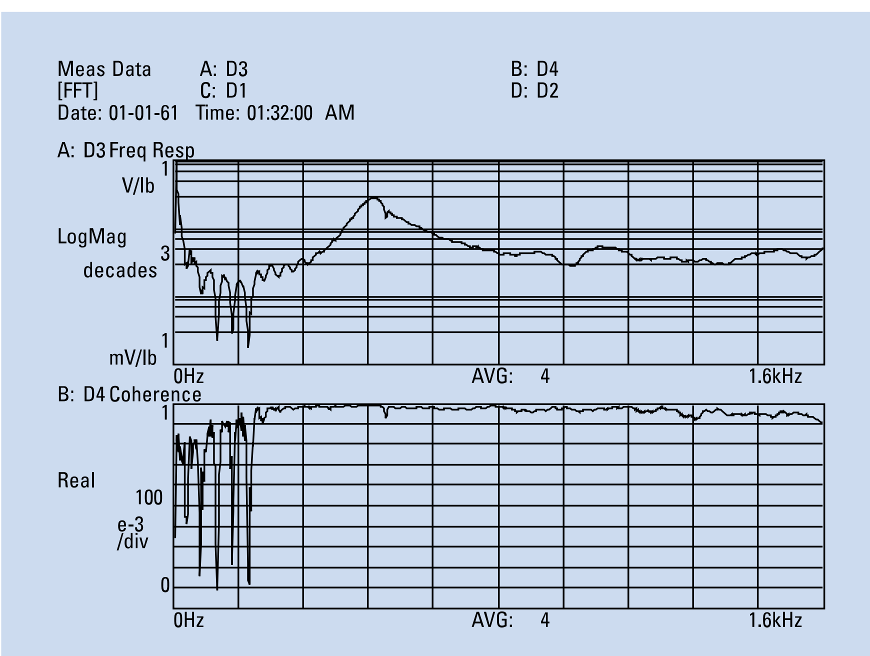


Figure 3
Here's the same structure, measured again with wax inserted in the joints to quiet the rattling.

Realtime Answers

Question:
I am using an HP 35665A and trying to convert the measurement data to ASCII with the Standard Data Format utilities. How do I make the SDFTOASC.EXE program convert my data so that the ASCII data looks like my instrument display?

Answer:
(Standard Data Format (SDF) is a data format used by the HP 35665A and many other HP analyzers. This answer applies to HP 3566A/67A, 35670A, 3589A, 89410A/40A/41A, 3587S, 3562A/63A, 3560A, 3569A, 35660A, and 3588A.)

When you store a measurement in SDF, the analyzer saves an extensive set of header information in the file. These headers contain all the information you need to reconstruct the measurement, including the product being used, number of channels, measurement type, engineering units, set-up information and other details. The actual measurement data are stored as volts (peak). The conversion to the desired unit type is calculated from the header information.

When you use SDFTOASC.EXE to convert a file, it reads the data header and automatically selects the unit type to display. This selection is a function of the data element and the units stored in the header. If you get ASCII results that do not match the analyzer data, there are two likely causes:

1. The wrong data were converted (e.g., correction factors instead of power spectrum).

2. The automatic selection of units produced an unwanted conversion (e.g., Vrms instead of Vp).

Selecting data results

The first step in using any of the SDF conversion utilities is to see what data results are in your file. You do this with the /I switch. For example, you can examine a time capture file with SDFTOASC A:\CAPT1.DAT /I, which yields the following display:

Data	Name	Rows	Cols	Scans	Points	Complex	Space
0	TCapture Ch1			10	1024	No	Lin
1	Freq Crtn Ch1			401		Yes	Lin

This display indicates that the time capture file, CAPT1.DAT, contains two data results:

“0” is the time capture data for channel 1, with 10 scans (or records) of 1024 points each. Each record has noncomplex data (real) that is linearly spaced in time.

“1” is a frequency correction for channel 1 containing 401 complex pairs that are linearly spaced in frequency. This information is needed for the analyzer’s internal corrections to be applied.

Before converting the file to ASCII you must determine which data element to convert. Usually the data of interest are in data result “0”. If the measurement being made involves more than one channel, each additional channel is saved as another row. A two-channel power spectrum, for instance, would yield a “2” under the “Rows” heading.

Converting units

After examining the SDF file, you’ll be able to identify which data results to convert to ASCII. SDFTOASC (SDF to ASCII) is a powerful utility with 21 switch fields to help you get just the resutls you want. (You can type SDFTOASC /U for instructions on using the switches.) Here are some quick examples of using the switches:

Filenames: If the input file is TEST1.DAT, make the output file TEST1.ASC; this helps separate converted files from original source files.

Data results: Specify the data results you want with the /D switch; the default is result “0.”

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Multiple channels: To make sure you convert all the channels, use the row switch. Note that the first channel is number 0. The C gives one channel per column in the output file:

/R:0-N,C
where N is the last channel. (i.e., 2 channels = /R:0-1)

/R:N
where N is the only channel to convert.

Multiple scans: If your measurement is a time capture, a waterfall or a map, it will have multiple scans, each representing one time block or trace. The first scan is number 0. The C gives one scan per column in the output file:

/S:0-N,C
where N is the last scan. (i.e., 10 scans = /S0-9)

/S:N
where N is the only scan to convert.

X-data: The X-axis units help you understand the data. Use the /X switch to include this data. In time captures, the time data will reset to 0 for each successive block of points.

Y-units: You may combine several together. Some likely combinations are:

/Y:L	linear Y-units, in peak
/Y:LR	linear Y-units, in rms
/Y:PR	power, rms in $volts^2$

Y-coordinates: These default to real or real, imaginary pairs. Use the switches /T:<c1>,<c2> to control the Y-axis for the units you want:

/T:M,R	magnitude, real data
/T:M,D	magnitude in dB
/T:S,D	dB with ± sign (e.g., for sound intensity)

dB reference: Defaults to 1, which is the standard for dB volts:

/G: or /G:20E-6

Either setting gives dB for SPL or sound intensity

Data field separator: Many spreadsheets require a "," between data elements:

/B:,

Use with any string variable as a separator.

Examples

Here are two examples of using SDFTOASC with various switches:

Converting a linear magnitude vibration spectrum to ASCII, rms values with x-axis values and a comma separator between data points:

SDFTOASC VIBE1.DAT VIBE1.ASC /X /Y:LR /Y:MR /B:,

Converting a 20-record time capture file to comma-separated ASCII values with time values included. The data will show up as two long columns:

SDFTOASC TIME1.DAT TIME1.ASC /S:0-19 /X /B:,

Remove the /X to create a single column of data.

The SDF utilities also convert data to other formats including MATRIXx, MATLAB and DATASET58. In addition, you might want to consider the Data Viewer for Windows (HP 35639A), which makes data and graphics exchange with Windows programs easier.