Technical Papers

DTC
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VENZO 800

Vibtaion Controller

A Guide to Mechanical Impedance and Structural Response Techniques

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Background

In recent years there has been a rapidly developing interest in the field of mechanical dynamics for a variety of reasons. Firstly, the development of stronger materials and greater economy in design has led to increasingly lighter structures, more prone to vibration problems. At the same time, increasing rotational speeds also give increasing likelihood of having to deal with structural resonances.

Another important factor is the recent upsurge of interest in environmental questions since the improvement of both noisy and vibrating environments often can be simplified to a question of reducing the mechanical vibration, either at its source or somewhere along the transmission path.

The overall result is that the dynamic behavior of a machine or structure is now an important factor in design and development along with the analysis of static stresses and deflections, and is normally studied in its own right, rather than just being allowed for in an excessive "safety factor", or treated as an afterthought when problems have been encountered.

One very useful experimental technique for the study of dynamic behavior of machines and structures concerns the measurement of what is loosely termed "mechanical impedance". Broadly speaking, this defines the relationships between forces and motions at various points, both with respect to amplitude and phase. Following lists the three main applications of impedance testing as:

1. Determination of natural frequencies and mode shapes.
2. Measurement of specific material properties such as damping capacity or dynamic stiffness.
3. As a basis of an analytical model. From measurements of the impedances of individual components or substructures it is possible to predict the behavior of combined systems, in a manner completely analogous to the study of complex electrical circuits.

Mechanical Impedance and Mobility

Mechanical impedance and mobility (for simple harmonic motion) are defined as the complex ratios of force vector to velocity vector, and velocity vector to force vector respectively. This is shown in Table 1 where, in addition, the similar ratios involving acceleration and displacement are given. The terms given in the table are taken from the American Standard USAS S2.6-1963: Specifying the Mechanical Impedance of Structures (1). Other terms have been used by different authors but will not be given here. The units after each ratio are SI-units*.

As both force and motion are vectors in space as well as in time care should be taken to define directions of motion relative to the direction of force when this is not obvious from the measurement conditions or from the calculations.

Dynamic Mass (Apparent Weight)	$\frac{F}{a}$	$[\frac{Ns^2}{m}]$	(Acceleration through Force)	$\frac{a}{F}$	$[\frac{m}{Ns^2}]$
Mechanical Impedance	$\frac{F}{v}$	$[\frac{Ns}{m}]$	Mobility (Mechanical Admittance)	$\frac{v}{F}$	$[\frac{m}{Ns}]$
Stiffness	$\frac{F}{d}$	$[\frac{N}{m}]$	Compliance	$\frac{d}{F}$	$[\frac{m}{N}]$

Table 1 Terminology for complex dynamic ratios of force and motion

When force and motion values are measured at the same point and in the same direction the ratios are termed driving point values, or in short, point values, e.g., point impedance.

When force and motion are measured at different points or at the same point with an angle between them they are termed transfer values e.g., transfer impedance.

The ratios given in the first and second column of Table 1 really represent, as functions of frequency, the difficulty or ease, respectively, with which a structure can be set into motion. By measuring, for ex- ample, the mechanical impedance of points on a structure, knowledge is gained about its response to vibrational forces at different frequencies. Similarly, a measurement of the motion of the structure, after it has been placed on a vibrating support, may be compared to its mechanical impedance to obtain information about the forces which act on the structure.

To solve vibrational problems, therefore, mechanical impedance may have to be measured, and a narrow band frequency analysis carried out to obtain detailed knowledge about the response ability of the structures involved, and of the actual responses or forces. After combination of this information the need or the possibility of corrective measures may be evaluated.

Practical considerations in the measurement and evaluation of mechanical impedance, mobility, and other ratios of force and motion

To measure mechanical impedance it is necessary to have a force source, force and motion transducers as well as analyzing and recording equipment.

In Fig.1 is shown an example of a measurement arrangement which provides the various functions which may be needed for most impedance or mobility measurements. The arrangement was first used in the measurement of stiffness of elastomer to provide the complex modulus of elastomer at frequencies below the first bending resonance.

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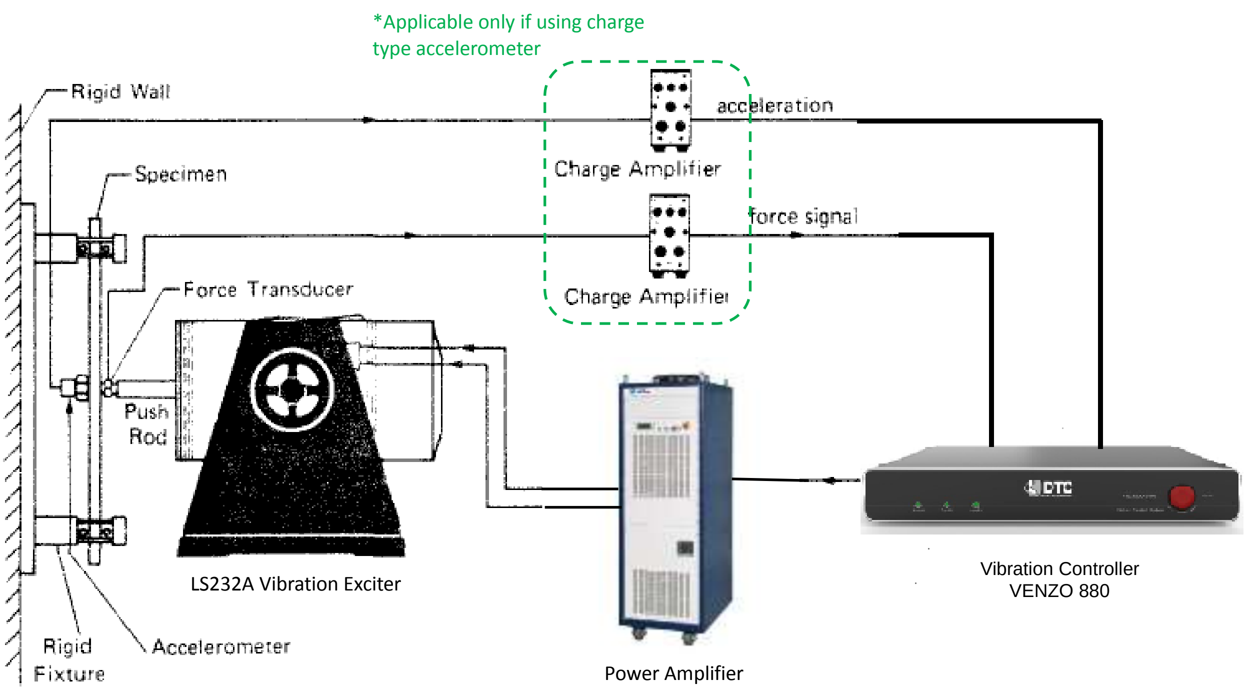


Fig.1. Measurement Arrangement for Mechanical Impedance Measurements

The Vibration Exciter and Power Amplifier

The molecular structure of elastomers is of extreme flexibility, elastomers can reversibly extend from 5-700%, depending on the specific material. A long stroke exciter such as the ETS Solutions LS Series, MPA404/LS232A with displacement of up to continuous 90mm peak to peak and its wide excitation frequency range provide extensive testing capabilities to derive the desired results.

The Force and Mobility Transducer

The demand to the force transducer is that it provides a true force signal to the preamplifiers in the force range required. The motion is normally best measured by an Accelerometer. This is due to the large dynamic range, the large frequency range, and the reliability provided by these transducers. However, some consideration should be given to the choice of accelerometer type.

Preamplifiers

As Accelerometers and Force Transducers have very high electrical output impedances, a preamplifier must be inserted after each transducer in order to provide high input impedance to the transducer signal and low output impedance to the following electronic instruments. Thereby low frequency and low noise operation is made possible.

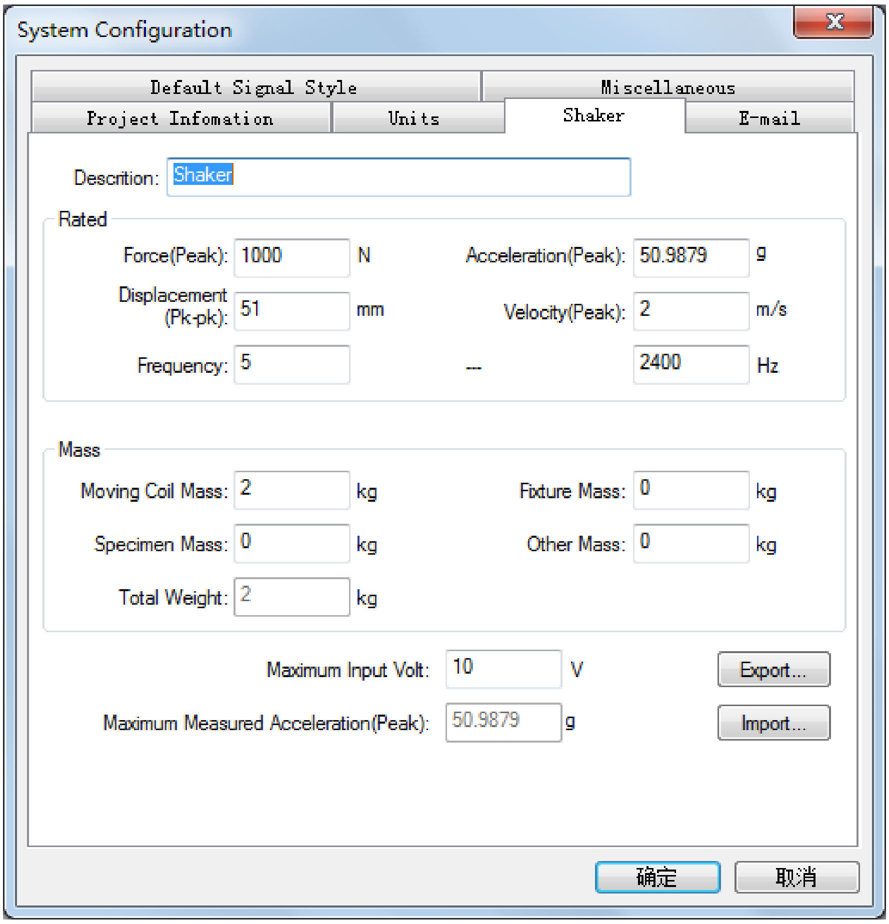
Vibration Controller

The Vibration Controller VENZO 880 features with full control applications, and can provide 0.01Hz~20 kHz frequency range test. Ethernet connection to PC which removes grounding problem. No-fan**s** structure greatly reduces the background noise, and which means VENZO has wide range of working temperature from -30℃ to 70℃. VENZO 880 provides extensive analysis capabilities, such as Data Recorder, FFT, SRS, FRF, Waterfall View, Signal Calculation, Waveform Editor, Off-line Viewer and etc., which are saving customer's investment and simplifying the test.

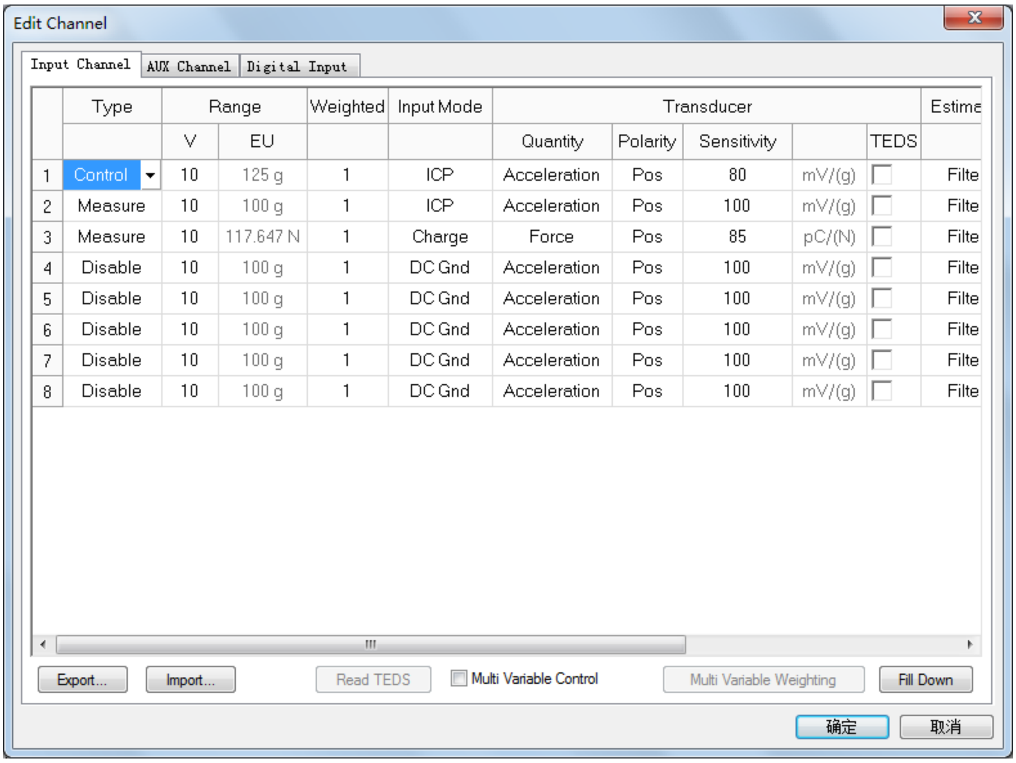
After finished connection with all instruments and sensors, then let us see the friendly-use interface and steps to test the mechanical impedance:

Step 1, open the VibExpert, select Sine test:

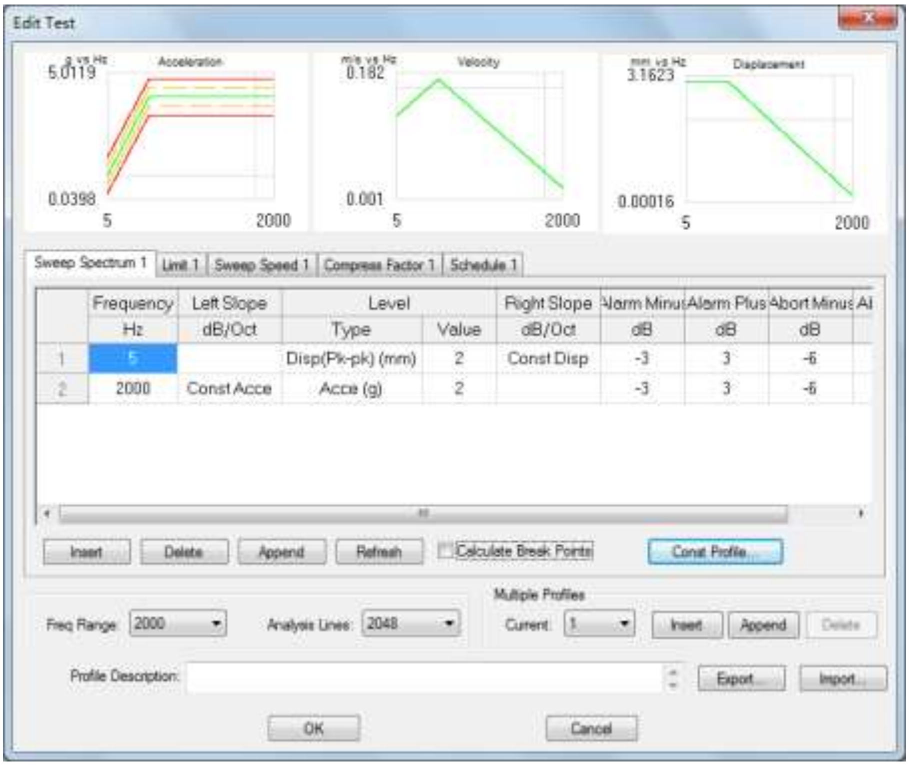
Step 2, enter into Sine test, click icon  to input system information:



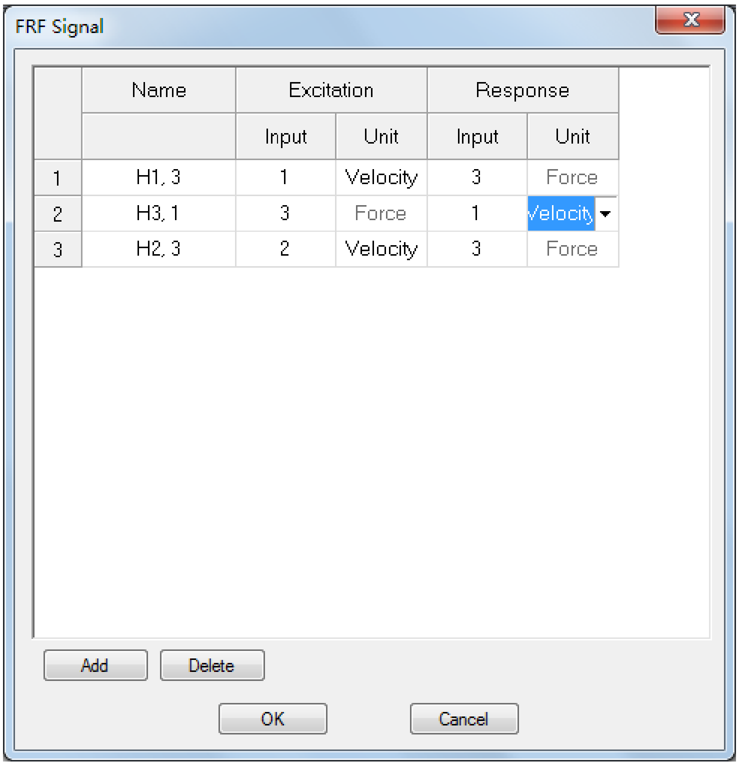
Step 3, click icon  to input channel information, we use two accelerometers and one force sensor in this test:



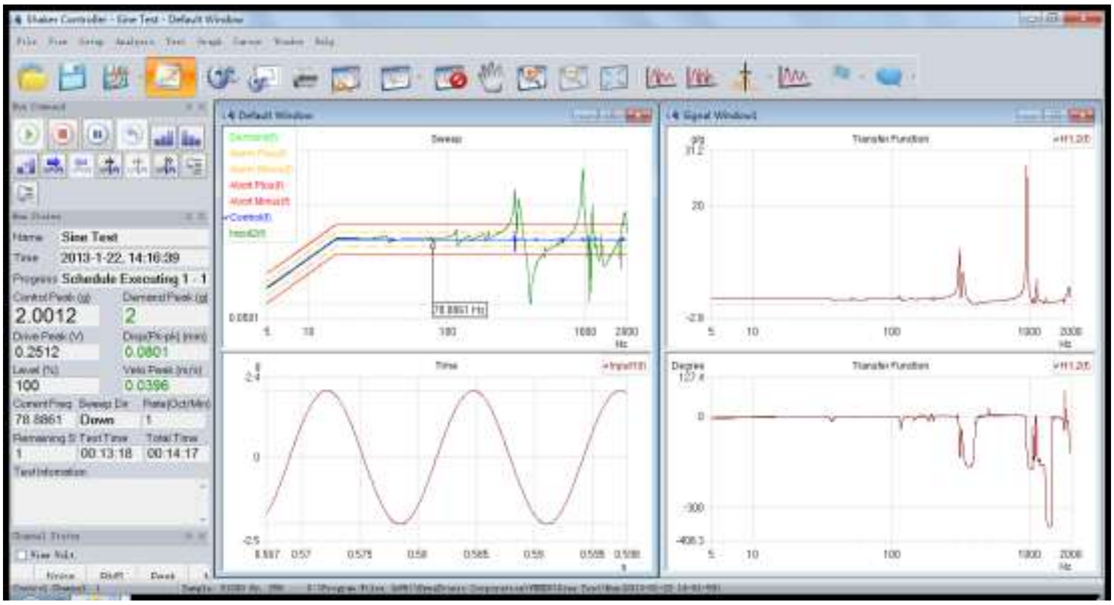
Step 4, Edit test profile as to the requirements:



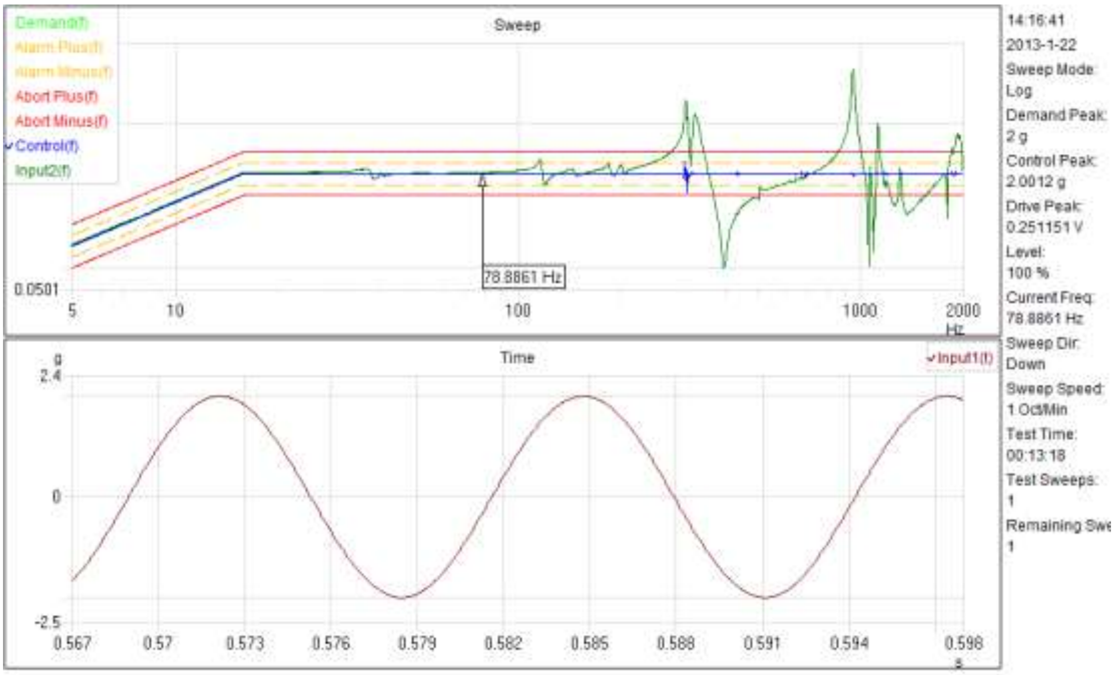
Step 5, click Analysis-FRF Signals to add FRF signal, change accelerometer's unit as velocity, then software will automatically calculate it:



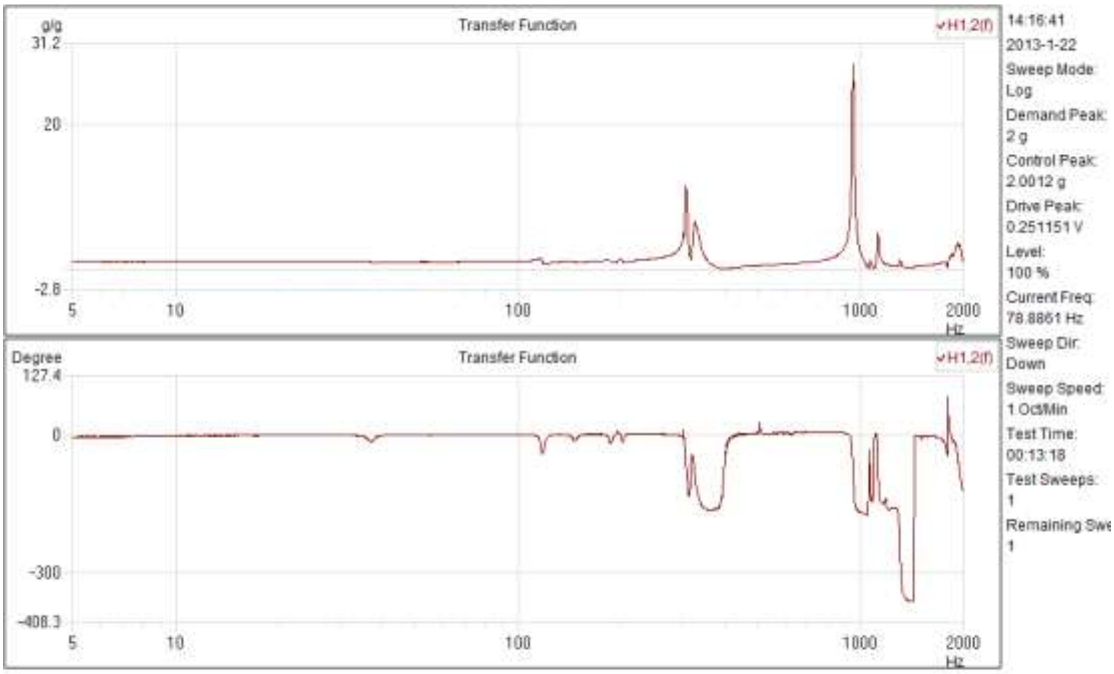
Step 6, add FRF signals to each panel to derive the below results:



Post analysis can be made results to identify the natural frequencies, damping ratios, and mode shapes of a structure.



Sine Test



Sine Test

Conclusion

The purpose of this modal testing is to identify the natural frequencies, damping ratios, and mode shapes of a structure.

Natural Frequencies

Bridges, aircraft wings, machine tools, and all other physical structures have natural frequencies. A natural frequency is the frequency at which the structure would oscillate if it were disturbed from its rest position and then allowed to vibrate freely. All structures have at least one natural frequency. Nearly every structure has multiple natural frequencies.

Resonance occurs when the applied force or base excitation frequency coincides with a structural natural frequency. During resonant vibration, the response displacement may increase until the structure experiences buckling, yielding, fatigue, or some other failure mechanism.

The failure of the Cypress Viaduct in the 1989 Loma Prieta Earthquake is example of failure due to resonant excitation. Resonant vibration caused 50 of the 124 spans of the Viaduct to collapse. The reinforced concrete frames of those spans were mounted on weak soil. As a result, the natural frequency of those spans coincided with the frequency of the earthquake ground motion. The Viaduct structure thus amplified the ground motion. The spans suffered increasing vertical motion. Cracks formed in the support frames. Finally, the upper roadway collapsed, slamming down on the lower road.

Dynamic Analysis

Engineers performing dynamic analysis must

1. Determine the natural frequencies of the material or structure.
2. Characterize potential excitation functions.
3. Calculate the response of the material or structure to the maximum expected excitation.
4. Determine whether the expected response violates any failure criteria.