# Vibration test fixtures: theory and practice

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Vibration test fixtures are required to allow mounting of the test specimen to the vibration table as well as to allow for testing in the three orthogonal directions.

The design of test fixtures is critical to avoid errors in equipment test response due to any resonances of the laboratory's shaker, table (movable part of the shaker) and the fixture itself. Ideally the laboratory mounting should replicate the physical conditions seen in service, such as the stiffness, mass and the consequent resonant responses of the actual service installation.

### Typical mounting fixtures

Examples of several vibration fixtures are shown in Figures 1 through 4. Figures 1 and 2 show a front and side view of a ship's hatch door mounted on its vibration fixture. The fixture includes a tank for performing hydrostatic leakage checks of the door seals. Furthermore, it serves to replicate the actual service installation by canting the unit as it is installed aboard the ship. Figures 3 and 4 show a heat exchanger mounted on its fixture with an added support around its middle. This fixture replicates the bulkhead mounting of the actual shipboard installation. The middle support was installed to limit the lateral vibration motion of the long cylindrical section of the heat exchanger.

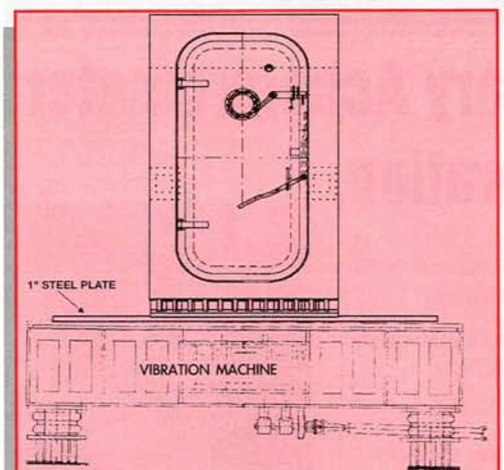


FIG. 1—Front view of a ship's hatch door, mounted in its vibration fixture.

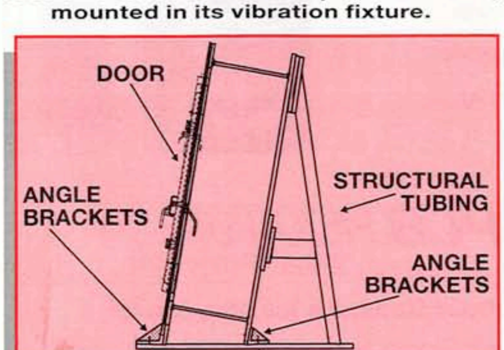


FIG. 2—Side view of hatch door shown in Figure 1.

### Theory of fixture design

The key issues in the design of a vibration test fixture are as follows:

*1.* Allow for ease of mounting of the test item to the vibration machine;

*2.* Allow for vibration testing in each of the three orthogonal directions with minimum cross talk, i.e., motion in the two orthogonal directions not being tested;

*3.* Ensure the absence of fixture resonances within the specified test frequency range by tailoring the dynamic response of the fixture and the table;

*4.* Weight and force limitations of vibration machine;

*5.* Distribution of vibration energy uniformly throughout the test item.

### Mounting

The fixture is the interface between the test unit and the table of the vibration machine. It must allow for proper mounting to the table. The number and size of attachment points must be sufficient to transmit the vibration energy equally to the fixture without losses.

### Directional characteristics

Vibration testing is usually performed in each of the three orthogonal axes, one axis at a time. The real service environment is seldom uni-directional. However, for testing purposes, to allow for control and standardization of test specifications and methods, uni-directional motion is desired.

To avoid or minimize orthogonal motion, commonly known as cross-talk, various steps are taken:

• Maintain the center of gravity of the test unit and fixture at or close to that of the vibration machine table;

• Increase fixture stiffness and mass where required to minimize the effects of test item resonance.

### Dynamic response

Ideally, the vibration response characteristics of a test fixture should replicate those of the actual service installation. Often, however, these characteristics are not specified by the customer or are not known. The designer of a test fixture must therefore use engineering judgement based on experience to achieve an optimum design.

Generally the approach is to make the test fixture as rigid as possible, within the allowable weight limits of the shaker. The test fixture should therefore have no resonances within the frequency range as specified by the customer. That is, the first resonant frequency should be above the maximum specified test frequency.

### Vibration machine limits

The weight (test item, fixture plus table) and force limits of the machine must be observed to avoid overloading and possible damage.

### Energy distribution

The test fixture shall be designed to transmit vibration energy from the machine table to the test item in an approximately uniform manner over its mass. This goal may be achieved by designing the fixture to be as rigid as possible within the weight limitations of the machine.

### Heat exchanger test fixture

To illustrate some of the issues presented herein, a test fixture used for vibration testing of a heat exchanger will be discussed. The test fixture was provided by the customer and consisted of four vertically mounted one-inch steel angles, 3/16-inch thick. Each angle supported one corner of the heat exchanger, which was rectangular in shape. The angles were attached to lugs on the heat exchangers and then attached at the bottom to the table of the vibration machine.

After the commencement of testing, the welded fins on the tubular members of the unit, as well as the tubes, began to crack. It soon became clear that the vibratory response of the heat exchanger was excessively amplified due to the insufficient stiffness and mass of the four supporting angles.

Furthermore, the heat exchanger had four inlet and outlet connections which were provided with closure plugs. During

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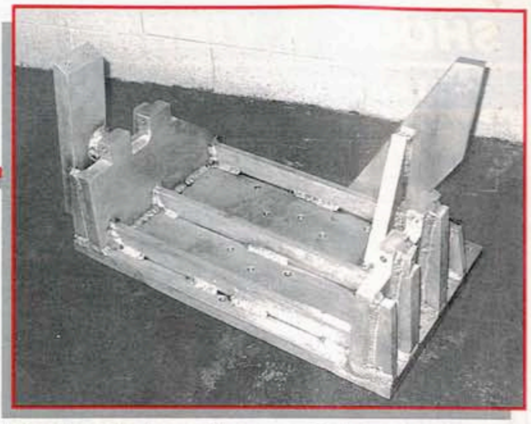

FIG. 5—Heat exchanger fixture as reconfigured to survive vibration testing.

testing, these unsupported ports began to vibrate excessively.

Consequently the fixture was completely reconfigured, resulting in a unit of vastly increased stiffness and mass. Also, supports for the inlet and outlet ports were provided on the fixture.

The reconfigured fixture (see Figure 5) enabled the heat exchanger to survive the vibration testing. The lesson to be observed is that vibration testing imparts significant energy into structures and equipment. Poorly designed fixtures will quickly lead to failures under the repetitive stress cycles that are imposed during vibration testing.

## *Test fixture qualification*

Upon the conclusion of the design of a vibration test fixture it is sometimes required that the fixture be qualified to determine its resonant characteristics. This requirement is imposed to demonstrate that the dynamic motion of the fixture will not adversely affect or skew the results of the vibration testing.

Test fixture qualification can be performed numerically by hand analysis or finite element analysis (FEA), or in the laboratory by impact or bump testing. Another test technique is modal analysis. Except for simple fixtures, test methods are preferred, since hand analysis using basic static and dynamic methods usually results in imprecise results. FEA methods are complex and costly.

## *Finite element analysis*

Finite element analysis is a computer-based analytic tool for solving field-flow problems. It allows for problem solving in the areas of structures, fluid flow, heat transfer, and electric fields due to the similarity in the partial-differential equations which characterize these fields.

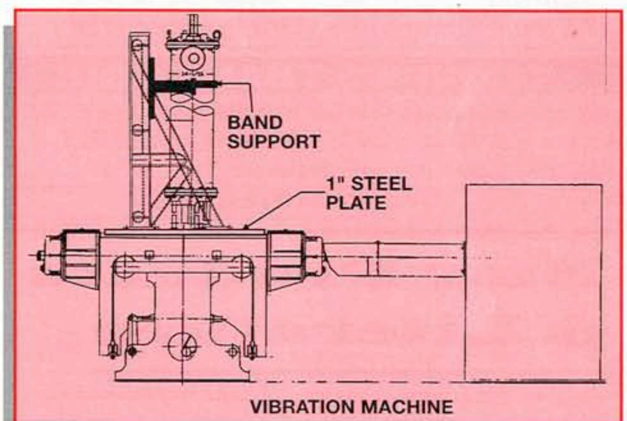


FIG. 3—Side view of heat exchanger mounted on its fixture with added support around its middle.

The FEA for structural design starts with modeling of the structure by dividing it into an equivalent system of simple elements, such as rectangles or triangles, with easily obtained stress and deflection characteristics. Upon specifying the material, material properties, boundary conditions, and loads, the analysis is completed by computer programs, utilizing arrays of matrix equations.

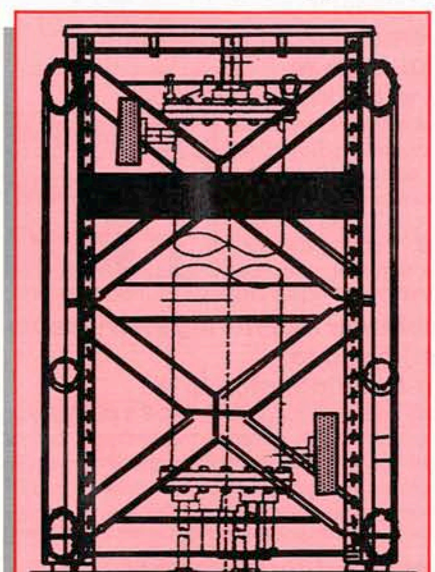

FIG. 4—Front view of heat exchanger shown in Figure 3.

FEA allows for the determination of free-vibration natural frequencies and the associated mode shapes of a structure. It provides valuable information for use in the design stages of a program, allowing optimization of the design by varying key parameters.

The major issue with the use of FEA's is the relatively high cost associated with modeling, inputting properties and loads, debugging, running of the computer analysis, interpreting of results, etc.

## *Impact or bump testing and modal analysis*

Impact or bump testing is a powerful tool for testing the vibratory response of structures. It consists of a device for impacting energy, such as a hammer, into a structure. The frequency spectrum of the hammer force impact signal is nearly flat over a wide frequency range. Figure 6 shows the time history of the force impact for various hammer tips. It is a typical impulsive load response. Figure 7 shows the frequency spectrum of the impact force. Therefore it is seen that a single impact will excite all the natural frequencies within the frequency band. In other words, the energy content of an impulsive impact is broadband.

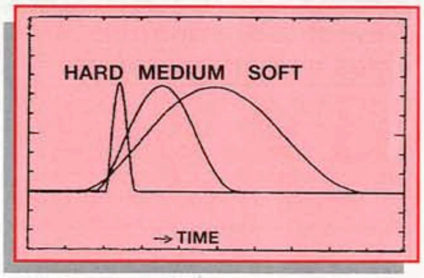


FIG. 6—Time history of the force impact for various hammer tips.

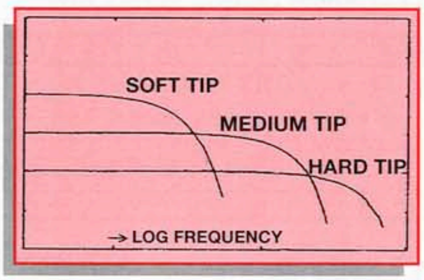


FIG. 7—Frequency spectrum of the force impact for hammer tips.

Utilizing a hammer with a force transducer and displacement transducers placed at numerous locations throughout the test item to measure the response motions, along with a Fast Fourier Transform (FFT) spectrum analyzer, allows the determination of the structure's dynamic response. The response is defined by the natural frequencies, mode shapes and damping factors. This method is called modal analysis. Electric impact hammers are also available to yield controlled repeatable impact forces.

## *Conclusion*

The design of vibration test fixtures is critical to the successful performance of vibration testing, thereby yielding data which is both reliable and predictive of results in actual service.