# SHAKER/STINGER EFFECTS ON MEASURED FREQUENCY RESPONSE FUNCTIONS

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## ABSTRACT

Shaker testing is utilized in the development of many experimental modal tests. The setup of the shaker, stinger and transducers can cause difficulties that are often misunderstood. Many times incorrect measurements are obtained and the test engineer may not realize that the measurements are not appropriate.

This paper overviews some of the common problems that are typically encountered. Measurements are made on several structures to better understand some of the common problems observed. These include shaker alignment, stinger arrangement, reciprocity, impedance head difficulties and many other common issues that must be clearly understood in order to make the best possible overall measurements.

## INTRODUCTION

The most commonly used excitation techniques for modal testing are impact and shaker excitation. While both techniques have advantages and disadvantages, shaker testing tends to lead to higher quality frequency response functions (FRF) over greater bandwidths. Using shaker excitations, generally there is much better control on the frequency ranges excited as well as the level of force applied to the structure. While the measurements obtained with shaker excitation tend to be of higher quality and more consistent, greater caution must be taken during the setup of a shaker test to obtain these pristine measurements. Various elements of the test setup can contaminate the FRFs, primarily due to the type of shaker attachment on the structure.

The most common way of attaching a shaker to a test structure is through a stinger. Stingers, also called quills, are typically made of drill or threaded rod. This type of geometry can provide high axial stiffness while attempting to keep bending stiffness to a minimum. While the main purpose of the stinger is to dynamically decouple the shaker from the test structure, this is impossible to fully achieve. Force transducers between the stinger and structure can only decouple the structure in the axial direction of the stinger. Any force acting in any other direction can change the stiffness of the structure, thus having significant effects on measured FRFs.

While there is a limit to the ratio of axial stiffness to bending stiffness for any type of stinger, this ratio can be adjusted by changing the effective length. While a longer length will have a lower bending stiffness than a shorter length of equal material and diameter, resonances of the stinger becomes an issue which will contaminate the measured FRFs. And if the stinger is too short, dynamic effects of the shaker will be imposed on the dynamics of the structure.

Another type of attachment method not often employed is piano wire. This type of attachment provides essentially no lateral stiffness, while keeping axial stiffness through a preload on the wire. This preload is normally on the magnitude of

3 to 4 times the range of the alternating load.  While this method avoids additional stiffness on the structure, resonances of the wire will still have an effect on the measured FRFs.  Typically both the test structure and shaker must be fixed in order to keep tension on the wire.

There are many ways to set up for a shaker excitation test and no one way is always perfect.  The following cases studied in this paper present common issues the test engineer may run into while performing shaker tests.  Many of these issues cause variations and inconsistencies in FRFs, which cannot always be avoided.

## CASES STUDIED

A recent modal test being performed as part of a demonstration, resulted in some poor reciprocity measurements that were obtained.  As a result, there were several questions raised as to how to best set up for a shaker test.  There is not much published in the literature [1,2] as to exactly how to set up these types of tests from a practical standpoint and what types of effects might be observed in FRFs if a shaker test is set up incorrectly.  In order to understand some of the issues, several test configurations were studied for a structure that has been used for several laboratory studies.

Several scenarios are explored in this study, but all stem from a multiple inputs multiple output (MIMO) measurement with bad reciprocity.  This measurement leads to a series of cases which investigate the effects of the shaker and stinger on the test structure. These cases can be summarized as:

Case 1 – Stinger Location
Case 2 – Alignment
Case 3 – Stinger Length
Case 4 – Stinger Type

### Structure Descriptions & General Testing Performed

The test structure, referred to as BU (base – upright), is made of 3/4" aluminum plate.  The 24"x30" upright is rigidly connected to the 24"x24" base plate using 1/4" thick steel angle brackets and is rigidly bolted to floor at four locations.  Multiple inputs multiple output (MIMO) and single input single output (SISO) tests were performed on the structure.  Shaker attachment locations for each type of test are shown in Figure 1.  Impact testing was also performed at all measurement points for a basis of comparison.  All tests used a burst random excitation with a 1024 Hz bandwidth and 4096 lines of spectral resolution.  For all tests, 50 averages were used to obtain accurate measurements.  The Modal Shop 100lbf electrodynamic shakers [3] were used with LMS Test Lab [4] controlling a SCADAS 316 data acquisition system also shown in Figure 1.  PCB impedance heads were used to obtain drive point measurements and were attached using Loctite® Super Glue.  For reference, some of the expected mode shapes for the structure are shown in Figure 2.

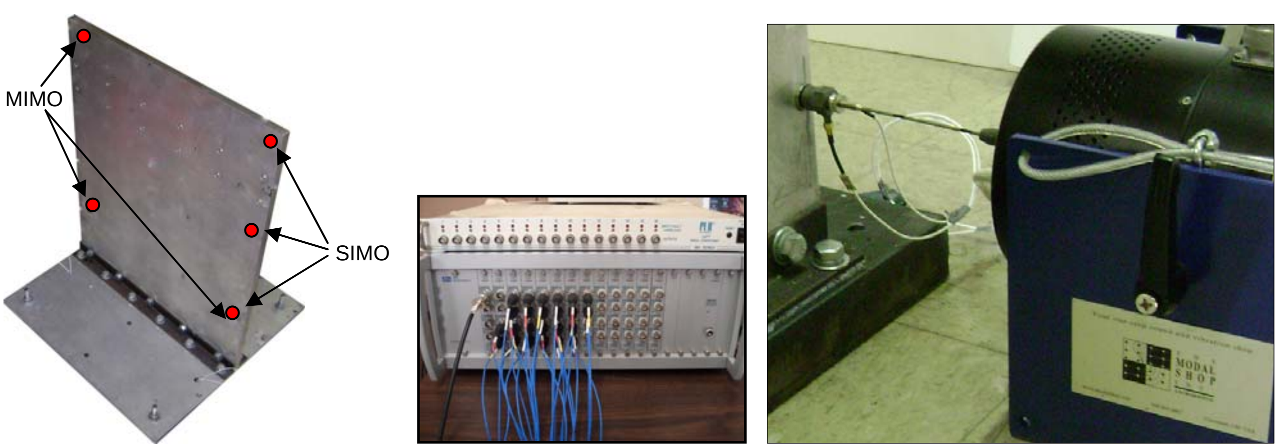


Figure 1: Base Upright Test Structure Displaying Stinger Attachment Locations and LMS SCADAS acquisition system

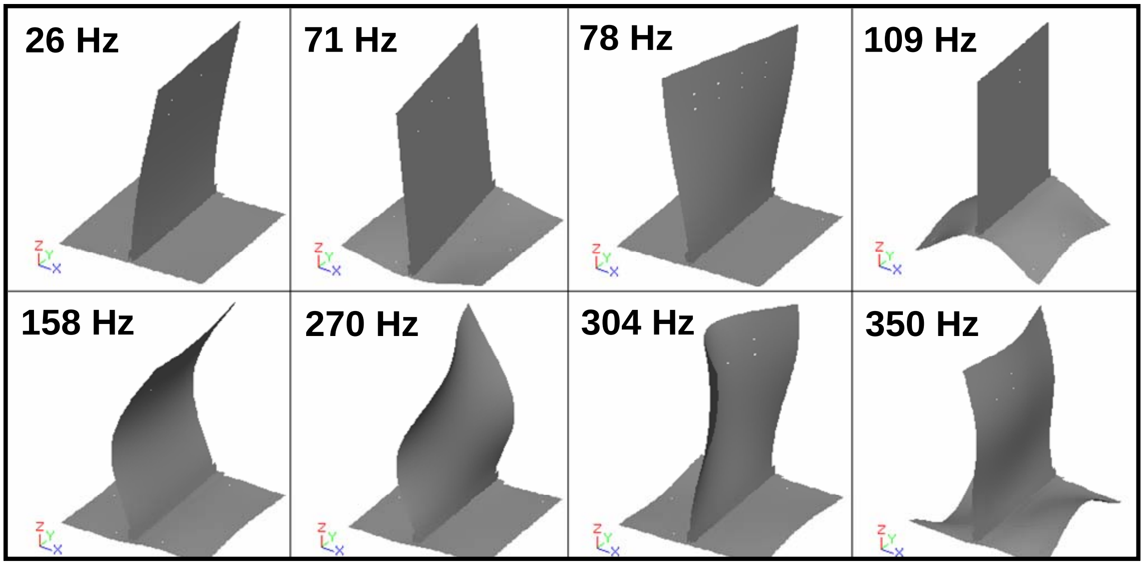


Figure 2: Typical Mode Shapes for the Test Structure.

Initial Measurements Prompting Stinger/Shaker Study

Initially, a MIMO test was performed on the BU with the shakers as seen in the left of Figure 3 below. One shaker was attached to the upper left corner of the upright and the other to the lower right. The quill length was approximately 10 inches. While the individual FRF measurements appeared acceptable with good coherence, the initial reciprocal FRF measurement appeared to be unacceptable with extra modes not anticipated for the structure. The initial reciprocal FRF measurement is shown in Figure 4. Clearly, the measurement does not satisfy reciprocity as expected. The shakers appeared to be properly set up with the use of impedance heads to minimize any distortion in the measurement. To further check the measurement, both shakers were located at the same (lower) elevation on the structure and the measurement was repeated. With the relocation of the shakers, the measurement appeared much better overall and satisfied the reciprocity expected (note that this measurement is not shown but was of very good quality). As a result of this initial measurement, several issues were identified as areas where some exploratory measurements were needed to better understand the effects of shaker/stinger set up/arrangement. These are identified in the following cases studied.

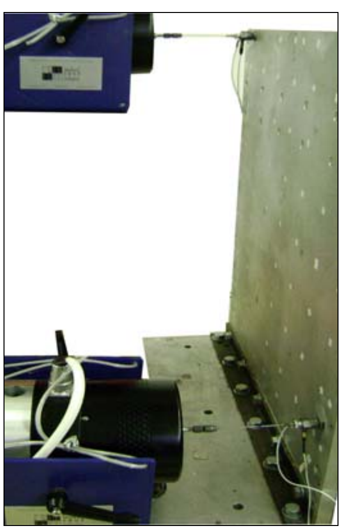

Figure 3. MIMO Shaker Setup

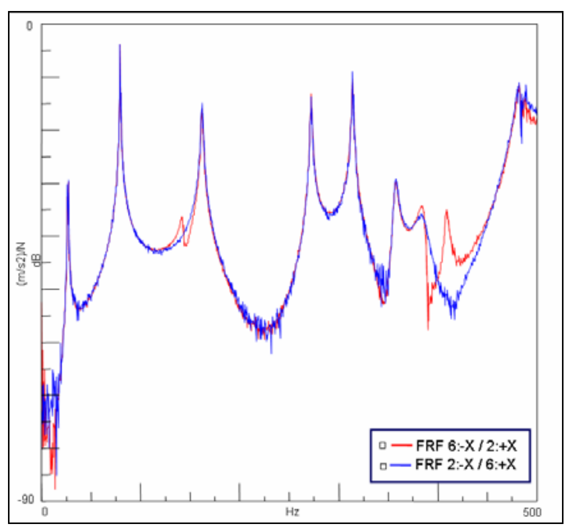


Figure 4. Reciprocity Measurement for MIMO Test

*Case 1 – Stinger Location*

As previously mentioned, the function of the stinger is to decouple the shaker from the test structure. While all stingers have some bending stiffness, if the proper location is chosen on the structure this stiffness will not contribute to the addition stiffness in resonances of the structure. This can be a major issue when the structure is very compliant, as these structures can have large displacements and corresponding rotations at resonance. The most problematic is the rotational effect at the stinger location due to high frequency mode shape structure rotations.

SISO measurements were taken at three different heights as shown in structure description section. While no specific discrepancies are consistent at any specific height, a reciprocity check between upper and lower measurements shows differences as seen in Figure 5. The inconsistency in the measurements does indicate that there are effects from adding the shaker at different locations on the structure. Clearly some of the frequencies are different from the various shaker height locations. This can be due to the stinger stiffness which may have a more significant effect on the higher modes which have more curvature than the lower order modes of the upright. (Note that all measurements taken are not shown to reduce clutter in figure; this figure is typical of results obtained for all heights investigated.)

One very important item to note is that the stinger is intended to impart motion only in the axial direction and the force imparted is intended to only be in that direction. However, any rotation of the structure causes bending in the stinger and is not accounted for in the FRF measurement this then introduces stiffness in the structure which affects the frequencies of the structure to some degree. In addition, the force gage does not measure any moments imparted from these rotations and is only designed to measure axial motion.

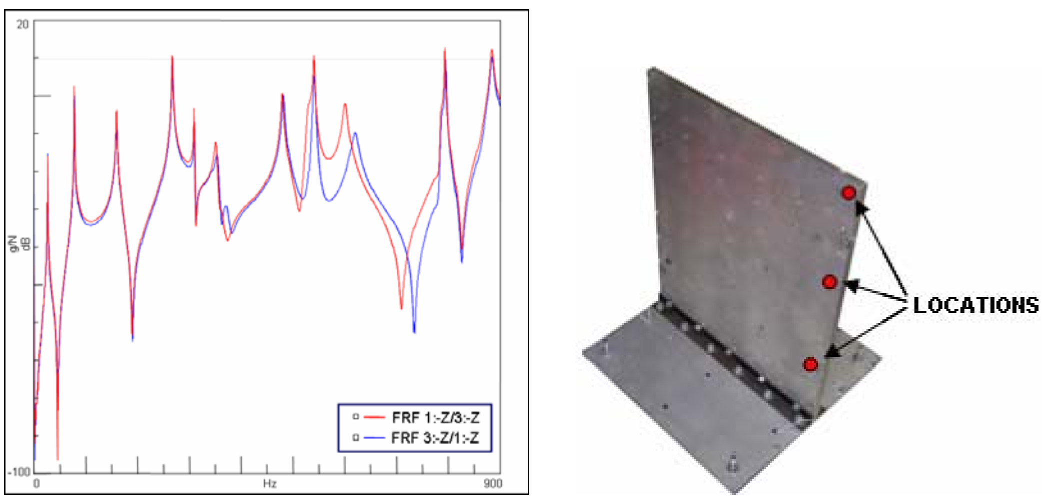


Figure 5. Reciprocity Measurement between Upper and Lower SISO Measurements

*Case 2 – Stinger Alignment*

Many times the set up of the shaker and stinger can be difficult. The alignment of the shaker and stinger is a very important item of concern when the structure and shakers are set up for testing. Misalignments are a cause for concern. The effects of stinger misalignment are examined in this case. A 5 inch stinger length was attached to the structure and the shaker was shifted to have approximately 10 degrees of misalignment. Figure 6 displays this measurement compared to the aligned shaker and impact measurements.

With the shaker misalignment, measurement differences are clearly seen in the FRF in the 400-450 Hz region. The specific reason for the differences may be due to a combination of effects including the intentional misalignment that was introduced into the measurement. With a better aligned shaker, this frequency band also had an extra peak, possibly due to a resonance of the stinger. While these results are not completely conclusive, one clear statement that can be made is that care needs to be exercised to assure that the alignment is proper. Misalignment can cause distortion of the measured FRF.

Another misalignment issue lies in the stinger itself. This can result from misalignment of the shaker (as just presented) or can result from poor fabrication of the stinger system. Any misalignment can result in the possibility of bending the stinger. Figure 7 shows a damaged stinger used for testing and a comparison of the measured FRFs with a good stinger. As shown in the figure, the mode at approximately 1130 Hz is completely distorted when the damaged stinger is used.

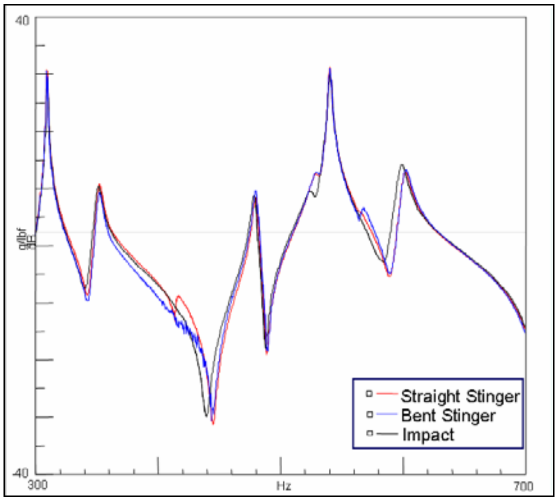


Figure 6. Intentional Stinger Misalignment

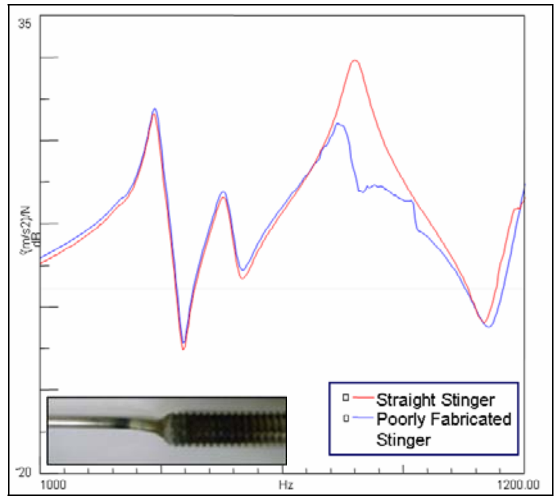


Figure 7. Poorly Fabricated Stinger Assembly

*Case 3- Stinger Length*

While the location of stinger attachment may already be pre-determined, the stinger length can be adjusted. This parameter can have a significant effect on measured FRFs. If care is not taken in a shaker test setup, measured FRFs can easily be corrupted. A quick preliminary impact test is recommended in order to confirm the accuracy of the shaker test.

In this case, three different quills supplied by The Modal Shop were used - a 2150G12 (1/16" diameter steel rod), a 2155G12 (3/32" diameter steel rod), and a K2160G (0.028" steel piano wire). Lengths were varied from 1" to 7", and the shaker was used in both fixed and hanging positions. Figure 8 shows the measured FRFs of the 1/16" drill rod at different lengths. For these measurements the shaker was fixed at the lowest attachment point, although similar results are obtained with all the stingers.

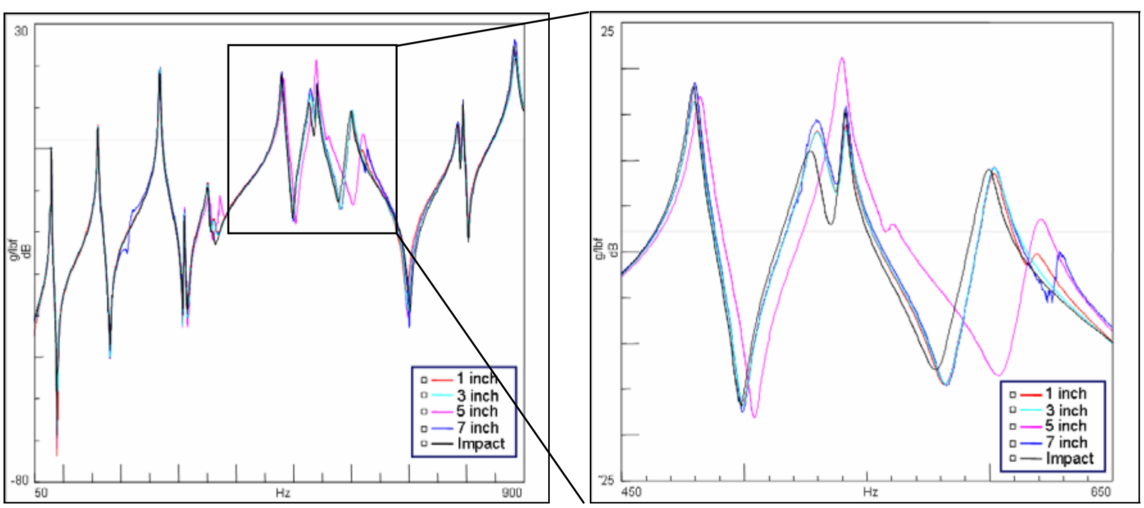


Figure 8. Stinger Length Comparisons.

The discrepancies in the measured FRFs are clearly illustrated in Figure 8. No stinger length matched the impact measurement exactly, although a 3 inch stinger length seemed to be ideal for this structure. While a 3 inch stinger is ideal, a 5 inch stinger yields differences in the FRFs. Piano wire obtained accurate FRFs at shorter lengths than the quills, typically around 1 inch. Generally, if the stinger is too short, the structure will have increased stiffness which can lead to shifts in mode frequencies and possibly additional modes. On the other hand, too long of a stinger can introduce additional peaks due to stinger resonances.

*Case 4 – Stinger Type*

While steel threaded and drill rods are the most commonly used stingers, piano wire and nylon threaded rod are also available. This case will compare these stingers to show what effects each can have on the test structure. Five different types of quills supplied by The Modal Shop were used, a 2150G12 (1/16" diameter steel rod), a 2155G12 (3/32" diameter steel rod), a 2120GXX (10-32 Threaded Steel Rod with three different lengths, 9", 12", and 18"), a 2110G12 (10-32 12" Threaded Nylon Rod), and a K2160G (0.028" steel piano wire). Ideal lengths determined by Case 3 were used with the steel rod and piano wire, whereas the threaded rod was at set lengths. The shaker was used in both fixed and hanging positions. Figure 9 shows typical FRFs comparing measurements obtained with the various stingers.

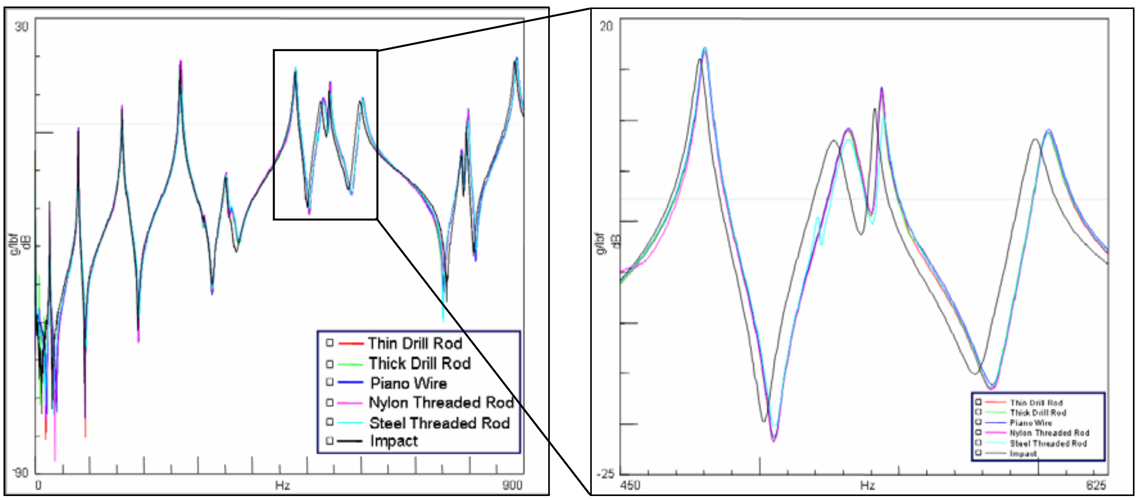


Figure 9. Stinger Type Comparison

While the overall measurements compare well, closer examination shows discrepancies in the steel threaded rod measurement. An extra mode appears around 520 Hz and the amplitude is slightly decreased in the following two modes. With all stingers there is a common frequency shift that increase with frequency. Noted that the effects of each stinger can dramatically vary depending on the mass and stiffness of the test structure and must be considered when setting up the test.

## SOME THOUGHTS AND OBSERVATIONS FROM PREVIOUS EXPERIENCES

While this paper has presented some very specific examples, some general thoughts and observations are presented in this section. In performing shaker testing, some general rules of thumb are generally followed. These are presented below. Shaker testing is commonly utilized in order to obtain high quality FRFs. Care needs to be exercised to assure that accurate measurements are obtained. When setting up for shaker testing, the shaker location, stinger length and stinger type needs to be checked to determine that proper FRFs are obtained.

Shaker testing and shaker set up is greatly facilitated with shakers specially designed for experimental modal testing. These generally have some special features not found on conventional shakers for general use. One important feature is the through hole in the armature of the shaker along with the collet clamping design (as well as the shaker trunnion). This allows for very easy use of stingers of arbitrary length and arbitrary types to be employed. Conventional shakers do not have this feature and the set up of arbitrary length stingers is extremely cumbersome and difficult. With the collet and through hole set up, the shaker can be easily shifted closer or farther from the structure to investigate stinger length effects on the measured FRFs. Typically, the length of the stinger should be varied with +/- 25% of the suggested length to understand the effects of the variation of the stinger length. If the FRFs are all very similar, then the effects of the stinger are not critical to the accuracy of the measured FRFs. If variations are observed, then additional studies need to be performed in order to identify the appropriate stinger length to be used for the conduct of the test.

One very important check that should always be performed is related to the actual attachment of the stinger to the force gage or impedance head. This threaded attachment should be made with very simple finger threading of the stinger to the mating thread in the force gage or impedance head. Any resistance in the thread is a clear indication that the alignment is not correct and misalignments may exist. This should also be checked at the end of the test. Any resistance in the disconnection of the threaded stinger is again a clear indication that misalignments may exist. If resistance is noted, then the drive point FRFs should be checked at the end of the test and compared to the drive point FRFs at the beginning of the test. (These measurements should be made as standard practice in any modal test.)

Misalignments can also be seen when an experimental modal test is conducted over several hours or even over the course of one or two days. Many times the structure may shift during test, the shakers may shift during test, or the structure support system (most common in flexible free-free testing) may creep with time. Standard practice is to disconnect the shaker/stinger during periods of extended time when testing does not occur. However, the structure alignment to the shaker stingers may vary slightly with time and realignment may be necessary. If the shaker/stingers are continuously attached during periods of inactivity (overnight for instance), then shifting or creep in the test set up may cause stinger misalignment to occur. This may have an effect on the measured FRFs and again drive point FRFs should be checked at the beginning and end of the experimental modal test (and possibly at intermediate points during the experimental modal test).

While some brief points are mentioned here, a more detailed set of Frequently Asked Questions related to shaker testing in general can be found at www.modalshop.com

## SUMMARY

Shaker testing for the development of experimental modal models can be affected by shaker/stinger location on the structure, stinger length and stinger type/material used. These effects must be understood in order to obtain the best possible FRF measurements. Several different sets of FRF measurements were obtained with a variety of different parameters studied to show the effects of shaker/stinger set up on the measured FRFs.

While explicit parameters are impossible to identify due to the wide variation in types of structures that may be subjected to this type of test, the measured FRFs do show that the parameters of shaker/stinger location, stinger length and stinger type/material can have a pronounced effect on the measured FRFs. Clearly, these parameters need to be explored at the start of the experimental modal test to identify appropriate parameters for the specific experimental modal test to be performed.

## REFERENCES

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