EFFECTS OF ACCELEROMETER MOUNTING METHODS ON QUALITY OF MEASURED FRF’S

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Modal testing is a vibration testing method that can be used to achieve the intrinsic properties of structures such as natural frequencies, damping coefficients and mode shapes. Accelerometers are one of the vital equipment’s in modal testing. Selection of the appropriate method for connecting these sensors to structures plays an important role in achieving frequency response functions with minimum noise. Different methods exist for installation of accelerometers in structures. This paper identifies and clarifies issues regarding mounting of accelerometers. In this study, accelerometers are mounted with three different procedures (magnet, wax and stud) on a steel beam and results of modal testing have been compared in all three conditions. The results of this study show significant effects of the sensor installation methods on the response of the structure in both time and frequency domains. Based on these measured results and predictions from mathematical model, it is recommended to mounting accelerometers with studs as possible and the next priority is the use of wax (or instant adhesive) and magnet.

1. Introduction

The method of mounting contact-type vibration transducers (such as accelerometers) can have a significant influence on the sensed vibration signals. The accelerometer mounting method will almost always have some influence on the frequency response. In some cases, the influence is negligible; in other cases, the mounting method can have a significant influence. Choosing the optimum mounting arrangement will significantly improve the accuracy. For an accelerometer to generate accurate and useful data, it must be properly coupled to the system under investigation. This means that the mounting must be rigid over the frequency range of interest to avoid distortion of the frequency response function. Figure 1 illustrates typical reasons for coupling errors. For best performance, particularly at high frequencies, the accelerometer base and the test object should have clean, flat, smooth and unscratched surfaces. The transmission of higher frequencies can be improved by a thin layer of silicon grease at the coupling surface.

Figure 1. Typical reasons of coupling errors

Uneven surface  Rough surface  Flexible coupling
Since the natural frequency of an accelerometer, when mounted, is dependent on the stiffness of the coupling method (see Figure 2), choosing the correct method very important.

![Figure 2. Frequency response characteristics of different mounting methods](image)

### 2. Mechanics of mounting

The ability to couple motion, (in the form of vibration), to the accelerometer with high fidelity, is highly dependent upon the method of mounting the instrument to the test surface. For best accuracy, it is important that the mounting surface of the accelerometer be tightly coupled to the test surface to ensure the duplication of motion and avoiding relative motion effects, especially at higher frequencies. Since various mounting methods may adversely affect accuracy, it is important to understand the mechanics of mounting the accelerometer for best results.

If we think of the piezoelectric material as having finite stiffness and damping which resist the deformation (strain) imposed by the seismic mass, then we can represent the accelerometer as shown in Figure 3a. This emphasizes that the accelerometer is a dynamic system itself with its own natural frequency that could affect the measurement result. For this reason, accelerometers are designed to have high natural frequencies. So a piezoelectric accelerometer can be regarded as a mechanical low pass with resonance peak. It shows the typical resonance behaviour and defines the upper frequency limit of an accelerometer. In order to achieve a wider operating frequency range the resonance frequency must be increased. This is usually done by reducing the seismic mass. However, the lower the seismic mass, the lower the sensitivity.

The illustration in Figure 3a, is correct if the sensor is connected rigidly on the structure. In reality, this is not to be the case. An accelerometer has to be mounted non-rigidly on a structure for measurement. If considered as a rigid mass block, the accelerometer and its mount can be modelled as an SDOF system as shown in Figure 3b.

![Figure 3. The accelerometer and its mounting as a spring–mass–damper system](image)

(a). rigid connection, (b). non-rigid connection
The accuracy of the acceleration measurement depends largely on the mounting which is modelled by a spring and a damper. The accelerometer is of course more than just a mass block and it has its own natural frequency. This frequency is usually much higher than the frequency of the SDOF system in Figure 3b. The best accuracy would arise if the mounting were rigid. The flexibility of the mounting means that the characteristics of the accelerometer are compromised somewhat. Because of it, acceleration from the structure may be different from the experienced by the accelerometer. However, if the natural frequency of this SDOF system is five times or more of the frequency of the acceleration signal from the measured structure, then there is effectively no magnitude and phase distortion.

According to last paragraph, during the mounting, other springs are inadvertently interposed between mating surfaces creating secondary spring-mass systems with lower natural frequencies than that of the accelerometer itself. So one can model the whole system as a two DOF system as shown in Figure 4. There are now two spring-mass systems and both will affect frequency response.

![Figure 4. A two DOF model of an accelerometer and its mounting](image)

(a). schematic model, (b). mass-spring-damper model

3. Experiment

3.1 Case study

A steel beam is used to investigate the effects of different mounting methods on the quality of the structural response in time and frequency domains. The beam has cross section of $b \times h = 40 \times 12 \text{ mm}^2$ and a length of $L = 500 \text{ mm}$ (Figure 5). Various modes of bending have been studied. In table 1, the first two natural frequencies of the beam are calculated using the methods of numerical solution and the exact solution.

![Figure 5. Geometric dimensions and physical properties of beam](image)

Table 1. Natural frequencies of beam using numerical and analytical methods

<table>
<thead>
<tr>
<th>Solution method</th>
<th>Natural Freq. # 1 (Hz)</th>
<th>Natural Freq. # 2 (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numerical</td>
<td>248.59</td>
<td>683.51</td>
</tr>
<tr>
<td>Exact</td>
<td>249.05</td>
<td>686.51</td>
</tr>
</tbody>
</table>
3.2 Accelerometer mounting methods

The key question is which mounting method is most suited for the intended purpose. The recommended mounting method is that used for calibration. In this study, three different methods that have been considered for mounting accelerometers on the structure are magnet, wax, and stud. These methods are shown in Figure 6 and Figure 7. It is recommended that for using stud, the threaded depth should be at least 6.25 mm.

![Magnet](image1)

(a) Magnet

![Wax](image2)

(b) Wax

Figure 6. Installing accelerometers a. magnetic property, b. wax

![Stud](image3)

Figure 7. Installing accelerometers using stud

3.3 Modal testing

Since a frequency range of 800 Hz is considered for modal testing, all three methods of installation (stud, magnet and wax) are applicable for this study. A modal hammer is used to excite the Structure with free-free support condition as shown in Figure 8. For better excitation of the first two modes, a plastic hammer head is used. Six number of impacts were used to excite the structure at certain points of interest and the responses were averaged to obtain a used in signal processing. Duration for data collection after each impact is 2.5 seconds and Data acquisition was performed using YE7600 software. Signal processing performed using N-Modal software.

Positions of accelerometers on the beam are shown in Figure 9. As it can be seen, the sensor cables are restrained by tape on the beam. Oscillation of these wires in connecting point to the sensor is one of the sources of error in modal testing, so be sure they're firm and their motion constrained very well. Modal tests have been performed on typical IEPE Accelerometers: Model CA-YD-1181 from TMC Solution Company weighs 10 grams and has a flat frequency response of 1-10 kHz when stud mounted (Figure 10).
4. **Structural response in time domain**

Structural response to applied excitations in all three cases of mounting is presented in Figure 11 to Figure 13. The prominent aspect in these figures is the presence of different response damping rate in three situations. In installation with stud, relatively rigid connection is created compared with the other two methods. So in this case, the connection stiffness (k) is greater than the other two methods and relative motion between vibrating structure and accelerometers is much less. In this case, the outputs of accelerometers are almost pure response of the structure. But in other cases, especially in the magnet mounting method the damping rate of structural response is lower due to relative motion effect between the structure and the accelerometers.
5. Structural response in frequency domain

With plotting the response of the structure in frequency domain, important information is extractable about the dynamic characteristics of the structure. A peak point in this diagram demonstrates the resonant frequencies of the structure. Around these points, structural damping is dominant and simple procedures such as Peak-Picking can be used to obtain the initial estimate of damping ratios. Modal Indication Function (MIF) for the three cases is shown in Figure 14 to Figure 16. Low noise and increasing the quality of the MIF Graph are clearly visible in Figure 16. The stud mount method yields the best results because when the instrument is installed in this fashion, the accelerometer and the test surface are essentially “fused” together by virtue of the high clamping force of the stud, ensuring the exact duplication of motion of both bodies at all frequencies.
In table 2, the values of the first and second resonance frequencies of the structures using any of accelerometer installation methods are presented. In table 1, the frequency values from analytical methods (exact solution) and numerical methods (finite element analysis with a converged mesh) are shown for comparison.

### Table 2. Experimental resonance frequencies of beam

<table>
<thead>
<tr>
<th>Mounting method</th>
<th>Resonance frequency # 1 (Hz)</th>
<th>Resonance frequency # 2 (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnet</td>
<td>246.09</td>
<td>673.34</td>
</tr>
<tr>
<td>Wax</td>
<td>248.05</td>
<td>666.02</td>
</tr>
<tr>
<td>Stud</td>
<td>247.07</td>
<td>669.92</td>
</tr>
</tbody>
</table>
6. Conclusion

The results of this research indicate that different methods for accelerometer mounting, affect the accuracy of the FRF data in an experimental modal analysis. To achieve the greatest accuracy in modal testing especially at higher frequencies, connection of the accelerometers to structure must to be sturdy and rigid to minimize relative motion. The stud type mounting is for this reason prevails. In this case, the accelerometer and structure surfaces are paired perfectly with each other, especially if you use a thin layer of grease between the surfaces.

Mounting wax is very convenient to use but it should only be used when no other alternatives are feasible. The low modulus (rigidity) of wax makes the results unreliable at higher frequencies. Magnetic mounting adapters are used to attach accelerometers to ferromagnetic surfaces. In general, magnetic adapters should be used with caution and rarely trusted at frequencies above 1 kHz.

REFERENCES