Assessment of Rotational Accelerometer Mountings for Rotational Frequency Response Function Measurement

W I I W I M¹, M NA Rani³, M I M Rosli¹, M A Yunus¹,³, R Febrina² and M A S A Shah¹

¹Structural Dynamics Analysis & Validation (SDAV), Faculty of Mechanical Engineering, Universiti Teknologi MARA (UiTM), 40000 Shah Alam, Selangor, Malaysia
²Department of Civil Engineering, Malahayati University, Lampung, Indonesia
³Institute for Infrastructure Engineering and Sustainable Management (IIESM), Universiti Teknologi MARA (UiTM), 40450 Shah Alam, Selangor

Corresponding author: mnarani@uitm.edu.my

Abstract. Kistler Kshear 8840 piezoelectric rotational accelerometer is designed with an M5 bolt type of mounting and a 5mm diameter of through or pre-tapped hole is required in a structure under test. However, the mounting is not applicable for some cases, and other types of mounting need to be used. This work investigates the applicability and accuracy of five different configurations of mounting for Kistler Ksher 8840 piezoelectric rotational accelerometer for the measurement of the rotational FRFs of a steel plate. The mounting configurations consist of 3D printed PLA and ABS mounting, bee’s wax, steel, and bolt mounting. The rotational FRF of the steel plate was measured by using impact testing method. The applicability and accuracy of the mountings were evaluated by comparing the measured FRFs with the finite element (FE) FRFs counterparts. The comparisons of the results revealed that using the bee’s wax mounting had produced the most accurate and least noisy FRF. It was also found that using the 3D printed PLA mounting had contributed to the highest contamination of noise and several spurious peaks in the measured FRFs. These findings provide useful information for selecting the appropriate types and designs of mounting for the Kistler 8840 rotational accelerometer.

1. Introduction
Rotational FRFs have important contributions in certain structural dynamics applications such as structural modification, substructuring and model validation. Although the rotational FRFs represents 75% of all the existing FRF matrix, they are often omitted because they are difficult to measure [1]. Several rotational FRF measurement techniques have been proposed and used by researchers [2,3] to estimate the rotational accelerations using two spatially separated and sensitivity-matched accelerometers. For example, [4,5] showed that the rotational FRFs were indirectly obtained using T-block mass attachment. The system was then decoupled to obtain the rotational FRF. This approach is also known as transmission simulator [6]. Another similar striking method employed in estimating
rotational FRFs is the use of an X-block attachment with several translational accelerometers demonstrated in [7]. The X-block attachment was used for the investigation of a structural modification of a helicopter tail. Although there are several techniques to directly measure the rotational data, the proposed techniques usually require special equipment such as laser vibrometer rotational accelerometers, which may not be readily available in most laboratories [8].

Recently, the use of piezoelectric direct rotational accelerometer has gained much attention among the structural dynamicists. A Kistler Kshear 8840 piezoelectric rotational accelerometer, as shown in figure 1, provides researchers with a great opportunity to perform the measurement of the rotational FRFs of a test structure [9]. The sensor is based on a very stable quartz crystal and can be powered by any commercially available 20–30 VDC power supply. The technical specifications of the rotational accelerometer is presented in table 1 and the details can be found in [9,10].

![Figure 1. Kistler Kshear 8840 rotational accelerometer.](image)

| Specification       | Value | Unit   |
|---------------------|-------|--------|
| Acceleration Range  | ±150  | krad/s² |
| Maximum Limit       | ±200  | krad/s² |
| Sensitivity         | 35    | μV/rad |
| Frequency response, | 0 - 2000 | Hz     |
| ±10%                |       |        |
| Source Voltage      | 20-30 | V      |
| Source Current      | 4     | mA     |

The comparison of Kistler 8840 rotational accelerometer with the indirect T-block technique was shown in [10]. It has been reported that the piezoelectric rotational accelerometer is far more accurate and reliable but with slightly higher levels of noise in signal compared to the indirect method. The resulting higher level of noise is observed and found to be linked to the types of mounting configurations. Therefore, the installation and mounting configurations of rotational accelerometers on a structure under test are crucial in ensuring the accuracy of the measurement. This is because mounting configurations may differ, with some transferring information more efficiently than others. Previous studies [11–13] have showed that stud mounting is perceived to be the best for translational accelerometers, but the conclusion cannot be directly applied for Kistler 8840 rotational accelerometers. This is because the accelerometer comes with an M5 mounting bolt and definitely a 5mm diameter of through or pre-tapped hole is required in a structure under test for the accelerometer attachment. However, in some cases, especially when drilling the structure is not an option, therefore, other types of mounting need to be used for the measurement of rotational FRFs.
This work investigates the applicability and accuracy of five different configurations of mounting for a Kistler 8840 piezoelectric rotational accelerometer used in the measurement of the rotational FRFs of a steel plate. The mounting configurations consist of 3D printed PLA and ABS mounting, bee’s wax, steel, and screw mounting.

2. Materials and methods

Five types of mounting configurations were investigated in this work. The mounting configurations are presented in figure 2 and are as follow:

1. 3D printed PLA mounting
2. 3D printed ABS mounting
3. Bee’s wax mounting
4. Steel mounting
5. Bolt mounting

![Figure 2. Rotational accelerometer mountings.](image)

The PLA and ABS mounting were developed by using CAD and printed using a 3D printer. Both PLA and ABS mounting were 5mm in diameter and 15mm in length. Meanwhile, the steel mounting was an M5 steel bolt with the bolt head being removed. The PLA, ABS and steel mounting types were attached to the test structure using adhesive. The mounting configurations are presented in figure 3.
2.1 EMA for the test structure

The applicability and accuracy of the mounting configurations for a rotational accelerometer were evaluated by observing the FRFs obtained from experimental modal analysis (EMA). In this work, the impact testing method was performed to obtain rotational FRFs. The test configuration is illustrated in figure 4. The experimental work was performed by hanging the steel plate with soft suspensions to mimic a free-free configuration [14,15]. The experimental configuration was designed as to the finite element model [16]. A Kistler 8840 rotational accelerometer was used to measure the dynamic data, and a 21.65mV/N modal hammer was used to excite the structure. Leuven Measurement System (LMS) data acquisition was used to acquire the data. The frequency bandwidth was set between 0 Hz to 2000 Hz with 1 Hz frequency resolution. In this work, only rotational x and y-axis were measured. The measured rotational FRFs from impact testing were then validated with the FE counterparts.

2.2 FE modelling and FRF synthesis method.

MSC Patran was used in the development of the FE model of the steel plate. The FE model consisted of 54660 elements and 70115 nodes, as shown in Figure 5. The material properties were defined as follows; density = 7850 kg/m3, Young’s modulus = 70GPa and Poisson’s ratio = 0.33. The dynamic behaviour of the FE model was then calculated by using normal modes solution.

Figure 3. Mounted rotational accelerometer on using respective (a) 3D printed PLA (b) 3D printed ABS (c) steel s(d) bolt (e) bee’s wax mounting.

Figure 4. Test configuration of the steel plate.
The FE FRF was derived using FRF synthesis method. For this method, the synthesized FRF matrix \( H_{\text{syn}}(\omega_k) \) and mode shapes are expressed by:

\[
H_{\text{syn}}(\omega_k) = \sum_{i=1}^{N} \left\{ \phi \right\}_i \left\{ \phi \right\}_i^T \left( \omega_{n_i}^2 - \omega_k^2 \right) + j2\xi_i\omega_k\omega_{n_i}
\]

where \( N \) is the number of calculated modes, \( \{ \phi \}_i \) is the \( i \)th mass normalised mode shapes, \( \omega_{n_i} \) is \( i \)th natural frequency and \( \xi_i \) is the \( i \)th modal damping ratio. The FRF derived from the FE model was compared with the measured counterparts for validation purposes. From the derived FE FRF, four resonance peaks at the rotational \( x \) FRF and seven resonance peaks at the rotational \( y \) FRF were identified.

3. Results and discussion
Figures 6, 7, 8, 9 and 10 present the rotational FRFs measured in the \( x \) and \( y \) axis using 5 types of mounting configurations. From the figures, all the resonance peaks in the rotational \( x \)-axis were successfully measured using all type of the mounting configurations. However, using 3D printed ABS mounting had led to the presence of two spurious peaks in the frequency range between 1000 to 1500 Hz as shown in figure 6. The presence of the spurious peaks may be because resonances occurred in the mounting. Meanwhile, all the resonance peaks in the rotational \( y \)-axis were successfully measured using the steel, bolt, and bee’s wax mounting types, as shown in figures 8, 9 and 10. However, a resonance peak for the 6th mode within the frequency range between 1800-2000 Hz was not visible in the measured rotational \( y \) FRFs using 3D printed ABS and PLA mounting as shown in figures 6 and 7.
Figure 6. Measured (a) rotational x (b) rotational y FRFs using the 3D printed ABS mounting configuration.

Figure 7. Measured (a) rotational x (b) rotational y FRFs using the 3D printed PLA mounting configuration.

Figure 8. Measured (a) rotational x (b) rotational y FRFs using the bolt mounting configuration.
Figure 9. Measured (a) rotational x (b) rotational y FRFs using the steel mounting configuration.

Figure 10. Measured (a) rotational x (b) rotational y FRFs using the bee’s wax mounting configuration.

All the resonance peaks for the rotational FRFs in the x and y-axes were successfully measured using the steel, bolt stud and bee’s wax mounting types as presented in figures 8 to 10. However, it was shown that using bee’s wax appeared to be the least noisy and produced the highest quality of FRF compared to the other mounting types. It was also found that the pattern of resonance and anti-resonance calculated was also almost similar to the FE counterparts, as shown in figures 11 and 12. Therefore, bee’s wax is the most suitable mounting configuration for the rotational accelerometer and impact testing purposes.
Figure 11. Comparisons of rotational x FE and measured FRF using bee’s wax mounting configuration.

Figure 12. Comparisons of rotational y FE and measured FRF using bee’s wax mounting configuration.

4. Conclusions
The applicability and accuracy of five different configurations of mounting for Kistler 8840 piezoelectric rotational accelerometer in the measurement of the rotational FRFs of a steel plate were investigated. The mounting configurations consisted of 3D printed PLA and ABS mounting, bee’s
wax, steel, and bolt mounting. The measured rotational FRFs using the mounting configurations was observed and compared with the FE FRF counterparts. The comparisons of the FRFs revealed that all the five mounting configurations were capable of measuring all the resonance peaks in the rotational x-axis. It was found that bee’s wax as the mounting had produced the most accurate and least noisy FRF. On the other hand, using both 3D printed mounting had produced several spurious resonance peaks and poor quality of FRF. The outcome of this study suggests that using bee’s wax as the mounting configuration for the rotational accelerometer is the most suitable mounting for impact testing purposes. These findings are thought to provide useful information for selecting the appropriate types mounting for the Kistler 8840 rotational accelerometer.

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