# Preliminary Investigation of the Vibration Characteristics and Isolation Requirements of a Prototype MRI Scanner

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## Introduction: MRI Vibration Problem and Project Description

A persistent issue with MRI machines is inadequate vibration isolation. This problem is two-faceted. First, the scanner produces significant noise and vibrations during operation. These vibrations, when transmitted to the machine's environment, have negative repercussions such as the production of uncomfortable and even harmful acoustic noise. Second, MRI scanners take relatively long to perform a scan. Any motion of the scanner or test subject will produce noise in the image, thereby limiting the resolution that can be achieved by the scanner. Therefore, it is necessary to isolate the machine from its environment as much as possible. As a result, current MRI suites machines require significant and costly physical modifications to make them suitable for MRI operation.

Since the 1990s, numerous relatively successful passive and active methods have been implemented to address this issue. A recurring design element makes use of a compliant passive component coupled with piezoelectric actuators[2]. Unfortunately, these patents do not seem to have been taken up by manufacturers, potentially since they require changes to the internal structure of the MRI machine as suggested by Lee et al[2]. As such, there is a need to develop a means of isolating an MRI machine from its environment that does not require modifications to the internal structure of the machine. The objective of the work presented herein was to implement passive vibration isolation in the base of a low weight prototype MRI scanner. The first step was the creation and validation of a finite element (FE) model of the MRI base, which requires computational and experimental modal analysis. The second step was the analysis of a load-dependent natural frequency, high damping pneumatic isolator to assess its suitability to this application.

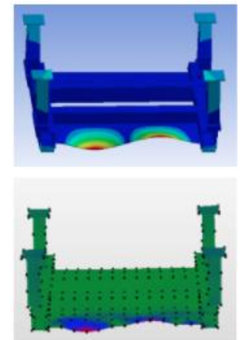

*Figure 1 Correlated Mode Pair*

## Modal Analysis Method and Results

Modal analysis is to describe a system in terms of its dynamic characteristics: natural frequency, mode shapes, and damping ratios[1].

A simplified model of the MRI scanner base was imported into the FE modelling software ANSYS for modal analysis. Free-free boundary conditions were used. The natural frequencies and mode shapes of the model up to 600 Hz were calculated.

Subsequently, a modal test was performed on a prototype of the MRI support structure. A shaker provided burst random excitation for 50% of the sample window while accelerometers were roved to 310 points on the surface of the structure. The base was set on rubber mounts to simulate free-free boundary conditions.

Seven mode pairs were successfully visually correlated. An example of a mode pair is shown in Figure 1. The natural frequencies of correlated mode pairs are within 4% difference of each other. One way of evaluating the degree of correlation between the mode pairs is to plot the experimental frequencies versus the computational frequencies and fit them with a linear regression. A slope of 0.968 indicates good correlation. Thus far, good subjective correlation between experimental and computational results has been found. Conclusions can now be drawn from the FE model with confidence in their accuracy.

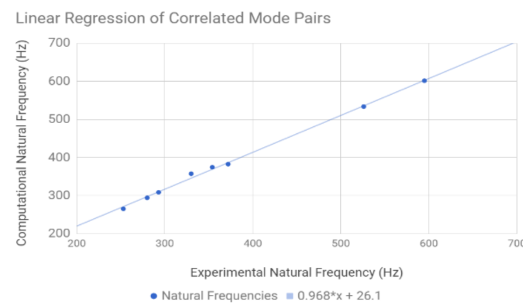


*Figure 2 Linear regression of Correlated Mode Pairs*

## Isolator Analysis Method and Results

Small-scale testing had three objectives: to establish the dynamic properties of the isolator for future modelling, to confirm that the isolator behaves according to product specifications, and to quantify transmissibility at expected excitation frequencies. The isolator was shown to perform well overall but having a lower transmissibility as load increases. The results also seemed to indicate that the natural frequency of the isolator is higher than reported in the specifications (see Figure 3) at around 8Hz rather than the expected 4.25Hz.

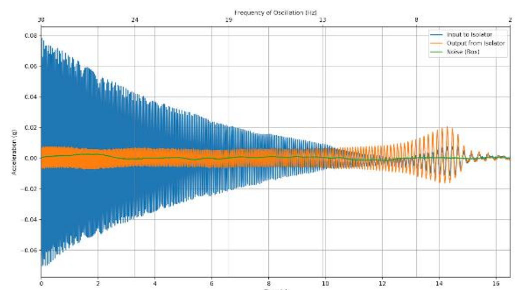

*Figure 3 Small scale isolator performance at 33% max load*

The large-scale testing was performed to give more insight into the full-sized isolators subjected to their operating conditions since substantial simplifications were necessary in prior analyses. For these tests, accelerometers were mounted above and below the isolators and the floor excited with a 3Hz (near isolator resonant frequency of 3.25Hz) impact excitation. The isolators were shown to perform suitably well (0.84-0.74 transmissibility, see Figure 4) in a typical environment, but do not meet isolation criteria comparable to MRI suites in high excitation environments.

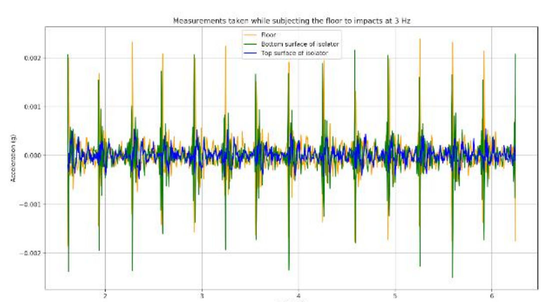


*Figure 4 Large scale testing results show good attenuation between floor (orange) and scanner (blue)*

Lastly, the isolators were modelled as a spring damper system with hysteretic damping as a function of excitation frequency. A harmonic analysis was performed at 3.25Hz at 10Hz, the estimated resonance frequency of the floor. The isolator performs very well at 10Hz, attenuating most vibrations (see Table 1). At resonance, it is not causing amplification indicating adequate damping is present.

*Table 1 Computational Analysis Results*

| Isolator | Excitation Frequency (Hz) | Transmissibility (Output/Input) |
|---|---|---|
| None (Aluminum) | 3.25 Hz | 0.9863 |
| None (Aluminum) | 10 Hz | 0.983 |
| Newport SLM-6A | 3.25 Hz | 0.9887 |
| Newport SLM-6A | 10 Hz | 0.0008 |

## Conclusions

Analysis tools were developed, and the performance of an isolator was evaluated. The isolator was shown to perform well but would not be suitable if in a high vibration environment. Overall, implementing some vibration isolation outside the scanner is feasible.

## References

[1] Avitabile, P. (2017). *Modal Testing: A Practitioner's Guide*. Hoboken, NJ: John Wiley & Sons.

[2] Lee, J., Rudd, B., Li, M., & Lim, T. C. (2008). Sound Reduction Technologies for MRI Scanners. *Recent Patents on Engineering, 2(2)*, 1-8.