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Reproducing a Component Field Environment on a Six Degree-of-Freedom Shaker

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ABSTRACT:

Researchers have shown that the dynamic field environment for a component may not be represented well by a component level single Degree-of-Freedom shaker environmental test. Here we demonstrate for a base mounted component, a controlled six Degree-of-Freedom component level shaker test. The field response power spectral densities are well simulated by the component response on the six Degree-of-Freedom shaker. The component is the Removable Component from the boundary condition challenge problem. The field environment was established with the component mounted in the AWE Modal Analysis Test Vehicle during an acoustic test. Interesting mileposts during the process of achieving the controlled component response are discussed.

Keywords: MIMO testing, 6 DOF testing, Removable Component BARC, Modal Analysis Test Vehicle MATV, Acoustic

MOTIVATION:

Currently, component qualification testing contains unknown uncertainty. Not enough measurements are provided to define the component motion in the system field environment, system component boundary conditions and impedances are ignored, and laboratory testing may contain different boundary conditions that change the stress fields and failure modes [1]. These uncertainties sometimes go ignored, and it is implicitly assumed that conservative envelopes on the available system measurements provide confidence in component testing [1]. These envelopes are specified in the individual X, Y and Z directions and the hardware is tested one axis at a time on single degree of freedom shakers. Laboratory shaker boundary conditions are constrained in the other 5 degrees of freedom, unlike the field boundary conditions. There is reporting evidence that the response of a structure excited simultaneously in multiple axes differs from sequential single axis tests [2, 3]. There is also evidence in difference in fatigue life and failure modes when comparing MDOF and 1DOF testing [4].

All of these changes provide additional uncertainties, especially when considering that the 'available measurements' used to develop these envelopes may be a non-negligible distance from the component base and rotations are completely ignored [1]. Ideally, one has measurements of the system and component of interest and can reduce these uncertainties while improving confidence in the enveloped test specification. Instrumentation, data acquisition, and telemetry technology has advanced to allow a sufficient sensor set to completely define the

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component motion. This work seeks to show proof of concept that better lab environment testing is possible using a MIMO 6DOF shaker to reproduce component field environment; here we assume the available measurements have been acquired at the system and component locations of interest and use those responses as the target control. This method would remove uncertainties in future testing and provide benefit in understanding accurate stress and damage potential.

INTRODUCTION AND BACKGROUND:

The instrumented Removable Component from the Box Assembly and Removable Component (BARC) was the structure of interest in a previous MATV acoustic test and the measured data was recorded and is used as the 'truth' field data for this investigation. Here, we use this field data of as the target control on a 6DOF shaker table. The Removable Component (RC) is a base mounted component. The BARC has been a structure of interest for many in the modeling, analytical, and experimental field [5, 6, 7, 8].

The Removable Component (RC) was mounted inside a Modal Analysis Test Vehicle (MATV) and subjected to a 147 dB acoustic "field" test using an acoustic horn in a reverberant chamber at the Institute of Sound and Vibration Research Consulting facility at the University of Southampton. Developed at the Atomic Weapons Establishment (AWE), the MATV is constructed of a conical composite aluminum shell with a foam filled steel pipe in the axial center, as seen in see Figure 1a. Additionally, the MATV consists an aluminum cover plate which is used to close off the larger end, and an aluminum component plate at the top of the steel pipe where the RC mounts to. This whole MATV structure has a mass of 47 kg. To simulate a free-free boundary condition, bungee cords were used to suspend the MATV during the acoustic test, which is shown in Figure 1b. 14 internal target control accelerometers were used. The four triaxial accelerometers used are shown in Figure 1c. Here, the focus is on whether the field could be replicated in a MIMO 6-DOF environment and use Nodes 1-4 (triaxial accelerometers on the RC) for the response control. The next section describes the 6-DOF lab environment test conducted to simulate the MATV acoustic test. In this case, we consider the MATV field test data as the 'truth' data and use it as the target control.

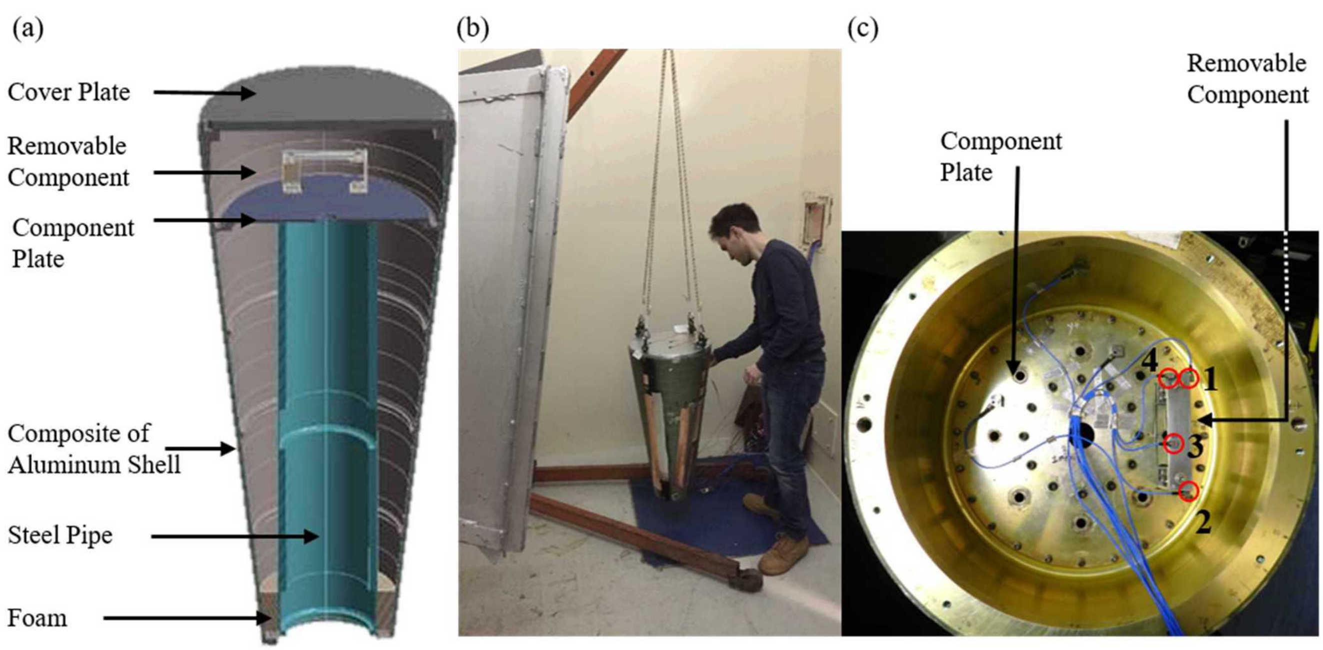

Figure 1: (a) MATV Finite Element Model Cutaway, (b) MATV Hardware in a Test Setup, (c) target accelerometer locations in large end of the cone.

EXPERIMENTAL RESULTS AND DISCUSSION:

A nominally identical RC [8] was instrumented using the same 4 triaxial accelerometers (Nodes 1-4) at the same locations and was mounted to the Team Tensor 900 6-DOF shaker. This shaker has 12 servos – 2 on each side of the plate and 4 below the shaker head. Two different adapter plates were used to accommodate the same mounting configuration as the IMMAT test. 9 additional accelerometers were used on the base plate, 4 on the sides on the plate and 4 equidistant on the top surface of the base plate and an additional one in the center, see Figure 2.

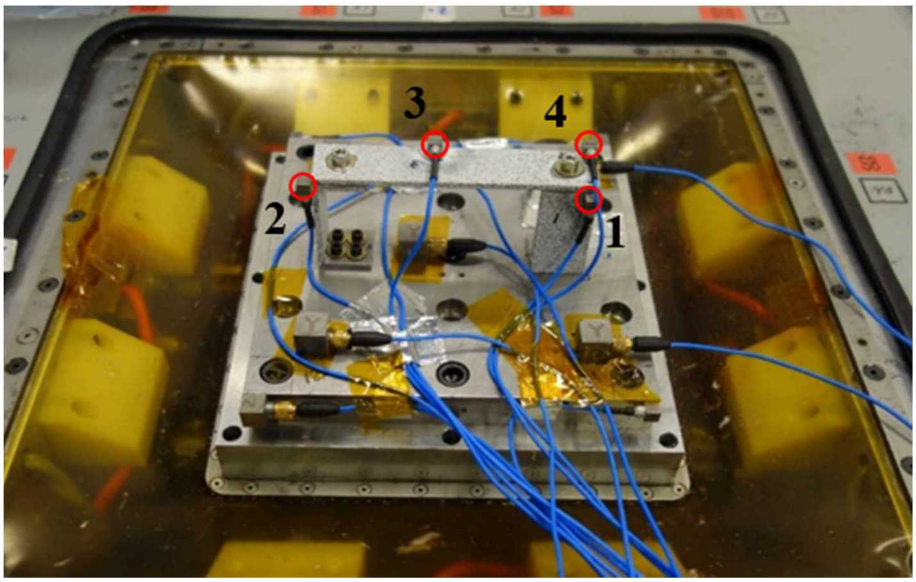

Figure 2. RC attached to Team Tensor 900 instrumented with 13 triaxial accelerometers

Two different tests were conducted using this configuration. First, a response control scheme using the Spectral Dynamics MIMO random controller was implemented to control the original 4 nodes (12 responses) to the measured MATV acoustic test data. The MATV ASDs were sampled at a 1.25 Hz resolution and truncated from 50 Hz to 2000 Hz to accommodate the Spectral Dynamics requirements. The measured ASD responses from the 6 DOF shaker test (red) and the target MATV acoustic responses (blue) are shown in Figure 3. Note, here we are trying to match all 12 responses on the 4 triaxial gauges using a multi-axis base excitation. The measured (red) and target (blue) ASD responses match well over most of the control bandwidth (50-2000 Hz). There are two consistent frequencies where the fit is less precise: 1140 Hz and 1900 Hz. The first discrepancy (1140 Hz) is only in the X direction of the four nodes and corresponds to the third fixed base mode where the RC component lunges side to side in the X-direction [5]. Mathematically, this fixed base mode is controllable, but the Spectral Dynamics control system did not have enough dynamic range to notch the inputs low enough to remove this fixed base resonant response. The second mismatch is near 1900 Hz and can be observed in all 4 nodes in the X, Y and Z direction. This corresponds to a twist mode of the 6 DOF [5] shaker and fixture plate which was not controllable in this experimental set-up with the Team-Tensor 900. We provide these curves as evidence that a controlled 6-DOF test can simulate a field response for a base mounted component.

The second test of interest with this configuration was to understand how well one could match the RC response using a single degree of motion test. To do this, first a simple buzz test was conducted using base control. The base accelerometers were used to produce flat broadband spectrum in all three translations (X, Y, Z), and all three rotation (Rx, Ry, and Rz). The six base acceleration inputs were uncorrelated. The responses of nodes 1-4 were measured and a transmissibility matrix was calculated to the six base inputs to understand the dynamic response of the RC on the 6-DOF shaker. The input for this single degree of motion test is an ASD for the X-direction only; this was directly measured on the MATV component plate approximately 4 inches away from the RC. Here the Y-direction and Z-direction translation motions and all three rotations (Rx, Ry and Rz) are ignored, this drastically affects the response. The results of this test are shown in Figure 4. The measured ASD responses from the 1DOF shaker test (red) and the target MATV acoustic responses (blue) is a poor recreation of the field responses. Using a controlled measured X input from the field as the target specification yields a different RC response when Y, Z, Rx, Ry, and Rz are constrained. For the frequency range 50 Hz to 1100 Hz, the measured response and target response match well for all 4 nodes in the X-direction only. However the overall amplitude and response structure for the constrained Y, Z, Rx, Ry, and Rz does not match.

MIMO testing can be complex, and this test series presented a few challenges that can be explored in future works to minimize the error between the target and measured ASD responses. Firstly, the reference response matrix must be a positive definite matrix. It is important to note that when using the Spectral Dynamic MIMO random controller, the software truncates all terms to 6 significant digits past the decimal point and this truncation can cause a positive definite system to become non-positive definite or the coherence to be greater than 1, which is physically impossible. One solution is to truncate the matrix in MATLAB prior to testing while ensuring positive definiteness or multiplying the coherence by 0.9999 (until it is less than 1) which is undesirable. Another important coefficient is the condition number of the matrix. With the current control scheme all twelve response were treated with equal importance and if the condition number is too high then the controller struggles to control to the target, sometimes even aborting prior to reaching steady state at low levels. This single degree of motion test is also related to the dynamic range of the controller software. If the target references span too many decades the drives of the servos will not have enough dynamic range to control and overcome dynamic response and unwanted resonances. For these series of tests, a condition number of 1000 was used, and the matrices were truncated in MATLAB while ensuring positive definiteness. Because there was insufficient dynamic range, the 1140 Hz mode could not be notched enough. If a higher condition number was used, the controller could not run the environment.

With these limitations, future work will consist of investigating and identifying better ways to condition the target reference file (matrix) to improve the match between the response and target near 1140 Hz and 1900 Hz. To improve the torsional mode (1900 Hz) mismatch, future work may consider including that mode in the base input in modal space. While this may approach dynamic range limitations, this mode is theoretically controllable.

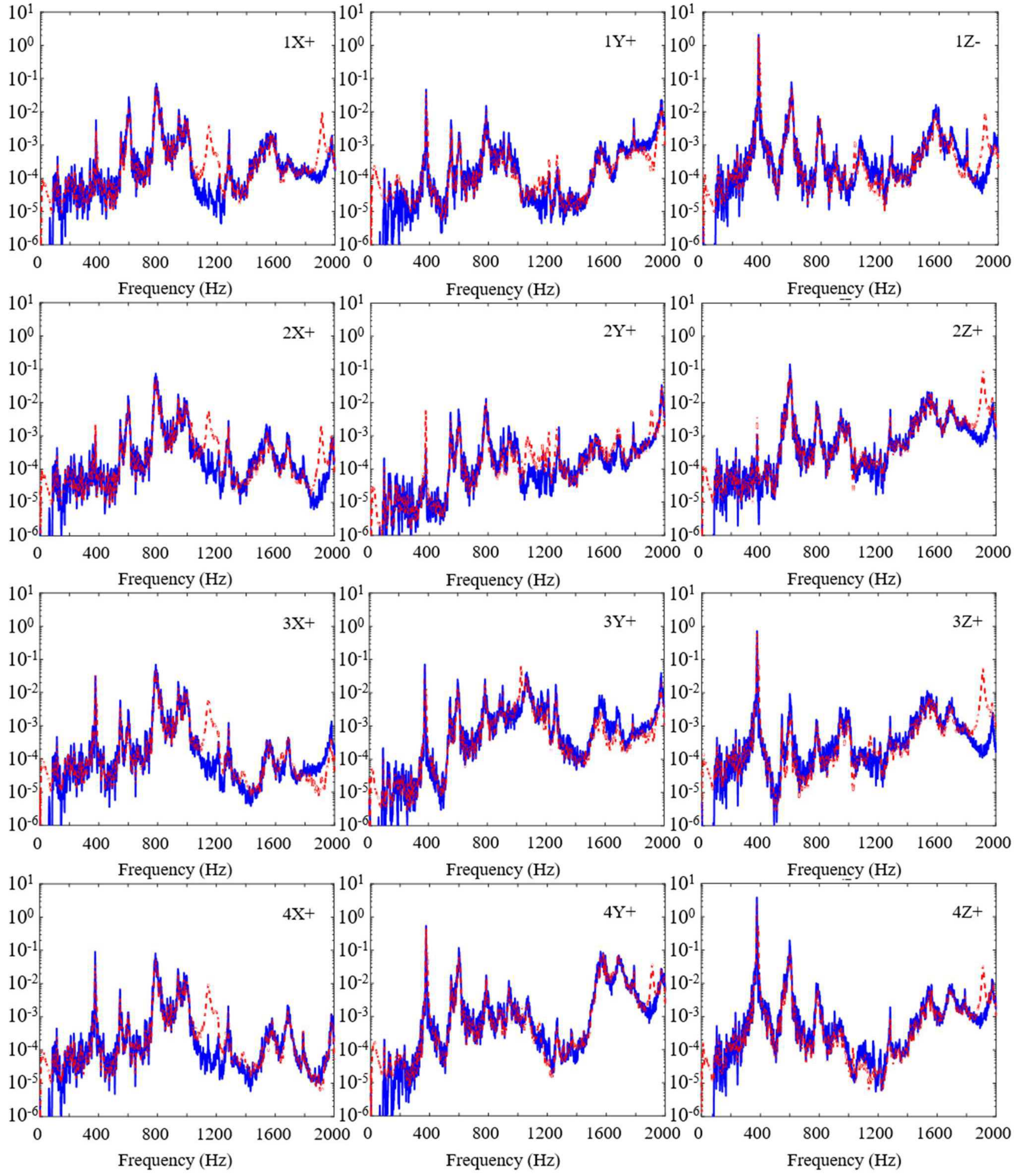

Figure 3. ASD responses from nodes 1-4 on the RC, where blue is the target MATV acoustic test and red is the 6DOF Team Tensor test. This was a 6DOF test were all 12 responses were used as the target control.

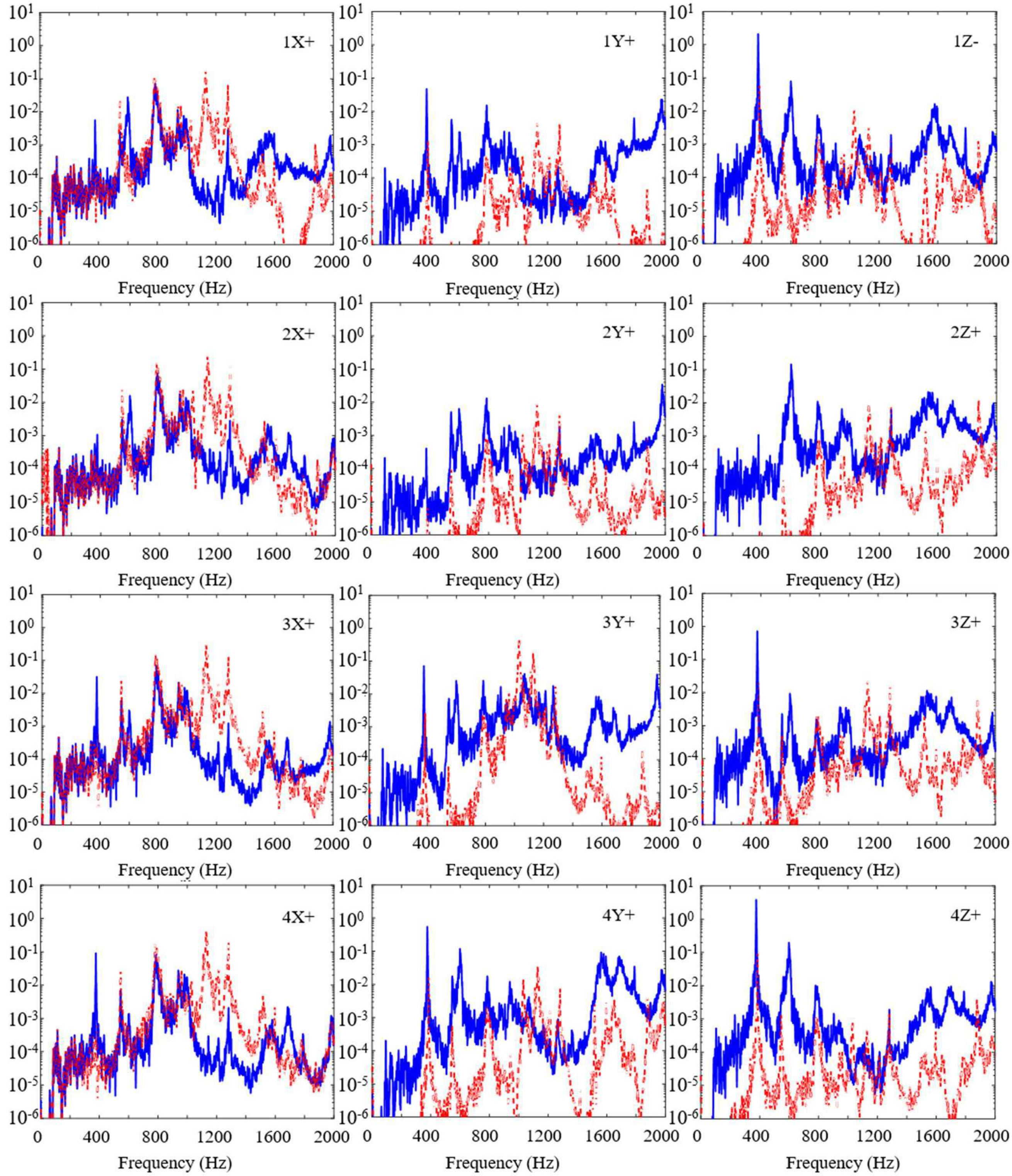

Figure 4. ASD responses from nodes 1-4 on the RC, where blue is the target MATV acoustic test and red is the 1DOF Team Tensor test. This was a 1DOF test in the X translational direction, where all 12 responses were used as the target control.

CONCLUSION

The good fit between the target MATV acoustic test, and the 6 DOF measured response shows that MIMO testing is a more suitable testing approach to achieve representative field environment reproductions. Additionally, the significantly poorer fit for the single degree of freedom test reinforces the importance of pursuing MIMO testing for component and system levels. The MIMO testing shows great promise for future investigations of combined axis testing. Understanding how to best identify MIMO specifications, and condition the reference matrices will improve testing and may allow for more complex structures. Investigations into MIMO Swept Sine tests, and MIMO Shocks along with MIMO combined environments should also be investigated in the future.

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