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AN ERROR MEASURE FOR THE SHOCK TESTING OF SCALE MODELS

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Abstract: In a variety of situations, an undesired shock excitation is applied to a master structure that supports shock-sensitive equipment. Often, one wishes to design and test a master structure that transmits the least amount of shock energy to the attached equipment. In scaled testing of new designs, a major task is to design and construct “equipment emulators” – inexpensive mechanical systems which approximately mimic the dynamic behavior of the actual full-scale equipment as seen by the master structure. A new method is presented for assessing the fidelity of equipment emulators and for interpreting test data taken in the presence of imperfect emulators. The proposed approach uses easily obtainable frequency-domain impedance descriptions of the master structure and actual equipment at the attachment points. These ideas may provide a path by which experimentalists can efficiently arrive at conceptual designs of emulators that promise a specified degree of fidelity in terms of attachment point velocities and their associated shock spectra. The ideas are illustrated by application to the emulation of commercial-grade electronic cabinets for the testing of novel ship deck structures.

INTRODUCTION

In the design and use of scale equipment models for shock testing, there are two principal objectives. The first is to produce conceptual mechanical designs that satisfy specified error and cost/complexity criteria. Given a mechanical emulator, the second objective is to develop post-processing techniques that account for emulation error in the interpretation of shock trial data.

Prior work on the design of mechanical equipment emulators is limited to acoustic performance. The design approach consisted of reproducing the first four fixed-base equipment modal frequencies and masses. Design refinement involved adding damping materials to the nominal design so as to minimize the difference between drive-point impedance of the actual and scaled equipment at the attachment-points (1). With regard to shock, Barbone is developing numerical equipment models, described by a small number of physically motivated parameters, that reproduce early-time relations between forces and displacements at the attachment points (2).

In both approaches, a physical understanding is employed to obtain a simplified model of an otherwise highly complex dynamic system. The modeling is performed independent of the dynamics of the master structure. And while the latter approach directly addresses error criteria during modeling, neither provides a means to post-process experimental data to account for emulation error. A significant issue is the lack of a generally accepted definition for emulation error in the context of shock loading and an easily evaluated metric for assessing this error. The contribution of this paper is to propose such a measure.

EMULATOR ERROR

Emulator error is evaluated in the context of the scaled master structure. It is defined as the vector difference between attachment-point velocities obtained with a particular emulator and those that would be obtained with perfectly scaled equipment. It can be expressed as a transfer function matrix relating measured scale model velocities to the velocity error vector. As a metric of emulation error, the maximum and minimum singular values of the transfer function matrix can be plotted as a function of frequency. These values represent the maximum and minimum gains for all possible attachment-point velocity vectors. By taking appropriate norms of a related transfer function, emulation error can also be expressed in terms of shock spectrum bounds. Using the proposed transfer functions, experimental data can be corrected for emulator error. Using norms, experimental shock spectrum error can be bounded.

As a simple illustration of this method, Figure 1 depicts an equipment cabinet mounted on a master structure consisting of a simply supported beam. Considering only vertical motion, an analytical model of the beam, together with experimental data from actual and scale model cabinets, is employed. Comparison between drive-point impedance of the actual and emulated cabinets in Figure 2 suggests minimal error from 0-200 Hz and large errors outside that range. In contrast, the singular values of the 2×2 velocity error transfer function matrix shown in

Figure 3 indicate significant error from 0-400 Hz and small error from 420-700 Hz. Note also the effect of master structure impedance on error. Roughly speaking, a modest error is amplified (attenuated) when stringer impedance is small (large). The proposed method offers the advantages of: (i) ease of application, (ii) error evaluation in the context of the master structure, and (iii) a means for considering all possible attachment-point velocities.

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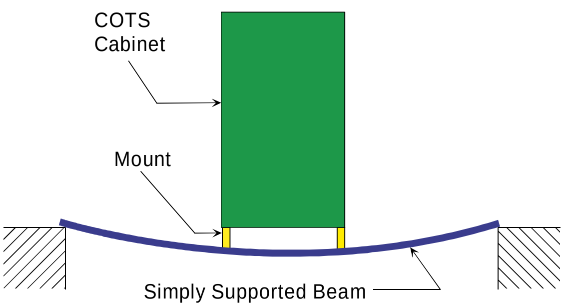

FIGURE 1. Equipment cabinet mounted on beam.

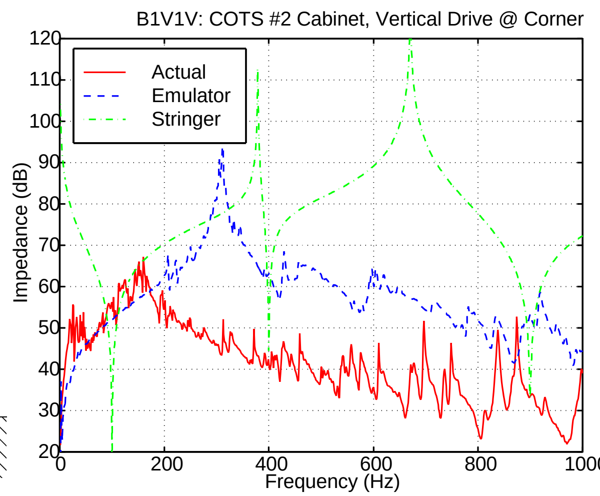

FIGURE 2. Vertical drive point impedance of cabinet, emulator and stringer (beam).

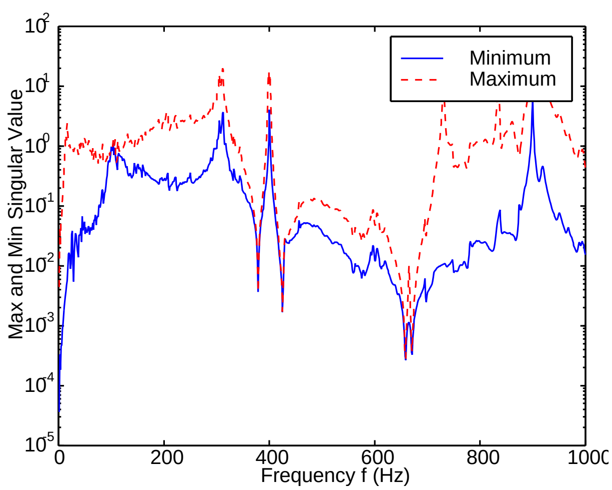

FIGURE 3. Maximum and minimum singular values of transfer function matrix relating measured vertical attachment point velocity to velocity error.