# Parameter optimization of a MWSM shock-test multibody model through SRS analysis

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**EXTENDED ABSTRACT**

## 1 Introduction

Shock tests represent an exigence for critical equipment mounted on warship vessels as a guarantee of their endurance against an eventual underwater explosion (UNDEX) without contact with the hull. According to the specification MIL-DTL-901E [1], the weight and size of the equipment determines the shock test machine to be used. All shock test machines are designed to impart an acceleration to the test item similar to the one which might experience when installed onboard. These accelerations of high frequency and amplitude are commonly analyzed through a Shock Response Spectrum (SRS) rather than time-domain analysis, being the SRS a measure of the maximum response of a 1-DOF system excited by a transient signal as a function of the 1-DOF system frequency [2]. The SRS analysis allows engineers to easily determine which are the frequencies which might be excited in a shock test, and therefore to be avoided in the design of equipment.

The Medium Weight Shock Machine (MWSM) is a machine for testing equipment from 250 up to 6000 lb [3]. It consists of an anvil table and a 3000-lb hammer installed over a massive concrete sprung foundation. In a MWSM shock test, the test item is not mounted directly upon the anvil table but upon some intermediate structures, such as supporting channels and fixtures. These intermediate elements behave as flexible bodies, and their deformation strongly determines the accelerations experimented by the test equipment.

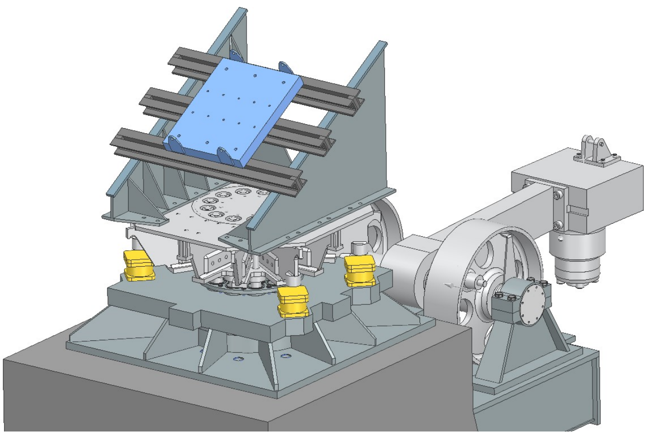

Figure 1: Shock test in a MWSM with an inclined fixture.

A complete multibody model of a MWSM shock test involves a considerable number of bodies, forces and constraints whose properties can be difficult to adjust from experimental data or in-field measurements. In addition, the parameterization of flexibility through modal reduction techniques adds another layer of complexity, requiring a study on the set of deformation modes which delivers the best ratio between accuracy and efficiency. The adjustment of system parameters is essential in this application, and different techniques have been used, being one of them parameter optimization [4]. Parameter optimization uses optimization algorithms to seek the set of system parameters that delivers the best fulfillment of an objective function while accomplishing a set of optimization constraints. In this context, it is possible to resort to multiple optimization algorithms, from gradient-based search [5] to global optimization methods [6]. In this work, both approaches are addressed.

The original objective of this work dwells in the accurate simulation of shock tests using efficient and robust methods. In accordance, an ALI3-P formulation [7] combined with the Floating Frame of Reference Formulation (FFRF) [8] has been used for the simulation of the MWSM shock tests modeled as a flexible multibody system. Flexibility has been parameterized through a modal reduction technique, in which deformation modes are obtained from modal and static analyses.

In this work, a MWSM shock test model is optimized according to experimental data obtained in shock tests on a real MWSM with different loads. The process determines from SRS data contact force parameters, structural damping, damping of the sprung foundation, and also parameters of the flexible bodies.

## 2 Multibody model and dynamic simulation

The MWSM model is composed of three sub-multibody models which are assembled together to build the main model: (i) the MWSM, including foundation, hammer and anvil table, the three of them modeled as rigid bodies; (ii) the intermediate structures of different type, modeled some as flexible and some as rigid bodies; (iii) and the test item, which can be considered as rigid or flexible depending on its physical properties. Additionally, the multibody model is subjected to forces and constraints, being the most relevant the contact forces between hammer and anvil table, the contact force of the anvil table with the top and bottom stops (which limit its travel), the elastic forces due to the elastic deformation of flexible bodies and the inertial forces.

Despite the low time step required for the dynamic simulation of a shock test, the ALI3-P FFR formulation in natural coordinates has performed excellently in terms of robustness, accuracy and efficiency with a proper selection of the penalty factors. Efficiency has been increased trough the use of a variable time step generalized-$\alpha$ numerical integrator.

## 3 Parameter optimization and results

As primary objective function, a measure of the deviation between experimental and simulated acceleration SRS has been selected, yielding:

$$\psi = \int_{f_0}^{f_{end}} \left(SRS_{sim} - SRS_{exp}\right)^2 \mathrm{d}f \tag{1}$$

The system parameters are subjected to a set of optimization constraints regarding its nature (no negative stiffness of damping coefficients) and other considerations (limitations on the difference of peak amplitudes at given frequencies and limitations on the difference between frequencies at which the peaks occur, among others).

In this application, a MATLAB multistart technique is combined with two gradient-based methods: a LBFGS algorithm and an in-house implementation of an augmented Lagrangian optimization algorithm. As a result, the convergence between experimental and simulated SRSs is greatly improved, leading to a multibody model of much higher fidelity.


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