Case Studies in Mechanical Systems and Signal Processing 4 (2016) 1–7

Contents lists available at ScienceDirect

Case Studies in Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/csmssp

Short communication

Measured-based shaker model to virtually simulate vibration sine test

Sébastien Hoffait[a,*], Frédéric Marin[a], Daniel Simon[a], Bart Peeters[b], Jean-Claude Golinval[c]

[a] V2i, Belgium
[b] Siemens PLM Software, Belgium
[c] LTAS Ulg, Belgium

ARTICLE INFO

Article history:
Received 25 February 2016
Received in revised form 7 April 2016
Accepted 24 April 2016
Available online 3 May 2016

ABSTRACT

During high level vibration test on a high mass specimen, the test engineer is often facing difficulty to pass properly the specified vibration level due to coupling between the specimen and the shaker. The present paper present a methodology to define a virtual shaker testing simulator. The first step involves the dynamic identification of a 80 kN shaker performed thanks to measurements (modal analysis and sine sweep). The second step is the definition of the physic represented in the simulator and the translation of the electromechanical equations in a home-made simulator. Controller developed by SIEMENS LMS and supplied to V2i for a use in the framework of the AOC project is introduced to close the loop. Two test cases are described to demonstrate the possibilities offered by the simulator.

1. Introduction

The feasibility to perform physical tests in the field of vibration testing cannot be entirely a priori assessed examining the shaker capability. In case of high load (injected level or mass), the test engineer can have to deal with couplings between the tested specimen and the shaker. There exists a demand from the test supplier to foresee such behavior prior to the test. By their contribution in several research [1], the space industry has shown its interest in order to reduce the risks during the qualification test campaign. The final goal is to give tools to manage adaptation in the control strategy and/or to justify levels reduction to protect both the shaker and the tested specimen.

Virtual shaker testing includes approaches to simulate the coupled behavior thanks to an electromechanical model of the shaker for which input voltage is assigned by a closed-loop controller. Refs. [2–4] present shaker modeling considering simple lumped-mass model. Such type of model is refined enough to represent a part of the coupling. Only the vertical degrees of freedom are considered in these studies and the transversal effects are neglected. The present work proposes to include the torsion and rotational degrees of freedom of the top part of the armature to complete the shaker representation. The measures performed on a 80 kN electrodynamic demonstrate the need to introduce additional degrees of freedom. In fact, low damped torsion mode is observed that can induce very large non-desired transverse accelerations.

* Corresponding author.
E-mail addresses: s.hoffait@v2i.be (S. Hoffait), f.marin@v2i.be (F. Marin), d.simon@v2i.be (D. Simon), bart.peeters@siemens.com (B. Peeters), jc.golinval@ulg.ac.be (J.-C. Golinval).

http://dx.doi.org/10.1016/j.csmssp.2016.04.001
2351-9886/

The present paper describes first the methodology to define the coupled electromechanical shaker model. Modal characteristics and sine sweep responses are analyzed to update the lumped-mass model. The controller introduced in the simulator is briefly described. The methodology followed to couple the specimen model to the shaker simulator is presented.

Secondly the Graphical User Interface functionalities are listed and two test cases, one of which is compared to measurements, are described.

The paper ends with some discussions about the possibilities offered by the simulator and the perspectives of improvement.

2. Electromechanical model of the shaker

Similarly to the philosophy adopted in Ref. [2–4], a lumped-mass model is considered to represent the mechanical part of the shaker. The latter is coupled to a RL model of the electric part in such a way that the force acting on the coil and the induced back-electromotive force are correctly introduced. The model is shown in Fig. 1

To the best of the author's knowledge, only the mechanical vertical degrees of freedom are considered in the model presented in the literature. In the present paper, the torsion and the plane rotations are added in the set of degrees of freedom, which results in a mechanical model including 7 degrees of freedom, i.e.:

$$\boldsymbol{x} = \begin{bmatrix} z_{Coil} & z_{table} & z_{body} & \theta_{z,table} & \theta_{x,table} & \theta_{y,table} & \theta_{z,Coil} \end{bmatrix}^{\boldsymbol{T}}$$

The only degree of freedom of the electric model is the current $\boldsymbol{i}$.

The electromechanical model is defined by the value of the stiffness $[\boldsymbol{K}]$, mass $[\boldsymbol{M}]$, damping $[\boldsymbol{C}]$ of the different mechanical parts, by the coil resistance R and inductance L and by the coupling terms F (if SI unit are used, the force to current constant and the voltage to velocity constant are equal) and F_θ.

The resulting equation system is:

$$\begin{bmatrix} \boldsymbol{M} & 0 \\ 0 & 0 \end{bmatrix} \ddot{\boldsymbol{q}} + \begin{bmatrix} \boldsymbol{C} & 0 \\ \boldsymbol{F}^{\boldsymbol{T}} & L \end{bmatrix} \dot{\boldsymbol{q}} + \begin{bmatrix} \boldsymbol{K} & -\boldsymbol{F} \\ 0 & R \end{bmatrix} \boldsymbol{q} = \begin{Bmatrix} 0 \\ V \end{Bmatrix}$$

where $\boldsymbol{q} = [\boldsymbol{x} \quad i]^{\boldsymbol{T}}, \boldsymbol{F} = [F \quad 0 \quad -F \quad F_\theta \quad 0 \quad 0 \quad 0]^T$.

Note that a coupling term F_θ applied between the coil torsion degree of freedom and the current is necessary in order to achieve a good correlation of the model with the observed torsion behavior of the electrodynamic shaker.

In order to simulate the shaker when positioned in its horizontal configuration, a finite element shell model of the slip table is linked to the electromechanical model of the shaker. The bearings are represented by "spring-damper" elements and the oil film interaction is taken into account thanks to local spring elements.

3. Shaker identification

For both vertical and horizontal configurations, two kinds of measurements were taken in order to build reference data set for the purpose of model updating:

1) Impact testing in order to perform modal analyses of the shaker when at rest. The Least Square Complex Exponential method implemented in the LMS software [6] was used for this purpose.

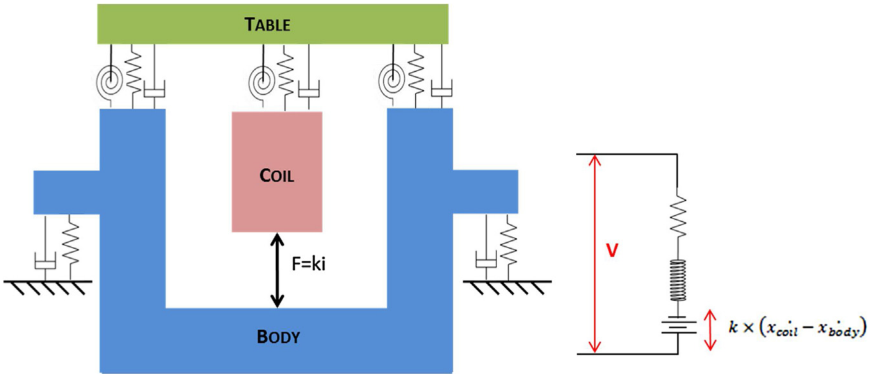

Fig. 1. Electro-mechanical model of shaker.