ARTICLE IN PRESS

Journal of Sound and Vibration ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Journal of Sound and Vibration

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

Experimental and numerical investigation of coupled microvibration dynamics for satellite reaction wheels

D. Addari [*], G.S. Aglietti, M. Remedia

Surrey Space Centre, University of Surrey, Guildford GU2 7XH, UK

ARTICLE INFO

Article history:
Received 19 May 2016
Received in revised form
1 September 2016
Accepted 3 October 2016
Handling Editor: M.P. Cartmell

Keywords:
Microvibration
Dynamic coupling
Dynamic mass
Reaction wheel assembly

ABSTRACT

Microvibrations of a satellite reaction wheel assembly are commonly analysed in either hard-mounted or coupled boundary conditions, though coupled wheel-to-structure disturbance models are more representative of the real environment in which the wheel operates. This article investigates the coupled microvibration dynamics of a cantilever configured reaction wheel assembly mounted on either a stiff or flexible platform. Here a method is presented to cope with modern project necessities: (i) need of a model which gives accurate estimates covering a wide frequency range; (ii) reduce the personnel and time costs derived from the test campaign, (iii) reduce the computational effort without affecting the quality of the results. The method involves measurements of the disturbances induced by the reaction wheel assembly in a hard-mounted configuration and of the frequency and speed dependent dynamic mass of the reaction wheel. In addition, it corrects the approximation due to missing speed dependent dynamic mass in conventional reaction wheel assembly microvibration analysis. The former was evaluated experimentally using a previously designed and validated platform. The latter, on the other hand, was estimated analytically using a finite element model of the wheel assembly. Finally, the validation of the coupled wheel-structure disturbance model is presented, giving indication of the level of accuracy that can be achieved with this type of analyses.

1. Introduction

Issues related to microvibration disturbances on a satellite are a major concern for missions where high levels of pointing accuracy and stringent platform stability are required [1–7]. Furthermore, it has also become of relevance for the low cost end of the market. For instance, mini- and micro- satellites such as the SSTL-300-S1 platform [8,9] or Skybox [10] have the mission to carry cameras with ground resolutions toward 1 m hence, even small displacements (i.e. in the order of micrometres) of the mounting interfaces of the instrument may lead to unacceptable large oscillations of the instrument line of sight. Microvibrations are classified as low level mechanical accelerations typically in the range of microgravity (μg) usually occurring at frequencies from a few Hz up to several hundred Hz [11]. Microvibrations are generally produced by internal mechanisms on-board spacecraft, including Reaction Wheel Assemblies (RWAs), momentum wheel assemblies, cryocoolers, solar and antenna pointing mechanisms, and thrusters. Among the various disturbance sources on a spacecraft, RWAs are commonly considered as the largest [12,13]. The induced disturbances are transferred through the satellite

---

[*] Corresponding author.
E-mail addresses: d.addari@surrey.ac.uk (D. Addari), g.aglietti@surrey.ac.uk (G.S. Aglietti), m.remedia@surrey.ac.uk (M. Remedia).

http://dx.doi.org/10.1016/j.jsv.2016.10.003
0022-460X/© 2016 Elsevier Ltd All rights reserved.

Please cite this article as: D. Addari, et al., Experimental and numerical investigation of coupled microvibration dynamics for satellite reaction wheels, *Journal of Sound and Vibration* (2016), http://dx.doi.org/10.1016/j.jsv.2016.10.003

structure towards the payloads and sensitive instruments, exciting their modes of vibration and severely affecting their performance. Moreover, estimates of the microvibration effects become more complicated as the dynamics of the microvibration sources also couple with those of the satellite structure [14,15]. In addition, the understanding and control of the vibration level at sensitive locations, using passive damping and active control technologies [16,17], is also a crucial factor in order to achieve the desired instruments' performance.

The rotor dynamics of a Wheel Assembly (WAs) for space application in both the symmetrical and cantilevered configurations have been extensively developed in literature [18–21]. Although the two arrangements are different, they show similar dynamic behaviour, except for the two flexural modes (radial translation and in-plane rotations) which are well defined and separated for the symmetrical design, but coupled for the cantilevered configuration. In this paper, a cantilever configured RWA, illustrated in Fig. 1, is considered and a mathematical model to describe its dynamics presented. The model is then implemented with a supporting structure (either stiff or flexible) to perform microvibration coupled analyses and tests, also described herein. The first challenge towards satellite microvibration analysis is the characterisation of the potential disturbance sources. Two different methods are usually adopted for measuring the RWA-induced disturbances depending on their boundary conditions: hard-mounted configuration (isolated, with the RWA rigidly grounded on a multi-axis dynamometric platform, e.g. Kistler table) and coupled (i.e. RWA mounted on a supporting flexible structure hung free-free by elastic cords). The former has been thoroughly developed in the past, and the most representative works are reported in [22,19,23,24,21]. However, dynamometric platforms cannot generally be used for coupled measurements, due to their size and weight. An air-floating vibration detection system was described in [24] and subsequently adopted in [25]. Although accurate, the system can operate only up to a maximum frequency of 20 Hz. The direct measurement approach for evaluating RWA-structure coupled microvibrations is, in contrast, not as mature.

For this reason, the current practice in the space industry is to use the outcomes from the hard-mounted configuration measurements as direct inputs for the satellite microvibration analysis. Its fundamental concept is, however, flawed as hard-mounted microvibrations do not represent the real environment in which the RWAs will operate. In fact, the RWA is mounted on a “flexible” satellite structure and therefore, the loads exchanged at the interface are different from those derived from the hard-mounted configuration. With the aim to analytically reproduce the dynamics between a source and its supporting structure, the dynamic mass (or its inverse, the accelerance) of the source or the driving point accelerance of the supporting structure need to be evaluated [23].

Generally, the forces and moments obtained from hard-mounted configuration measurements are applied at the location where the source is mounted on the structure, adding a lumped inertia to include the source [26–28,23]. This method is typically able to provide good predictions of the satellite performance if the RWA has resonance frequencies well above the frequency range of interest, which is not often the case for microvibration applications, hence the internal dynamics of the source (dynamic mass) need to be taken into account. Works to investigate and derive the dynamic mass of the source were initially carried out in [23,29,30]. However, all of them assumed the flywheel in a static condition (flywheel at zero speed) thus not including the gyroscopic effect. In [31], a detailed method to obtain the dynamic mass of a RWA including the gyroscopic effects was developed and validated. Although the results are accurate, this method is significantly challenging in terms of test configuration and computational effort.

In this article, the dynamic mass of the RWA, retrieved experimentally in a static condition and expanded analytically to include the gyroscopic effect by means of the RWA Finite Element (FE) model, is implemented with hard-mounted loads' measurements to estimate the coupled dynamics between a RWA and a supporting structure. The article aims to demonstrate the importance of the dynamic mass and, in particular, the improvements in the results due to considering both flywheel angular speed and frequency dependance.

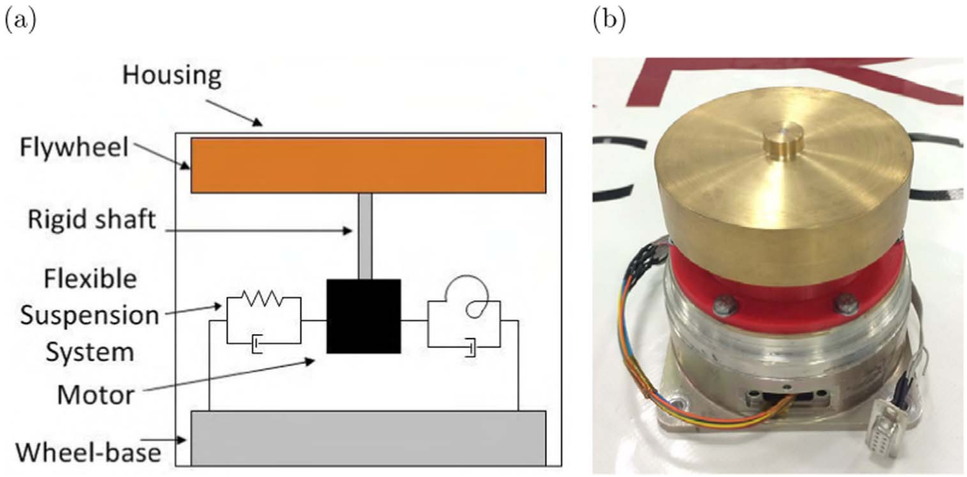

Fig. 1. Wheel assembly model: (*a*) cantilever configured RWA and (*b*) cantilevered RWA used in test.

Please cite this article as: D. Addari, et al., Experimental and numerical investigation of coupled microvibration dynamics for satellite reaction wheels, *Journal of Sound and Vibration* (2016), http://dx.doi.org/10.1016/j.jsv.2016.10.003