Measurement 85 (2016) 239–248

Contents lists available at ScienceDirect

Measurement

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

Air damping influence on dynamic parameters of laminated composite plates

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ARTICLE INFO

Article history:
Received 24 November 2014
Received in revised form 25 January 2016
Accepted 19 February 2016
Available online 27 February 2016

Keywords:
Air damping
Laminates
Vibrations
Vacuum chamber
Resonance
Loss factor

ABSTRACT

Damping performance of lightweight composite structures, like fibre reinforced plastics (FRPs) is more efficient than the conventional materials. This phenomena was found valuable in the aerospace and transport industries. For this reason accurate material properties of FRPs are required for precise prediction of dynamic response. However, the given properties are often burden with a significant uncertainty level due to environment influence which includes air damping, temperature changes, humidity, etc. The present study concerns with the air damping influence on the dynamic behaviour of laminated composites plates with moderate damping level. The effect on dynamic characteristics is evaluated experimentally using a vacuum chamber and a laser vibrometer. Resonant frequencies and modal loss factors changes are investigated in terms of material type, sample size and excitation amplitude. A semi-automatic and time efficient two-step testing procedure is developed for a precise measurement of loss factors of laminated composite plates.

1. Introduction

Damping analysis of lightweight composite structures, like fibre reinforced plastics (FRPs) or sandwich structures is covered by an excessive amount of research and scientific work. Comprehensive studies on the both analytical [1,2] and experimental [3–5] investigations of damping of composites has been already reported. Although the role of damping of composites has been widely appreciated, the effect of a structure's interaction with a surrounding medium e.g., air, has been left with little attention in a dynamic analysis of composite materials. The motivation for doing so is due to relatively small inertia forces caused by the additional mass of air compared to the mass of a vibrating structure. Also the dynamic testing using force transducers and accelerometers has prevented researchers from a precise assessment of air damping. However, depending on the applied damping model, the prediction of damping properties of FRPs or sandwich structures has still a significant margin of uncertainty [6] which is, amongst the others, due to air damping influence. In addition, a constant development of lighter and lighter composite materials motivates for a detailed study on the air damping influence on dynamic parameters of lightweight structures.

The air damping results from the air viscosity and inertia effects. The importance of this phenomenon was primarily encountered by space engineers due to vacuum-like operating conditions of space vehicles. In [7] the authors investigated the mechanism of air damping exhibited by isotropic materials with low material damping (stainless steel and aluminium) having shapes of beams, circular and rectangular plates, a sphere, and a cylinder. They found that the magnitude of the air damping contribution may exceed the material damping of the structure.

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http://dx.doi.org/10.1016/j.measurement.2016.02.036
0263-2241/

Table 1
Plates used in the experimental investigation.

Plate	Material	Stacking sequence	a (mm)	b (mm)	h[a] (mm)
PAL	Al (6082-T6)	–	300.0	200.0	2.0
LAM1	SEAL®	$[0]_{16}$	290.0	200.0	2.6
LAM2	TENAX/XP45	$[0/90/0/90]_s$	300.0	200.0	2.4
LAM3	TENAX/XP45	$[0/90/0/90]_s$	150.0	100.0	2.4

[a] Total thickness of a plate.

Table 2
Materials' properties.

Material	Material behaviour	E_1 (GPa)	E_2 (GPa)	G_{12} (GPa)	ν_{12}	ρ (kg/m^3)
Al (6082-T6)	Isotropic	68.9	–	26.3	0.31	2704.0
SEAL®[a]	Orthotropic	117.0	8.82	4.32	0.34	1546.6
TENAX/XP45[a]	Orthotropic	100.7	7.10	4.35	0.30	1479.0

[a] Material properties of a single lamina.

Further studies on air damping were extended to the anisotropic materials – fibre reinforced plastics (FRPs). In [8] the study was performed to investigate the air damping effect on the specific damping value and the dynamic Young's modulus of beams made of metals and FRPs composites. The results confirmed the strong influence of air damping on dynamic characteristic for low-damped materials. The authors underlined the difficulties in precise assessment of the air damping arising from the extraneous damping sources, such as additional mass of the measurement equipment, e.g., exciters, accelerometers, force transducers, cables, etc. Moreover, supporting a structure during a vibration test should be provided in such a way to have little influence the dynamic parameters [9]. Advances done in optical sensors, brought new devices for vibration sensing into dynamic testing. The most appreciated one are laser vibrometers, svd-cameras, and high-speed cameras. The most important advantage of the optical sensors is their capability of non-contact and non-invasive (or non-influencing) vibration sensing. Non-contact sensing reduces the extraneous damping sources acting on a structure. Laser vibrometers were primarily adopted for air damping investigation of microstructures. In [10] the authors proposed an analytical model for calculating air-damping effect in a bulk micromachined 2D tilt mirror and successfully validated the model experimentally using laser vibrometer. In [11] damping in a micro-cantilever beam was measured for a very broad range of air pressures by means of laser vibrometer. Besides the experimental investigations, excessive research work on the analytical prediction of air damping of microstructures has been also presented [12–14]. The advantage of optical vibration sensing has been further appreciated in dynamic testing of beams [15], and plates [16]. More recently the application of laser vibrometers has been widely used for layered composites vibration

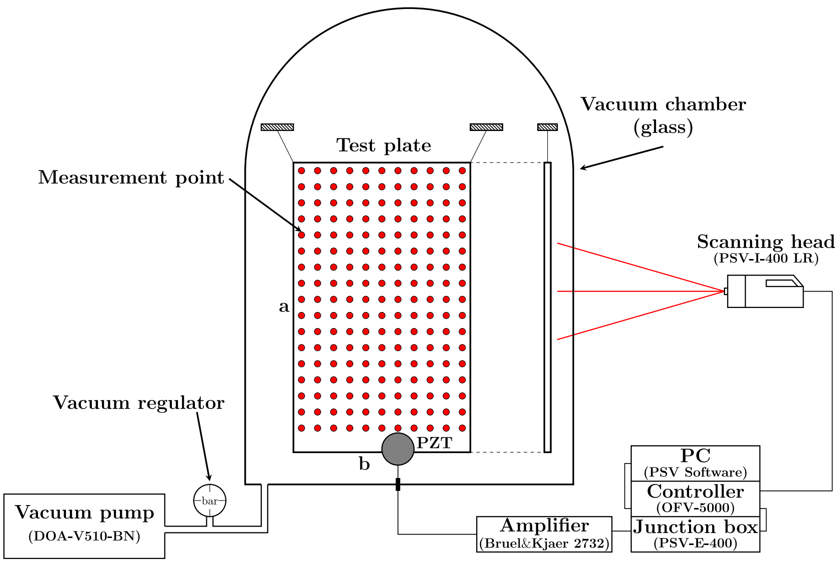

Fig. 1. Experimental set up with the scanning laser vibrometer and a vacuum chamber.