

Article

# Experimental Detection of Nonlinear Dynamics Using a Laser Profilometer

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**Featured Application:** Extension of the laser profilometer industrial applicability from static to dynamic measurements.

**Abstract:** This paper investigates a cantilever beam nonlinear dynamic behaviour, on which the nonlinearity is introduced with permanent magnet interactions or with a non-holonomic contact. The experimental time domain responses obtained from non-zero initial conditions are measured using a laser profilometer, conventionally adopted for product shape detections in online industrial applications. The Fourier transform, Continuous Wavelet transform, and Hilbert transform are used to investigate nonlinear phenomena in the frequency content, highlighting advantages and drawbacks of the three methods in catching instantaneous phenomena. Then, a Multi-Fhi approach is proposed to describe the time evolution of nonlinear systems by means of a discrete number of linearised systems. Therefore, two linearised models have been developed and tuned to describe the dynamic behaviour of different Euler–Bernoulli cantilever beam configurations. The experimental data of nonlinear systems are compared with the corresponding ones of the linear system to evaluate the effects of introduced nonlinearities on the overall dynamic properties.

**Keywords:** laser profilometer; cantilever beam; non holonomic constraints; magnetic stiffness; time frequency analysis



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## 1. Introduction

In structural dynamics, linearisation is a common practice in approximating system behaviour. From a physical perspective, the behaviour is well approximated if deformations are small enough to not exceed the material limit of linear proportionality [1,2] and displacements do not introduce geometrical nonlinearities [3,4]. Additionally, devices such as rolling bearings [5,6], hyperelastic springs/beams [7,8], non-holonomic constraints [9–11], and mechanisms such as play and hysteresis [1], friction [12], polynomial forms of restoring forces [13,14], and bistability [15] are usually neglected if their influences on the macroscopic behaviour of the system are marginal.

From an analytical perspective, a linear system can be studied with second order linear differential equations, hence the superposition of the free and forced behaviour of the system. Moreover, modal analysis and techniques directly linked with the linearity of the model can be used [16]. The linearised model behaviour allows the assessment of the stability of the equilibrium [17]. The differences between the actual behaviour of a structure and the predicted one are often explained by the departure from linearity.

The linearisation of models is affirmed strategy in Model Order Reduction (MOR) methods, developed to reduce the number of Degrees of Freedom (DoFs) and, therefore, computational cost, with a marginal loss of accuracy. In structural dynamics, two classes of MOR methods can be identified: data based and model based.

Data-based MOR methods are based on a database of previous simulations of the full original nonlinear system [18,19]. Instead, model-based MOR methods are based on the

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