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SCIENCE DIRECT
Mechanical Systems and Signal Processing 20 (2006) 1286–1299
Mechanical Systems and Signal Processing
www.elsevier.com/locate/jnlabr/ymssp

Vibration measurements using continuous scanning laser vibrometry: Advanced aspects in rotor applications

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Available online 28 February 2006

Abstract

This paper builds on previous work concerned with the development of a comprehensive velocity sensitivity model for continuous scanning Laser Vibrometry. This versatile model predicts the measured velocity for arbitrary mirror scan angles and arbitrary target motion and it has been especially valuable in revealing the sources of additional components seen in continuous scanning and tracking measurements on rotors.

The application to vibration measurements on rotors is the particular focus of this paper which includes, for the first time, a three-dimensional consideration of the incident point on the target and validation of the DC component of measured velocity leading to evaluation of the individual components of the small but inevitable misalignments between the rotor and optical axes. This has not previously been possible. Misalignments in the region 0.5 mm and 0.5° were found and the model shows how additional components of the order 10–20 mm/s result for typical measurements. Such levels are significant as they are comparable with vibration levels likely in real applications and, if unexpected, may lead to data misinterpretation.

The first thorough analysis of laser speckle effects in scanning Laser Vibrometer measurements on rotors is presented in the form of a speckle repeat map, together with experimental data quantifying the dramatic reduction in speckle noise found in tracking measurements. Finally, the velocity sensitivity model and the description of laser speckle effects are used to enable confident interpretation of data from a series of measurements on a rotating bladed disc.

Keywords: Laser Doppler Vibrometry; Scanning; Tracking; Vibration measurement; Rotating machinery; Laser speckle

1. Introduction

Laser Doppler Vibrometry (LDV) is now a well-established and commercially viable technique enabling non-contact vibration measurements in the most challenging of applications. Such instruments are technically well suited to general application but offer special benefits where certain constraints are imposed, for example by the context, which may demand high-frequency operation, high spatial resolution or remote measurement, or by the structure itself, which may be hot, light or rotating. Measurements on such structures are often cited as important applications of LDV and scanning LDV is of particular current interest. Commercial scanning Laser Vibrometers incorporate two orthogonally aligned mirrors and can operate point by point, or in

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0888-3270/$ - see front matter
doi:10.1016/j.ymssp.2005.11.009

continuous scanning mode [1–4], a special case of which is the tracking condition in which the probe laser beam remains fixed on a single point on a moving target such as a rotating bladed disc [5]. Throughout the remainder of this paper, ‘‘scanning’’ LDV refers to operation in continuous scanning mode rather than point-by-point.

Recent work resulted in the extension [3,4] of a totally general theoretical description of the velocity measured by a single laser beam incident in an arbitrary direction on a rotating target undergoing arbitrary motion [6] to the particularly challenging application of scanning Laser Vibrometer measurements on targets with flexible cross-sections. The advanced technique of circular scanning on rotating targets was investigated as a means of illustrating the effectiveness of the resulting velocity sensitivity model for the analysis of actual scan configurations. In particular, the origins of the additional components that occur in measured data due to instrument configuration were easily revealed using the velocity sensitivity model.

This paper begins with a discussion of the theoretical aspects of circular scanning Laser Vibrometer measurements, defining a means of calculating the required mirror scan angles necessary to produce arbitrary scan profiles and an expression to predict measured velocity for any scan profile. The analysis then builds on the previously reported model to show how target shape, whilst distorting the scan profile, does not influence the measured velocity. The measured velocity is, however, affected by the scan configuration and the ability of the velocity sensitivity model to predict this effect and its experimental validation is a further focus of this paper.

A particularly important practical aspect of scanning LDV is associated with laser speckle induced noise and the resulting degradation of measured data. This paper contains the first detailed description of the characteristics of laser speckle noise in scanning measurements.

In the final section of the paper, a series of actual measurements are presented and analysed, the particular focus being the correct interpretation of the data obtained in a tracking Laser Vibrometer measurement on a rotating bladed disc. The information presented in the preceding sections is utilised, accurately predicting the form of resulting frequency spectra and enabling complex measurements such as this to be made with confidence.

2. Theoretical aspects of scanning Laser Vibrometry

2.1. Velocity measured by a dual mirror scanning Laser Vibrometer

With reference to Fig. 1, a typical scanning measurement is performed by the introduction of two orthogonally aligned mirrors, separated by some distance d_S, into the laser beam path.

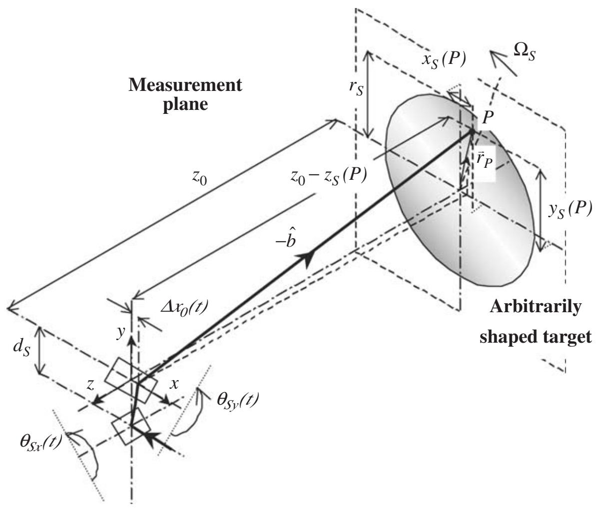

Fig. 1. The dual mirror scanning arrangement.