Advances in Ultrasonic Measurements Using Laser Doppler Vibrometry

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Introduction

Laser Doppler Vibrometry is a widely used technique to examine ultrasonic waves in solids, liquids and gases. The main advantages using a Laser Doppler Vibrometer in the field of ultrasonic measurements are the constant sensitivity over a very wide frequency range, the non contact measurement and the high spatial resolution.

Different application examples prove the high performance of this measuring technique. Finally the properties of new high-performance Ultrasonic-Laser-Doppler-Vibrometer systems will be discussed and new applications will be pronounced.

Laser-Optical 3-D Measurement of Ultrasonic Fields

Scanning LDVs and especially 3D SLDVs allow an easy and straightforward measurement and visualization of sound waves in solids at the solid–air interface. As an example time-domain measurements of ultrasonic sound wave propagation in concrete are displayed witch help to extract specific material parameters.

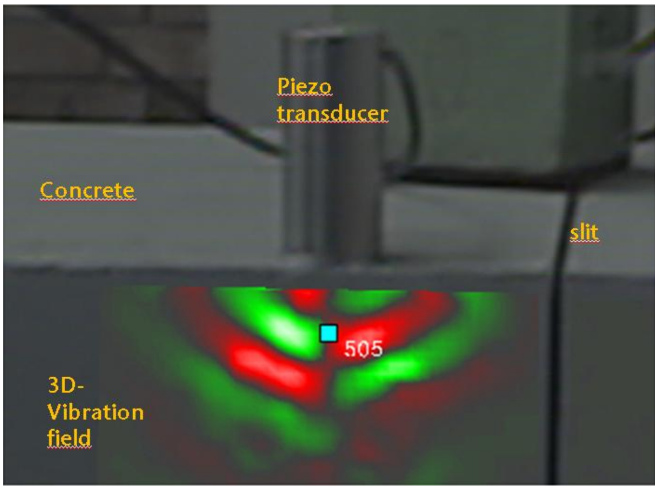

Figure 1: 3D-SLDV Visualization of sound wave propagation in concrete [1]

But Scanning LDV can also be applied to visualize the sound wave propagation in air. A sound wave propagating parallel to a stationary solid reflector wall introduces density variations in air which show up as local variation of the refractive index. Since the Vibrometer measures the variation of the optical path which is depending directly on the refractive index the method allows directly visualizing the propagating sound field in air. The method has been applied to a variety of measurement tasks including musical instruments, power tools and automotive components.

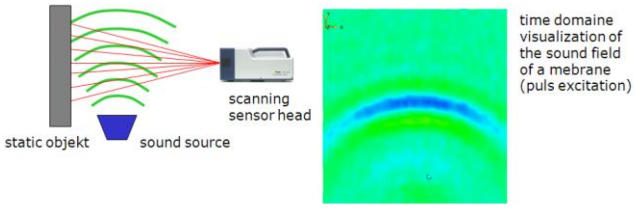

Figure 2: Experimental Setup for visualizing sound wave propagation in air

Quality Control of Ultrasonic tools

The non-contact optical measurement approach of Laser Doppler Vibrometry also allows for direct and straightforward quality control measurements of ultrasonic devices and thus has been established as a standard method for verifying functional mechanisms and mechanical properties of products.

For example an extremely quick quality testing and analysis procedure for aerosol generating membranes has been realized on the basis of non-contact vibration measurement with a Laser-Doppler-Vibrometer. The vibration signature corresponds directly to the nebulisation efficiency of the drug inhaler membrane and allows for a quality class selection.

The semiautomatic test station has completed more than 10,000 inspections within the first 6 months of operation. During the course of the measurements, the analysis algorithm has been continuously improved to further minimize the unnecessary rejection of good but wrongly evaluated test items.

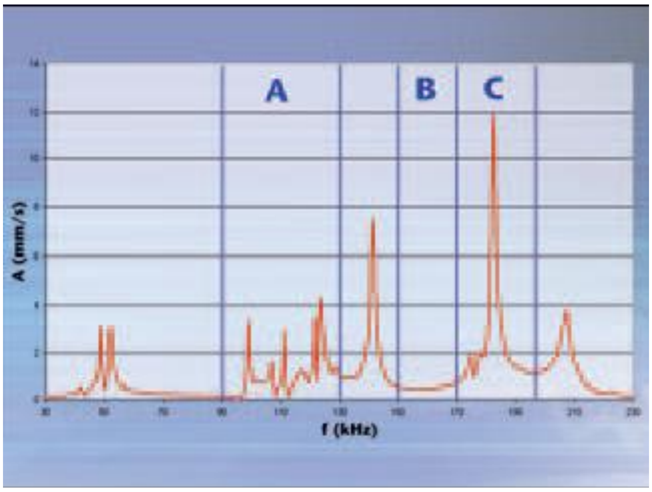

Figure 3: Typical vibration spectrum of a membrane [2]

a) Envelope assessment
b) Void area (no peak allowed)
c) Area in which there may only be one peak

NDT / Health Monitoring of Aricraft Components

Lamb wave inspection uses guided ultrasonic waves to detect damage in structures [3]. Its commercial exploitation has been limited by drawbacks in current detection techniques. Using a 3-D Scanning Laser Vibrometry as new detection technology, structural damage is clearly identified by locally increased in-plane and out-of-plane vibrations.

Figure 4: Experimental arrangements for Lamb-wave damage detection using 3-D laser vibrometry as a receiver.

Scanning Laser Vibrometry can reveal structural damage and its severity such as crack length and delamination area. Simple contour maps and profiles of Lamb-wave amplitude across the structure are sufficient to see the damaged areas and do not involve studies of complex Lamb-wave propagation in the structures, baseline reference measurements in undamaged structures, or signal post-processing to extract damage-related features. The method is straight forward, fast, reliable and immune to environmental effects.

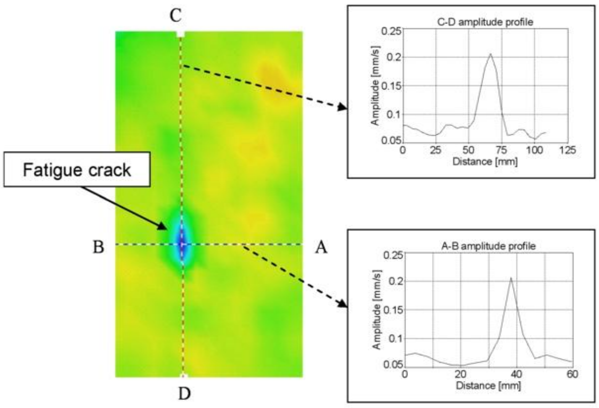

Figure 5: Fatigue crack detection in metallic structures using Lamb waves. The RMS amplitude contour map show the amplitude profile across a fatigue crack for a 325 kHz out-of-plane vibration.

Towards Higher Frequencies

Up to now Laser Doppler Vibrometry was limited to the frequency range below 30 MHz to due to restrictions in generating the optical carrier modulation frequency. Recent advancements in interferometer design now allow to shift the frequency range up to about 600 MHz, accessing the technologically important regime of current microstructure applications as RF-MEMS as SAW and BAW filters.

Figure 6: Ultra-High Frequency Vibrometer for measuring mechanical vibrations up to 600 MHz. [5]

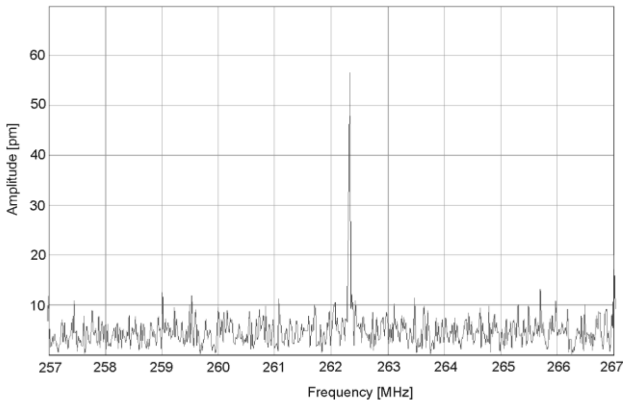

Figure 7: FFT spectrum of the digital demodulated displacement signal of the heterodyne interferometer. The 56 pm vibration amplitude of a SAW-device oscillating at 262.3 MHz can be measured accurately.

References

[1] Forschungsgruppe VIII.2 der Bundesanstalt für Materialforschung und –prüfung Berlin, private communication.

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[3] W.J. Staszewski, C. Boller and G.R. Tomlinson, Health Monitoring of Aerospace Structures, John Wiley & Sons, Chichester, 2003

[4] http://www.polytec.com/eur/_files/LM_AN_VIB-A-01_2006_07_US.pdf

[5] http://www.polytec.com/eur/_files/OM_DS_UHF-120_2009_01_E_preliminary.pdf