

Performance and testing of a four channel high-resolution heterodyne interferometer

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ABSTRACT

When studying complex vibrations, simultaneous measurements at several points are indispensable if one is dealing with objects whose vibrational behavior is not guaranteed to be stable over longer periods of time, such as biological specimens, micro-mechanical elements or objects characterized by nearly resonant normal modes with different vibrational patterns. Obviously, both amplitude and phase need to be measured at each point to obtain a full characterization of the vibration. We introduce birefringent beam displacers as a highly efficient beam multiplying method to create a system of four heterodyne interferometers operating in parallel from a single laser source. The design and the performance characteristics (resolution, cross-talk) of the instrument will be discussed. The system revealed the existence of running vibrational modes on an electrically driven plate clamped along its outer edge.

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1. Introduction

With a multiple beam interferometer, it is possible to perform vibration measurements at different object points simultaneously. Such an instrument is especially advantageous for the study of instable objects, such as biological specimens or micro-mechanical elements due to sudden changes and mode coupling which may occur in the vibrational behavior of these objects. We already demonstrated that a dual beam heterodyne interferometer based on a single laser source using analog FM demodulation performs almost as well as commercially available single beam vibrometer systems [1,2].

Two independent measurement points usually are not sufficient to gather enough information about complex motions. Simultaneous measurements on multiple object points are also necessary to measure complex three-dimensional motions, for instance in studies of the motion of the ossicles in the middle ear which transmit sound to the inner ear, or to measure non-linearities on several points of complex vibrating objects [3].

We therefore recently introduced a novel method to generate four measurement beams from a single laser source based on birefringent beam displacers [4]. In principle, laser energy is preserved in such beam displacers and rotation of the beam displacer allows the relative intensities of the transmitted beams

to be tuned to any ratio between 0 and 1. The transmitted beams are pair wise orthogonally polarized, allowing interference between the beams with the same polarization.

We shall first discuss the design and performance characteristics of the quadruple beam system and then present some measurements on a vibrating disc.

2. Design and performance of the quadruple beam heterodyne interferometer

2.1. Design

The optical setup of the quadruple beam system is shown schematically in Fig. 1.

The multiplication of the object and reference beams is achieved by passing each beam through two birefringent beam displacers placed in tandem, each with its optical axis oriented at approximately 45° with respect to the incoming polarization. In the dual beam system [1,2] we used a non-polarizing beamsplitter followed by a mirror for the multiplication of the beams, the beams propagated parallel to each other (at the recombination beam splitter) at about 10 mm distance and possessed the same polarization. In the quadruple beam system the beams of the different channels also propagate parallel to each other, but at about 4 mm distance and are now pair wise orthogonally polarized. Since spatially separated beams cannot interfere, we expect to preserve the excellent channel separation of the dual

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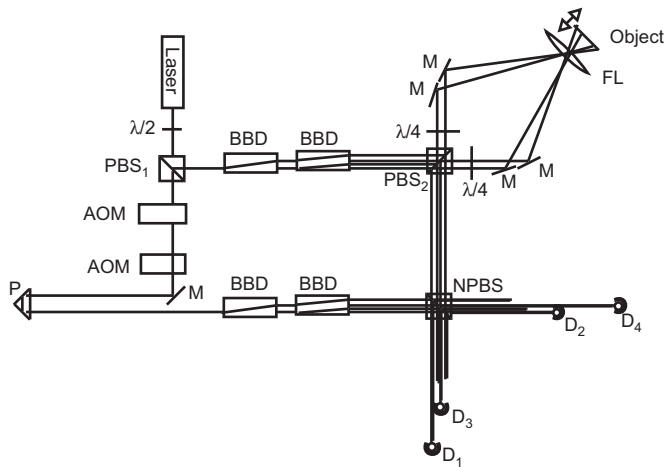


Fig. 1. Schematic layout of the quadruple channel heterodyne interferometer. Four measurement beams (solid lines) and four reference beams (dashed lines) are generated by passing the single laser beam through two birefringent beam displacers (BBD). Each BBD is aligned with its optical axis at 45° with respect to the input polarization for beams of equal intensity. The reference beam is frequency shifted by means of two acousto-optic modulators (AOM) to generate the heterodyne beat signal. The prism (P) allows for path length adjustment. A non-polarizing beam splitter (NPBS) recombines reference and object beams. The quarter-wave plate ($\lambda/4$) and polarizing beam splitter (PBS₂) redirect light, retro-reflected from the object, towards the NPBS. Measurement positions on the object(s) can be adjusted by altering the direction of the beams through the focusing lens (FL) or by directing each beam through its own lens. The signals are detected by photodiodes (D).

beam system [2], while introducing the possibility to adjust the relative intensities of the beams by slightly rotating the beam displacers with respect to the incoming laser beam. Because the beams gradually increase in diameter due to diffraction, propagation over appreciable distances will ultimately introduce (some) cross-talk.

We kept detection and processing of the velocity signal identical to that of the dual beam system [1,2] except for the obvious need to process four signals in parallel. The object is excited at a known frequency and its vibrational response is measured by detecting the Doppler shift impressed on each heterodyne carrier signal. Analog FM-demodulators convert the frequency shifts to voltages fed into a multiplexing A/D converter. The drive signal serves as a reference for the amplitude and phase of the interferometer signals and is fed into the A/D converter as well.

2.2. System performance: velocity resolution and cross-talk

The velocity noise level determines system resolution. We measured the velocity noise level in each measurement beam in frequency bands directly surrounding the frequency of the drive signal. In various experimental runs, the bandwidth of the measurement was changed. The noise level was found to be almost independent of the drive frequency and almost equal in each of the measurement beams. We therefore used the average value of all noise levels over the entire frequency range as an estimate of the noise level of the system at a specific bandwidth. In Fig. 2, these numbers are presented as a function of the bandwidth.

The theoretically expected square root dependence, which is indicated by the solid and dashed lines, clearly is obeyed. The velocity noise level equals $(3.1 \pm 0.4) \mu\text{m s}^{-1} \text{ Hz}^{-1/2}$ under optimal measurement conditions (perfect interferometer alignment and

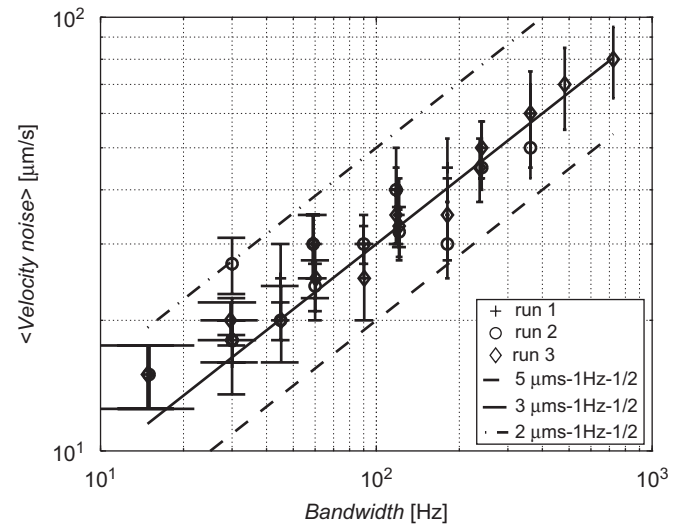


Fig. 2. Velocity resolution as a function of the measuring bandwidth. Data are taken from different experimental runs. Each data point represents the average noise level over the frequency range from 0.5 to 30 kHz of all four channels.

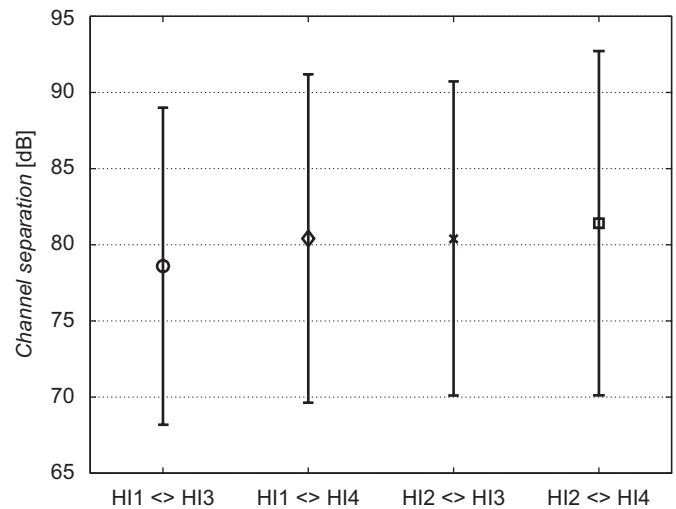


Fig. 3. Channel separation averaged over the entire frequency range (0.5–30 kHz) for each pair of measurement channels. HI1 & HI2 are focused onto the vibrating object, HI3 & HI4 onto the stationary object. HI1 & HI3 are vertically polarized at the detectors, HI2 & HI4 horizontally. Data from different experimental runs with different levels of acoustical cross-talk were combined before averaging. Error bars represent one standard deviation.

sufficient optical signal strength) [4]. It is slightly higher than the noise level achieved by commercially available single channel laser velocimeters [2].

When measuring channel separation, it is imperative to eliminate sources of crosstalk which are not induced by the interferometer. In our case, indirect acoustic coupling between different measurement points is the major point of concern. Using different objects and different suspensions, we suppressed the amount of acoustic coupling as good as possible. Two of the measurement beams were focused either onto the freely vibrating part of a piezo-electrically excited disc clamped at one point of its perimeter or onto the tip of a scattering polyethylene strip glued to the vibrating part of the disc. Differently shaped strips were used in different experiments. The other two beams were focused onto points near the edge of a rigid heavy metal cylinder which was in exactly the same plane as the disc or the polyethylene

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