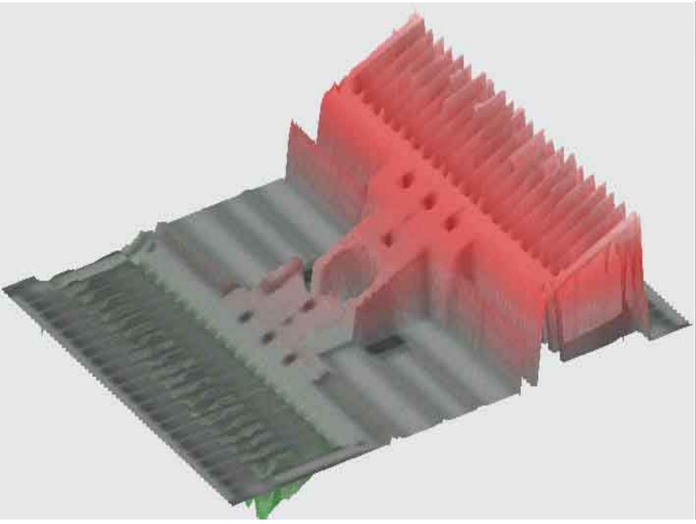
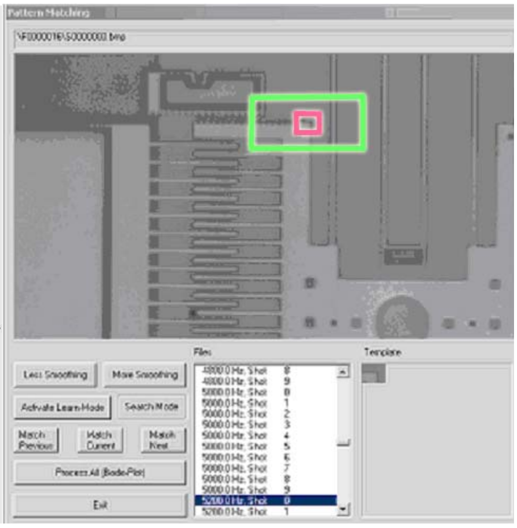
Application Note *M-01*





FIELD OF APPLICATION

- A Aerospace
- B Audio & Acoustics
- C Automotive Development
- D Data Storage
- G General Vibrometry
- **M Microstructures & -systems**
- P Production Testing
- S Scientific & Medical
- T Structural Testing
- U Ultrasonics

Measurements on Comb-drive and Cantilever Structures using new Hybrid Laser Doppler Vibrometer and Strobe Video System

Laser Doppler Vibrometry (LDV) is a widely accepted tool for dynamic characterization of MEMS. Using automated scan capability, the Polytec system can measure structural resonance and display out-of-plane deflection shapes with amplitudes down to the picometer level and frequencies up to 30 MHz. By adding stroboscopic video microscopy for in-plane motion analysis, our combined Micro Motion Analysis (MMA) system is capable of three-dimensional dynamic characterization. The MMA system opens up new possibilities to measure in-plane actuators previously difficult or impossible for LDV measurements.

Introduction

Use of LDV technology has been demonstrated as a valuable technique for non-contact, out-of-plane deflection measurements of MEMS.
All the advantages of LDV technology are realized for microscope-based measurements including real-time analog output, high resolution (picometer), small spot size (µm), wide frequency range (MHz), wide dynamic range (160 dB) and high accuracy.

With the scanning ability to automatically acquire, analyze and reconstruct complex vibration modes, the Micro Scanning Vibrometer (MSV) is an ideal tool for displaying out-of-plane deflections. However, there has been one major limitation to the instrument. It was difficult or impractical to measure in-plane motions since the Doppler shift is derived from a velocity vector normal to the plane of the moving surface.

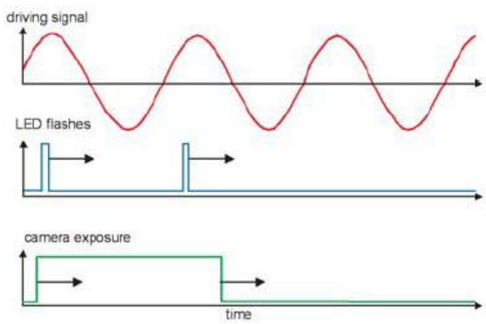


Figure 1: Principle of strobe video

Polytec has overcome this problem using stroboscopic video microscopy to measure in-plane motion of periodically moving structures.

Polytec GmbH
Laser Measurement Systems
Application Note

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The System

Time resolution of the system is defined by the pulse width of the LED-strobe flash such that events can be recorded with a time period much shorter than the exposure time of the camera. Although the camera's framerate is limited to 12 images per second, the shortest strobe illumination is 100 nanoseconds. Thus periodic motions out to 1 MHz frequency can be measured with at least 10 images per period. One image integrates hundreds or thousands of flash pulses at identical phase positions according to the driving signal. The signal driving the specimen, the LED-strobe flashes and the camera exposure have to be accurately synchronized. A timing diagram of the this synchronization is shown in Figure 1 for one camera shot.

Measurements

To exemplify the outstanding performance of our hybrid LDV / strobe video measurement system, we present characterization measurements on MEMS devices fabricated by Sandia National Labs SUMMiT V process (Figure 2).

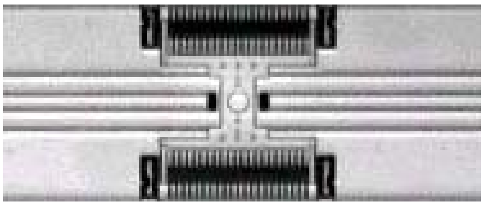

Figure 2: MEMS device (Courtesy Sandia Nat. Labs)

Multi-axis measurements reveal the complex motions exhibited by an electrostatic comb drive driven at resonance.

The comb drive is electromechanically actuated by applying voltage to either of two comb electrodes on both sides of the center shuttle mass. The natural frequencies are determined by various parameters as the Young’s Modulus, the mass density, the damping ration and the geometry of this spring-mass system. As seen in previous studies (cf. references), resonance modes are a sensitive indicator of repeatable geometry and material properties from fabrication processes.

Out-of-plane motion measurements are made first using Laser Doppler Vibrometry.

Although the resonator is designed to move only in the in-plane direction, some residual out-of-plane motion exists that can be detected through the high sensitivity of the LDV sensor. Here, real-time measurement capability allows use of any suitable broadband, non-synchronized waveform source to drive the device.

The time response from the LDV analog velocity is sampled and Fast Fourier Transformed using 12,800 lines FFT to reveal resonance frequencies out to 500 kHz (Figure 3).

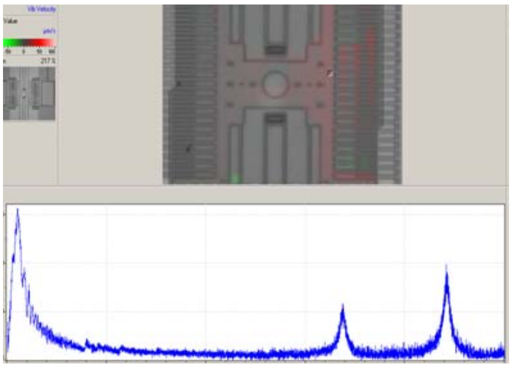

Figure 3: LDV FFT measurements

By scanning the laser beam and sampling this response at 200 discrete measurement points over the area of the shuttle, the operating deflection shape (ODS) measurement is made in less than 11 seconds. Figure 4 shows a snapshot from a 3-D ODS-animation of the fundamental resonance at 5 kHz. For a 10 V peak excitation a 250 nm displacement amplitude is determined for the tip of the shuttle fingers. Figure 3 also reveals two bending modes of the shuttle at the higher frequencies 340 kHz and 440 kHz.

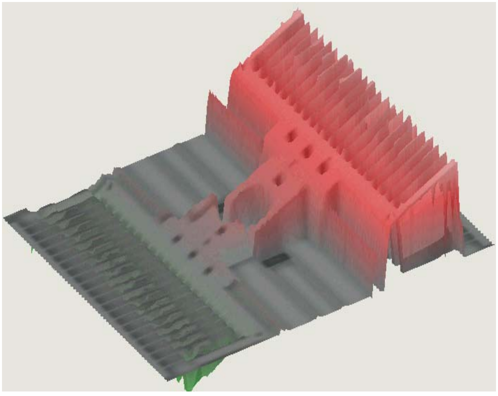

Figure 4: 3-D ODS animation of the fundamental resonance at 5 kHz

In-plane measurements are made on the same comb drive switching to the stroboscopic system. Having determined the resonance frequency already with the LDV, the in-plane measurement can be focused also at the 5 kHz frequency range.

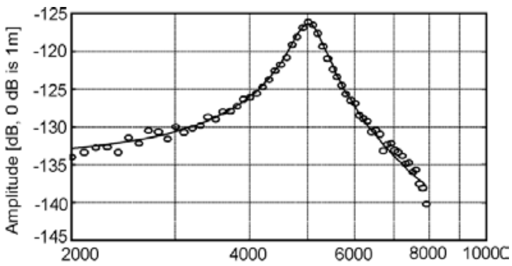

Figure 5: Bode-plot of Amplitude

Figure 5 shows a Bode-plot revealing magnitude determined from stepped sine measurements centered on the 5 kHz resonance frequency; figure 6 shows the corresponding phase.

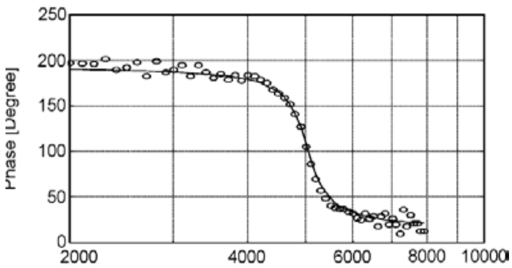

Figure 6: Bode-plot of Phase

Strobe video capture was performed for stepped sine waves from 2000 to 8000 Hz in 50 Hz increments. At each frequency the position shifts (δx, δy) of a user defined search pattern (Figure 7) are determined using machine vision analysis with sub-pixel resolution.

Even for pattern with poor contrast, the in-plane noise level is less than 0.03 pixel (corresponding to ~4 nm for a 50x objective). System accuracy has been measured with a traceable shaker and shown to be better than 0.2%.

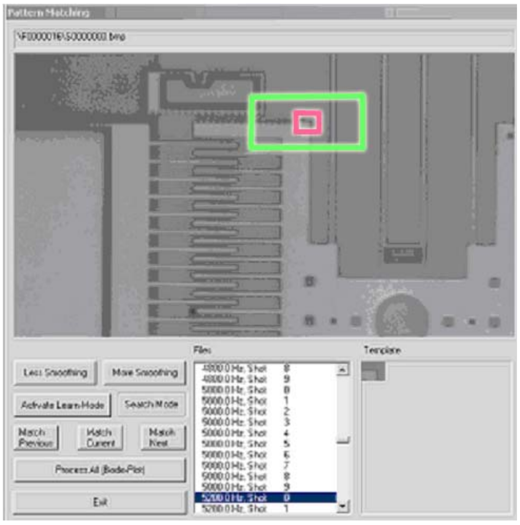

Figure 7: Machine vision analysis (search pattern: red box; region of interest: green box)

Fitting the resonance curve from figure 5 gives a resonance at 5036.1 Hz and a damping factor of 0.062.

Another part of this Sandia SUMMiT V MEMS die set includes an array of graduated cantilevers ranging in length from 100 to 1800 µm. Such cantilever structures are often built to determine mechanical properties such as Young's modulus of elasticity by measuring the resonance frequency. Previous studies on these cantilevers indicated that resonance can be excited by thermal oscillation alone.

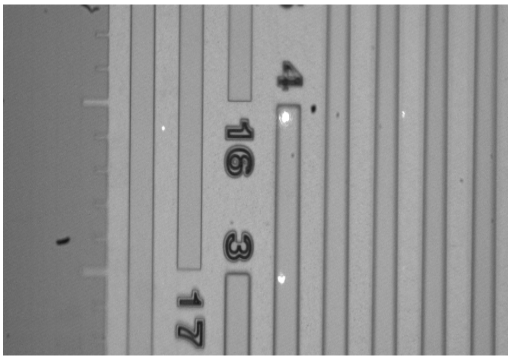

Figure 8: LDV spots on cantilevers

LDV measurements at the tip of the cantilever (Figure 8) yielded a thermal noise spectrum that can be decomposed by a dynamic spectrum analyzer. Such an analyzer is an integral part of the MSV system data acquisition system.

Figure 9 shows the thermal noise spectrum of a 400 µm cantilever with 6 µm air gap, revealing its resonance.

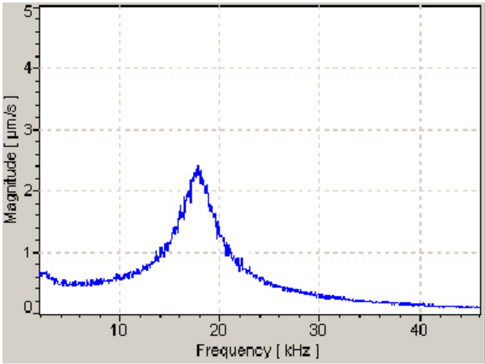

Figure 9: thermal noise spectrum

These measurements were performed for cantilevers from 100 to 800 µm lengths. Squeeze film damping effects were determined by measuring the width of the resonance peak at –3dB (half-power method). From this, the damping ratio could be estimated.

Conclusions

Laser Doppler Vibrometry is an established tool for non-invasive characterization for a multitude of MEMS applications. Our new hybrid MMA system uses the advantages of two measurement principles (Vibrometry and strobe Video Microscopy) and is state-of-the-art for characterization of MEMS.

The real-time response capability of LDV allows very fast broadband analysis of frequency response, rather than time intensive stepped sine methods. Pre-characterization of resonance frequencies by LDV allows planar motion analysis of in-plane behavior "right on the spot" without the need to hunt around at discrete frequencies.

Therefore, the MMA system offers an optimal solution for quick, accurate three dimensional vibration measurements of MEMS.

References

1. Eric M. Lawrence, Kevin E. Speller, "MEMS Characterization using Laser Doppler Vibrometry", Reliability, Testing and Characterization of MEMS/MOEMS II, SPIE Proceedings Vol. 4980, January, 2002.

2. Turner, Kimberly, "LDV Measurements in MEMS: A sampling of capability", Proceedings of 2002 PSV User's Meeting, San Diego, March 22, 2002.

3. Lawton, Russell, "MEMS Characterization using Scanning Laser Vibrometer", SPIE 1999 Symposium on Microelectronics Manufacturing Proceedings, September 1999.

4. Christian Rembe, Alexander Dräbenstedt, Frank Heimes, "Accurate New 3D-Motion Analyzer for MEMS", International Conference & Exhibition on Micro, Electro, Opto, Mechanical Systems and Components, Munich, October, 2003.

5. Andrew D. Oliver, Danelle M. Tanner, Seethambal S. Mani, Scot. E Swanson, Karen S. Helgesen, and Norman F. Smith, "Parametric Monitoring for the SUMMiT V Surface Micromachining Process", Micromachining and Microfabrication 2001, October 22, 2001.

6. Danelle M. Tanner, Albert C. Owen, Jr., Fredd Rodriquez, "Resonant frequency method for monitoring MEMS fabrication", Reliability, Testing and Characterization of MEMS/MOEMS II, SPIE Proceedings Vol. 4980, January, 2002.

7. Richard Plass, Jeremy A. Walraven, Danelle M. Tanner, and Fredrick W. Sexton, "Anodic Oxidation-Induced Delamination of the SUMMiT Polyt 0 to Silicon Nitride Interface", Reliability, Testing and Characterization of MEMS/MOEMS II, SPIE Proceedings Vol. 4980, January, 2002.

8. P. Oden, G. Chen, R. Steele, R. Warmack, and T. Thundat, "Viscous drag measurements utilizing microfabricated cantilevers", Applied Physics Letters, Volume 68/Number 24, June 1996.

9. Roman Vinokur, "Vibroacoustic Effects in MEMS", Sound & Vibration, Volume 37 / Number 9, September 2003. consuming imaging analysis and broadband sine-stepping.