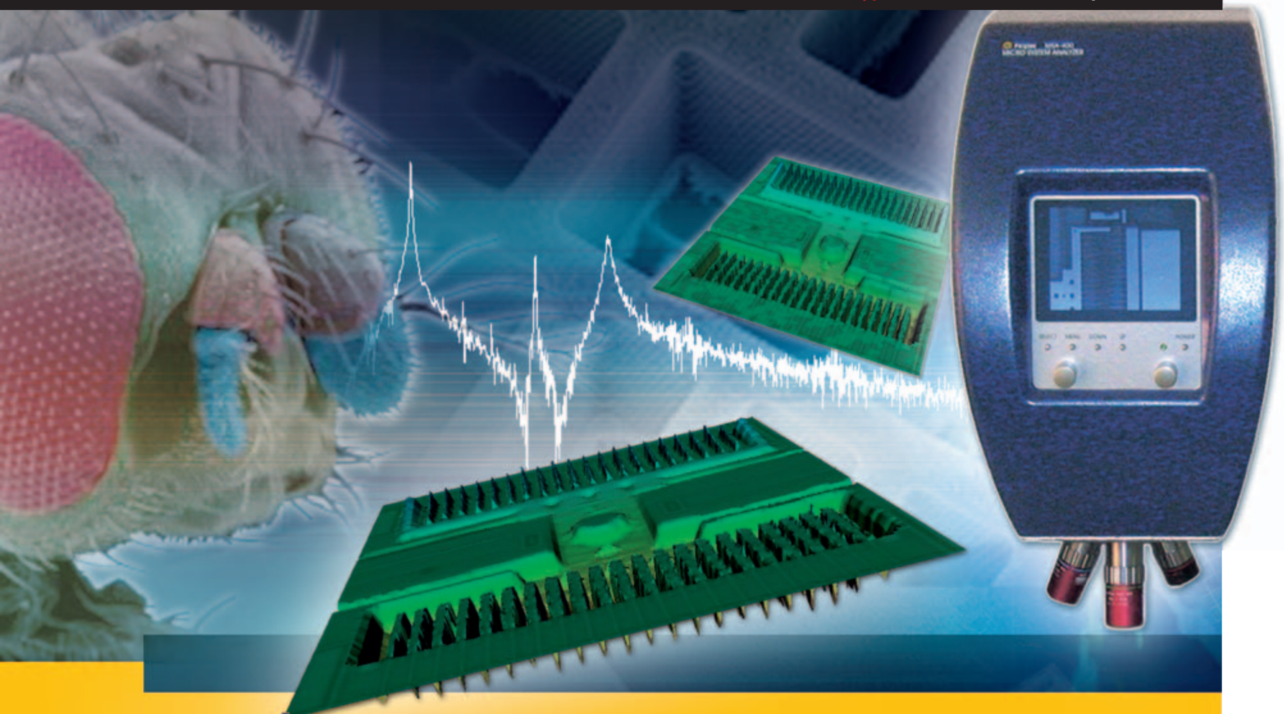
LM INFO Special

Polytec

LASER MEASUREMENT SYSTEMS ISSUE 1/2005



DYNAMIC MEASUREMENTS ON MICROSTRUCTURES

Polytec's instrumentation for micro motion analysis is critical to fueling the exploding application of microscopic electromechanical helpers to our everyday life.

MEMS (micro-electromechanical systems) are tiny micro-sensors and micro-actuators that are found in entertainment systems, guidance systems, automobiles, aircraft, computers and medical devices. R&D and production engineers must develop new devices quickly, precisely and cost effectively. Polytec's innovative Micro System Analyzer enables the systematic testing of the dynamic mechanical response to important electrical and physical inputs.

In this issue discover how the microscope-based vibrometer systems are combined with probe stations to test individual MEMS components or complete wafers prior to separation (page 3, 6); how they can verify the reliability of simulation models (page 10); and how they can test the sensitivity of chemical sensors that were built to measure in the picogram range (page 7). Equipped with a macro lens, the PSV Scanning Vibrometer can also help with MEMS characterization - consider the investigation of long-term reliability of automotive sensors (p. 16) and the clarification of complex biomechanical "MEMS", like the hearing mechanism in insects (page 18). All this and much more is included in this edition.

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Tutorial Series: 3-D Vibration and Motion Analysis of Microstructures

EDITORIAL

Michael Frech

Dr. Helmut Selbach

Dear Reader,

Vibrations can be measured with both contact and non contact transducers. Manufacturers of contact transducers (i.e. accelerometers) are working hard to minimize their mass and the corresponding influence on the sample being measured. There are many such sensors that weigh less than 1 g. These ultra light sensors are the direct result of microsystem technologies which allow the development and production of new, ever smaller sensors and actuators.

A contact transducer, no matter how small, is of course completely unsuitable for measuring vibrations on microstructures. In some cases, the mass and size of the sensor can even be larger than the object being studied. Proper vibration measurements on microstructures are most accurately done using a non-contact measurement procedure.

In this issue you will find many contributed articles concerned with using Polytec's latest non contact technology to study the dynamic response of microstructures. Customers report on their applications and experiences. In addition, discover the details about our newest product, the MSA-400 Micro System Analyzer, which is currently the fastest measurement system in the world for non-contact vibration measurement.

Enjoy reading on!

Michael Frech
Vice President
Laser Measurement Systems

Dr. Helmut Selbach
Managing Director Polytec GmbH

MEMUNITY – The MEMS Test Community

MEMUNITY was established in the spring of 2003 to promote the advantages of early testing of micro systems in the MEMS industry. Jointly founded by SUSS MicroTec AG and its partner DELTA, a Danish test company, MEMUNITY welcomed Polytec as its third partner by the end of 2003. MEMUNITY's charter encompasses two important objectives: first, to enlighten the industry about MEMS testing prior to packaging (i.e. on wafer level) and and the resulting cost and time savings for research, prototype production and manufacturing; second, to promote new test technology for frontend testing.

To fulfill their mission, MEMUNITY must disseminate information on existing test and measurement solutions that have a significant business impact on MEMS development and manufacture. Consequently MEMUNITY has planned a busy agenda for 2005 including revising the www.memunity.com website and generating new technical literature such as "Application Notes".

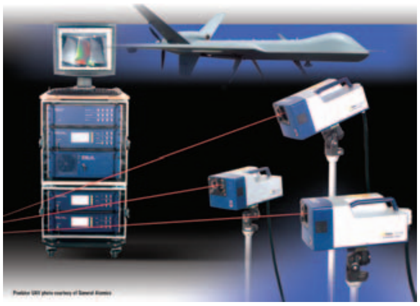
Workshops in Europe, North America and Asia are being planned as well as participation in well-known trade shows and congresses such as Sensors (USA), MST (D) and Nanofair (CH). Following the successful workshops in the spring of 2004, at Polytec in Waldbronn (D) and at SUSS in Sacka near Dresden (D), MEMUNITY has held a new workshop in March 2005 in Dortmund (D).
Check **www.memunity.com** for the latest information.

About SÜSS MicroTec

SUSS MicroTec AG (**www.suss.com**) is one of the world's leading manufacturers of production and process technology for the semiconductor industry. SUSS MicroTec primarily services niche markets, which are constantly converting to new technologies to ensure their continued ability to compete. With over 7,000 systems installed worldwide, SUSS products include coating and developing systems, proximity lithography systems, substrate bonders, device bonders and probe systems. Headquartered in Garching near Munich, Germany, SUSS has approximately 900 employees worldwide and provides support from sales and service centers in North America, Europe, Asia and Japan.

SUSS MicroTec Test Systems GmbH (Sacka near Dresden, Germany) is a subsidiary of SUSS MicroTec AG and specializes in test and measurement systems for the semiconductor industry. Since 1999, specific test systems for MEMS technology have been developed and produced. These novel systems are designed to combine traditional electrical measurements with mechanical response/stimulus, such as pressure, acceleration and movement, at the wafer level prior to packaging.

AFIT Uses Polytec's 3-D Scanning Vibrometer To Measure Aerospace Structures



The Air Force Institute of Technology (AFIT), Wright Patterson AFB, Ohio will utilize Polytec's PSV-400-3D Scanning Vibrometer to measure vibration characteristics of Unmanned Aerial Vehicles (UAV) and other intricate aerospace and vehicular structures. This innovative instrument permits engineers to perform complete 3-D vector component analysis on complex structures.

Berthold Award for Research on Non-Linear Laser Vibrometry

The German Society for Non-Destructive Testing (DGZfP) awarded the annual Berthold Prize to Dr.-Ing. Nils Krohn of DaimlerChrysler AG for his work on "Non-Linear Dynamic Material Behavior for Defect Selective Non-Destructive Testing". This study was performed at the Institute for Polymer Testing and Polymer Science (IKP) in Stuttgart, Germany using Polytec's PSV Scanning Vibrometer. We have reported on this work in the LM INFO Special issue 1/2004, pages 20/21. Please see **www.polytec.com/usa/LM-INFO**

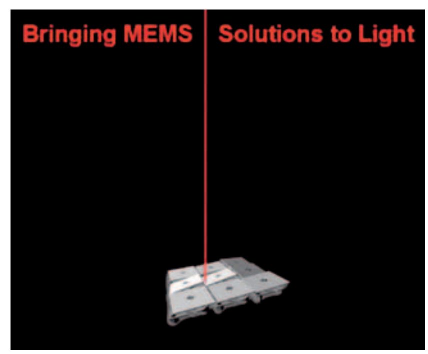
NADwork® Polytec® Connection

This software is a powerful tool for the simulation of air-borne noise based on vibrometry measurements (see page 21) and is a result of the cooperation of Polytec and NAD (Numerical Analysis and Design GmbH & Co KG, Vienna/Austria). NAD develops and sells the NADwork® Simulation Suite. NAD products are sold worldwide and are used for acoustic simulations in both sound engineering (especially loudspeakers) and noise engineering. More info: **www.NADwork.at**

Technology at Full Tilt

When Texas Instruments (TI) wanted to measure the dynamic response of the MEMS micro mirrors used in their Digital Light Processing™ (DLP™) chips, Polytec stepped up to the challenge.

Tilting on and off thousands of times per second, these tiny wonders are fast. Polytec's Micro Scanning Vibrometer (MSV) was able to capture the real time settling response at precise locations on the mirrors as they were being activated. Animated 3-D Deflection Shapes generated by the software show how these mirrors transition between on and off states giving TI unique feedback into their micro mirror dynamics.



Introducing Exciting New Instruments and Accessories

The new gold standard in MEMS vibration and motion analysis has just been released. Merging advanced software with integrated microscope and vibrometer optics, the MSA-400 Micro System Analyzer offers the most precise and convenient measurements available (see page 4). Also released, the redesigned LSV-300 Laser Surface Velocimeter for mill-tough velocity measurements offers the same outstanding performance as previous models but at a significantly lower cost (see page 13). Finally, sophisticated accessories and software continue to improve the performance of the PSV Scanning Vibrometer (see pages 20 and 21). Complete descriptions of all new and improved products can be found at **www.polytec.com.**

Additional MEMS Article

The article "MEMS – Reliable Helpers in Motor Vehicles" published in LM INFO issue 2/2004 is an excellent companion to the articles contained in this issue. The original publication had a few translation inaccuracies that have since been fixed in the on-line PDF version. Visit **www.polytec.com/usa/LM-INFO** to read or download the corrected version.

Get to Know the MSA-400

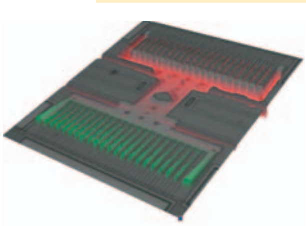
To see a live demonstration of Polytec's innovative Micro System Analyzer, please visit us at upcoming trade shows focused on MEMS. See the back page or go to **www.polytec.com/usa** for the latest show information. For a more thorough introduction, hands-on training and the opportunity to run tests on your own MEMS device on a fully equipped probe station, consider attending one of our complimentary "MEMS Workstation and Tools" seminars. The seminar and workshop will be held at six North American locations in 2005. For the latest information and to register for the seminar visit **www.PolytecUsers.com/seminar1.html**.

Focus on *Microdynamics*

The Polytec MSA-400 Micro System Analyzer simplifies making precise measurements, quick analysis and complex dynamic characterization of MEMS components in three dimensions.

MSA-400 Micro System Analyzer – in Summary

- Measures the 3-D dynamics of microsystems using laser Doppler vibrometry and stroboscopic video microscopy
- Ideal tool for investigating MEMS and MOEMS (Micro-Opto-ElectroMechanical Systems)
- Promotes high productivity through a quick measurement process and a short measurement time
- Quickly identifies and visualizes all out-of-plane and in-plane resonances
- Integrated microscope optics with an optimized beam path guarantee the highest possible lateral resolution and image quality
- Simple and intuitive operation allows measurements in a matter of minutes
- Fits most Probe Stations



The new MSA-400 pushes the standard for optical microstructure metrology to the highest levels of performance, productivity and simplicity. As an All-in-One instrument, the MSA-400 combines the techniques of scanning laser Doppler vibrometry to measure out-of-plane vibrations (orthogonal to the surface of the component) and stroboscopic video microscopy to acquire the in-plane displacement (parallel to the surface of the component), thus allowing fast and complete dynamic characterization of microstructures.

Microsystem analysis is enhanced with the new capabilities of the MSA-400, redefining the gold standard in experimental modal analysis and simulation model verification.

The MSA-400 Micro System Analyzer features short measurement times, picometer displacement resolution for out-of-plane measurements, an extremely small, diffraction limited laser spot, integrated reflection-free microscope optics and live video monitoring of the measurement process.

Measurement Principle – Unifying the Best of Two Technologies

The scanning laser Doppler technology is ideally suited to depicting out-of-plane vibrations and deflection shapes. On the other hand, the stroboscopic process for in-plane motion measurement exploits the fact that high frequency vibrations can also be sampled by freezing rapid movements with short stroboscopic bursts of light and recording the image with a synchronized video camera. A detailed description of this technique is included in the article "3-D Vibration and Motion Analysis of Microstructures", an insert in the middle of this issue.

Equipped for all Applications: MSA-400 – the System and its Range of Models

The MSA-400 Micro System Analyzer is functionally separated into an optical unit and a signal processing unit.

The **MSA-400 Optical Unit** is made up of the compact sensor head, an optimized integration of vibrometer scanning optics, video stroboscope and microscope optics, and the fiber-optic laser interferometer for vibrometer measurements. The standard MSA model has one laser beam. The scanning interferometer can also make differential measurements with two laser beams. By measuring the relative movement between the two sample points, undesired whole body or common mode movements are eliminated.

The high-resolution video display on the sensor head is used to visualize both the object under investigation and the measurement process. Thus, the reference beam can be positioned at a suitable point and the measurement grid can be defined and oriented with respect to the object under investigation.

Adaptable to most popular MEMS Probe Stations (e.g. SUSS MicroTec, Micromanipulator), the MSA-400 sensor head easily integrates into standardized test sequences. Through the integrated design, the system can attain laser spot sizes close to the theoretical diffraction limits (~ 0.7 µm FWHM with a 50x microscope objective lens).

The **MSA-400 Signal Processing Unit** contains the vibrometer controller for demodulating the out-of-plane signal, acquiring the data and processing the signal. A high-performance software package is included to control the measurement process and then plot and visualize the data. Last but not least, the junction box is used to make the excitation signal available and to connect the components.

The MSA-400 Micro System Analyzer can be configured as an out-of-plane only measurement system (Micro Scanning Vibrometer) or as an in-plane only measurement system (stroboscopic video microscope). The out-of-plane components can be measured with acquisition bandwidths of 1 MHz, 2 MHz and 20 MHz. Differential measurements using dual laser beams is an option that can eliminate whole body movement.

User-Friendly Software

The MSA-400 Micro System Analyzer comes with the PSV 8.2 Polytec Scanning Vibrometer software for out-of-plane measurements. It offers quick and easy setups, simple data acquisition and outstanding data visualization (3-D graphics). Complementing the PSV software, the recently released PMA 2.2 Planar Motion Analysis software similarly controls the in-plane measurement process. Featuring a whole series of new benefits, the PMA software can now import frequency bands from out-of-plane measurements as input data for an even easier setup of associated in-plane measurements.

There is a split window display for simultaneous display of the measurement data together with the processed images. Most presentation modes of frequency domain data are also available for time domain data as well. The following data representations are now available: X(t),Y(t), Y(X), Amplitude(X(t),Y(t)), Direction(X(t),Y(t)).

An improved AVI export provides better compression of video files. Loading, saving, and presentation of several files is now possible simultaneously without any delay.

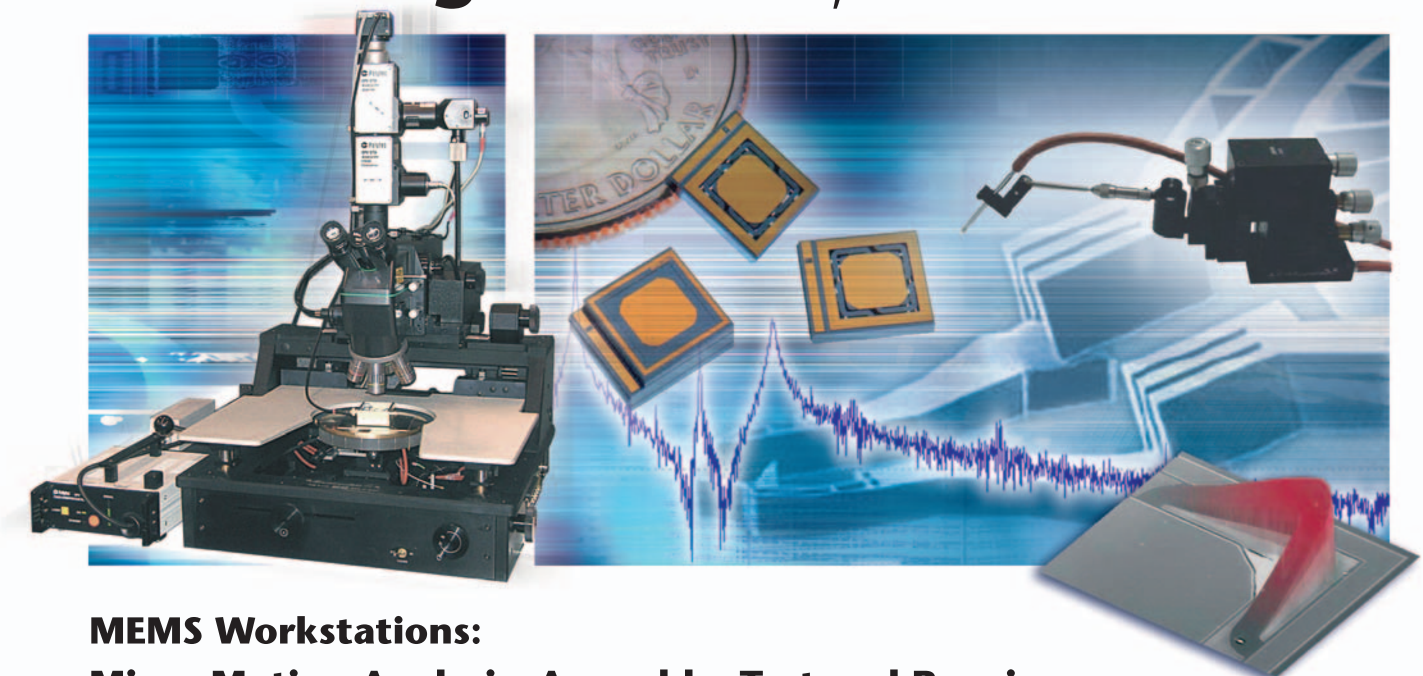
Applications

- Characterizing out-of-plane and in-plane dynamics of MEMS
- Frequency response measurements for analyzing the behavior of micro-components
- Failure analysis and reliability testing on microsystems
- Time-domain measurements for out-of-plane transient processes
- Identification of in-plane resonance through out-of-plane coupling
- Ring down measurements to determine time taken to attain steady-state condition and decay time
- Testing MEMS components at wafer-level through adaptation to Probe Stations
- Acquisition of data for Bode Plots

MORE INFO?

www.polytec.com/usa/microsystems

Technologies Unite *for Success*



MEMS Workstations: Micro-Motion Analysis, Assemble, Test and Repair

By combining Polytec's motion analyzer systems with a probe station the user can concentrate on the dynamic test rather than on sample holding, positioning and contact issues already addressed by probe station technology. These solutions were found for the early semiconductor and microbiology applications and are easily adapted to MEMS testing.

MEMS Applications and Challenges

The MEMS industry is challenged to discover, understand and address the novel failure mechanisms associated with different types of MEMS devices. Attempting to ensure device reliability without a full understanding of the basic failure mechanisms will likely result in "unexpected" field failures.

As a breakthrough technology MEMS will solve problems in fields previously unrelated to semiconductor technology with many new MEMS applications and will create products which are currently unidentified or unknown. As such this technology demands a wide range of general purpose tools to support broad testing requirements in research, development and pilot production of MEMS devices. The Polytec motion analyzer systems joined with semiconductor probe stations and a wide range of MEMS tools can provide the functions needed to analyze micro-motion, make electrical and physical contact with MEMS devices, and control the test environment.

The MEMS development process can be very costly. Scientists and engineers design, build and test proto-types then redesign rebuild and retest them. Finally they define the production processes to produce a device and optimize its performance and production yield. Even once a device is in production it is estimated that 65% of its cost is due to test, assembly and packaging. Failure rates for MEMS devices can be very high due to the fragile nature of many MEMS devices before final packaging.

Many MEMS devices have moving parts which may be detected and measured with a Polytec motion analyzer. Some potential applications (see page 14) are accelerometers and gyroscopes, RF MEMS, optical network components (MOEMS) and video displays.

Motion Analysis

The Polytec Micro System Analyzers are the ideal tool for detecting and analyzing MEMS motion. The ability to precisely measure and analyze out-of-plane and in-plane micro-motion without contact is critical to determine whether a MEMS device is functioning properly and within design specifications. The micro-scanning unit can resolve picometer out-of-plane Z motion within 0 to 20 MHz. The planar motion unit can detect in-plane XY motion within a frequency range of 0.001 Hz to 1 MHz with a resolution of better than 10 nm.

The Polytec systems are greatly enhanced by coupling them to a probe station with a complete set of tools for working with MEMS devices. Properly designed probe stations offer control of the test environment and a stable platform to mount the MEMS tools. Thus, a motion analyzer integrated with a quality general purpose probe station equipped with a thermal chuck system can provide a one-stop workstation to test, repair and encapsulate MEMS devices.

Continued on page 14: Probe Station Advantages, Applications and Examples

Sensing *Picogram Masses*

Laser Vibrometry Leads to Breakthroughs in MEMS Dynamic Analysis

Laser-Doppler Vibrometry (LDV) measurements have been instrumental in the development of resonant microelectromechanical systems (MEMS). In this article, the benefits of LDV for MEMS analysis and measurement are discussed for the specific case of a resonant Mass/Chemical Sensor.

Introduction

Only 10 years ago, quantification of three-dimensional motion in MEMS required placing the device in a scanning electron microscope, operating it, and videotaping the resultant motion. Video analysis could be done to quantify the motion, though substantial error remained in the measurement. On-chip measurement circuitry was also used, but this, too, had some problems, including not being able to diagnose motions or instabilities which were not anticipated by the designer. Due to these difficulties, it was not easy to get experimental verification of nonlinear behavior in MEMS devices, behavior which was often present, and detracting from the optimal operation of the device, be it a micro STM or micro AFM, switches, filters, resonators, accelerometer, or other resonant MEMS.

With the integration of an optical microscope and the Polytec LDV, the microscope-based vibrometer was born. This new instrument enabled single-point, out-of-plane measurements from a 1-micron diameter laser spot precisely located on the MEMS device. In-plane measurements could also be made with the same laser beam by integrating a 45 degree mirror into the device (see Figure 3; editor's note: or by using Polytec's planar motion analyzer). Measurements that had been tedious and error-filled became accurate and simple. The microscope-based LDV significantly increased the understanding and the ability to model nonlinear behavior in MEMS devices, resulting in many new applications based on this behavior.

Mass sensors are one such application which is being developed using LDV as a measurement technique. In this project, we use a different approach to improve sensitivity.

Mass Sensor Background

As the technology of miniaturization develops rapidly, building ultra-small micro/nano scale oscillators is achievable. In micro/nano chemical sensors, one commonly employed method involves tracking mass change on a surface-activated cantilever. The concept of tracking resonant frequency or phase shifts of micro/nano-oscillators in the simple harmonic resonance mode to measure mass change has become a well-established technology for chemical and biological sensing.

Since the fundamental resonant frequency of simple harmonic resonance depends on the mass and stiffness of the oscillator, mass change can cause the resonance frequency to shift and thus can be tracked. High mass sensitivity can be achieved by using an oscillator with extremely small mass and high resonant frequency. In a micro-cantilever array, information on cantilever resonant frequency shifts can be used for recognition of a variety of chemical substances, including water, primary alcohols, and alkanes.

By creating even higher-frequency nanoscale oscillators with a resonance frequency in MHz or GHz range, the ability to detect femtograms (10^{-15} g) or even attograms (10^{-18} g) of mass change may be achievable.

Theoretically, any mass change in the sensing oscillator can cause a certain amount of frequency shift. However, the performance of frequency shift detection is governed by many factors, including readout circuitry, noise, quality factor of the oscillator, and others. Quality factor (Q), which denotes the sharpness of frequency response curve of simple harmonic resonance, is one of the important factors that limit the sensitivity of simple harmonic resonance (SHR) based mass sensors. Micro/nano-oscillators with high Q can detect small mass changes because of the ability to resolve small frequency shifts. Currently, silicon oscillators can achieve Q~10^4 – 10^5 at high vacuum and low temperature. However, for detection of chemicals in air, the Q factors are significantly lower, due to higher damping conditions. For this type of sensing, we utilize another approach to improve sensitivity, while retaining the other benefits of microscale devices.

Parametric Resonance

Parametric resonance is a special case of mechanical resonance. Parametric excitation appears as a time varying modification on a system parameter (Editor's note. See also paragraph "Mass Sensing Results").

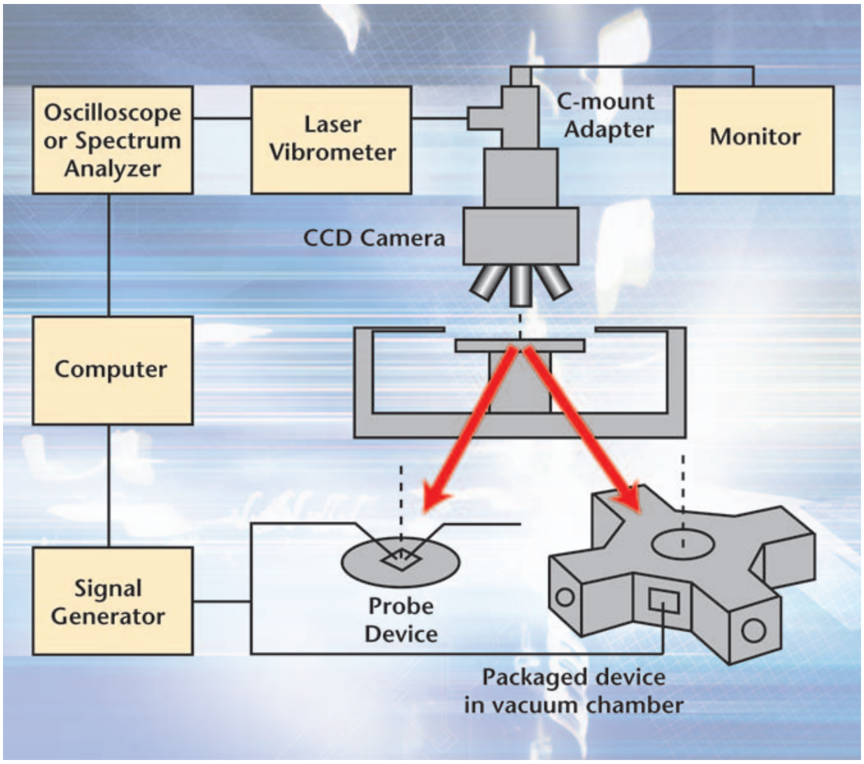


Figure 2: A schematic of the test setup used to perform the real-time dynamic analysis of MEMS

In the mass sensing process described here, mass change is monitored by measuring frequency shift at the stability boundary of the first order parametric resonance 'tongue'. The frequency transition at this boundary is very sharp, thereby making small frequency changes easily detectable. The sharpness of the boundary does not depend on the quality factor. Figure 1a shows the stability boundary, and how these boundaries respond to damping. Figure 1b shows that the device response amplitude (the quantity which must be sensed) does not depend on damping. Therefore, very small mass change can be detected in high-pressure environments, such as in air or even in water, where traditional resonant sensors fail. Of course this does not come for free, as there is more power required to create the oscillation in highly damped environments.

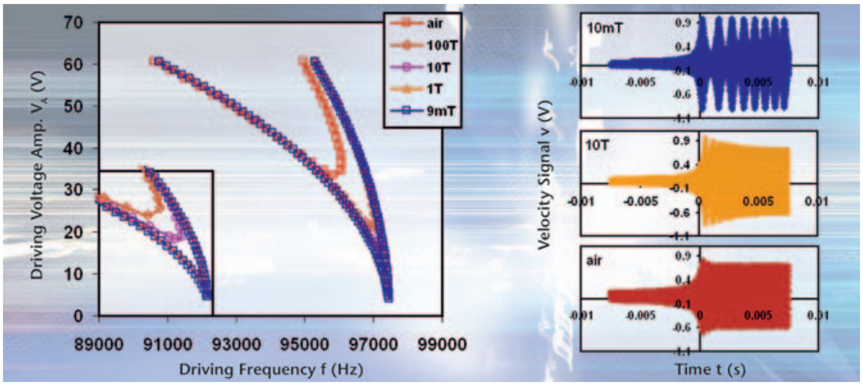


Figure 1: Damping Response. Left graph, instability regions of the sensor at different pressures. Right graph, sensor response inside the 'tongues' at different pressures (in Torr)

Testing Technique

Experiments are carried out using the approved MEMS characterization suite. By combining an optical microscope with long working distance (> 20 mm) objectives and a fiber optic laser vibrometer, the instrumentation suite shown in Figure 2 is used to measure the motion of MEMS.

Using a 50x final lens, the minimum spot size is ~1 µm and can be focused on a movable feature of most MEMS structures. Minor modifications allow the integration of a small vacuum chamber with a topside view port, which can control the pressure from atmosphere to 1.0 mTorr. The vibrometer instrumentation used here is capable of resolving velocities to 0.1 µm/s and displacements to 4 nm while operating with bandwidths up to 2.5 MHz. Other configurations would allow for even higher bandwidth and resolution. The real-time velocity and position information are viewed using an oscilloscope and a spectrum analyzer. These instruments are controlled using a LabView interface on a PC.

Laser vibrometry is typically limited to measuring motions perpendicular to the incident beam (out-of-plane); however, with one additional fabrication step, measurements can be made on MEMS devices which move in-plane. We have used a focused ion beam system to mill an integrated, 45-degree micro-mirror adjacent to a MEMS device (Figure 3).

Mirrors could also be made using other techniques, such as KOH etching, and used with microscope tilt to compensate for the incident angle difference. The mirror reflects the incident laser light into the plane of the wafer where it strikes the MEMS structure parallel to the direction of motion. Normal reflection from the MEMS structure and the micro mirror sends the interfering signal back along the incoming laser path. By integrating mirrors along the primary in-plane motion directions, and by also measuring the out-of-plane motion, three-dimensional motion characterization can be achieved.

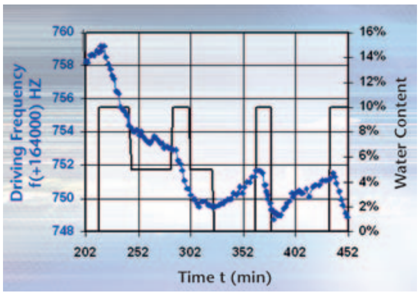


Figure 5: Frequency shifts at the right side of the first parametric resonance area as adjusting water content in the testing chamber. Resolvable mass change is less than 10^{-12} g

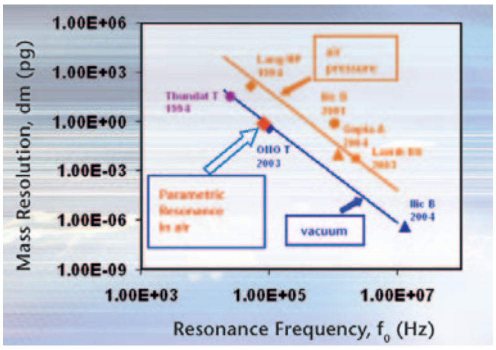


Figure 6: Comparison of Technology. Note that our sensor, although an air-sensor, is operating at the sensitivity of the sensors operating under vacuum

Mass Sensing Results

This mass sensor is comprised of a single crystal silicon micro-oscillator (Figure 4), in which the backbone is supported by four folded beams to provide recovery force for the oscillation and driven by a set of non-interdigitated comb-fingers using fringing-field electrostatic force.

Parametric resonance can be activated at certain frequencies because the non-interdigitated comb-fingers change the effective stiffness of the oscillator periodically in case an AC voltage signal is applied to actuate the oscillator. Mass change can be determined by measuring the frequency change at the boundary of parametric resonance. This preliminary device has sensitivity at the picogram (10^{-12} g) level when operating in air.

The ultimate sensitivity of this conceptual mass sensor is studied by testing water vapor content change in the test environment. Less than 1 pg of mass change in the oscillator has been detected in air. This sensing capability agrees very well with noise analysis results considering Brownian motion effects. Figure 5 shows the sensor response to water vapor adsorption tests.

Conclusion

Figure 6 compares a number of resonant mass sensors. By utilizing parametric resonance, vacuum level sensitivity can be achieved in air.
In conclusion, this example points out just one of many applications which have significantly improved development thanks to the measurements achievable with LDV.

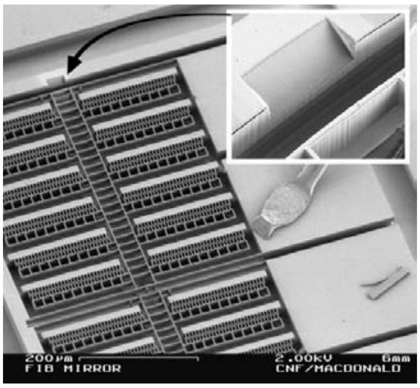


Figure 3: A MEM oscillator showing the 45-degree mirror

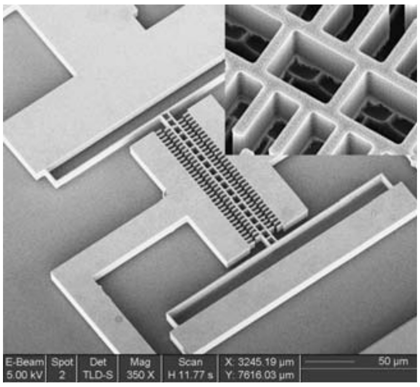


Figure 4: A SEM picture of the prototype mass sensor. It has a backbone and four springs with folded beams

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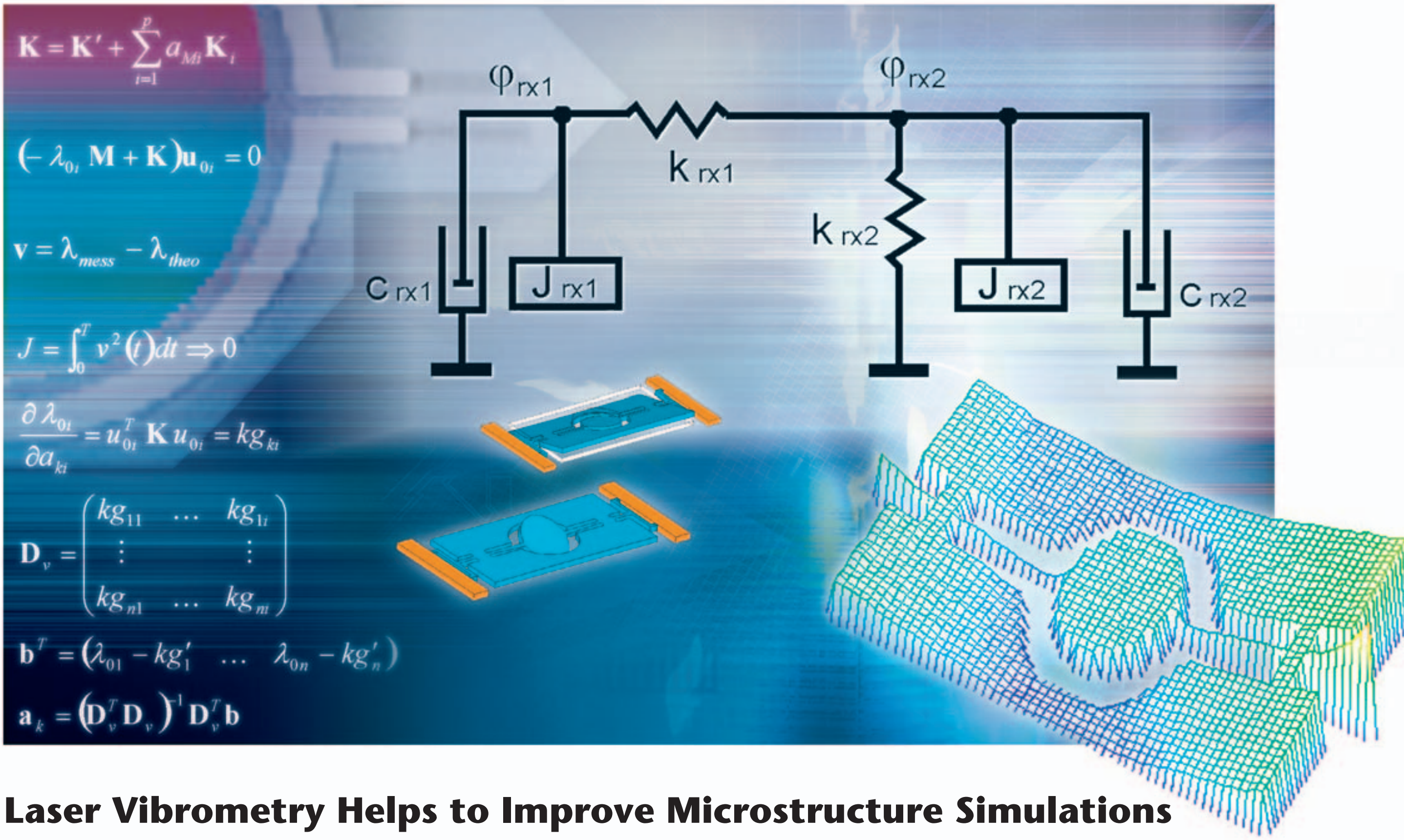
The full text of this article (including references) is available on the Internet and can be downloaded on **www.polytec.com/usa/Lm-download**.

Just How Precise are *Simulation Models?*



Laser Vibrometry Helps to Improve Microstructure Simulations

Computer simulation is essential to the development of MEMS devices. Simulation models are tested and refined through comparisons with precise experimental data. The data validating the model and showing the mechanical response of the MEMS structure is easily acquired through the combination of a Polytec Laser Vibrometer and a Wafer Probe Station.

Micromechnical Scanners

Tiny mirrors focus the light in bar code scanners up to several hundred times per second across the bar code. Scanning two-dimensional codes, made up like a mosaic of many dark and light fields, already requires significantly higher scanning speed and laser beam quality. Another development allows the use of a laser to project images. Just like an electron beam in conventional picture tubes, a laser beam is run across the image surface and its brightness is modulated. Such laser displays make the highest demands on scanning speed and beam quality. For example, in one second, up to 48,000 lines are written. The mirror surface must remain very flat, even while the scanner is working, to prevent distorting the laser beam. At the same time, these mechanical components should be small, robust and inexpensive. Such micromechnical scanners have been developed at the Fraunhofer IZM Institute in cooperation with the Center for Microtechnology at the Chemnitz University of Technology (Figure 1).

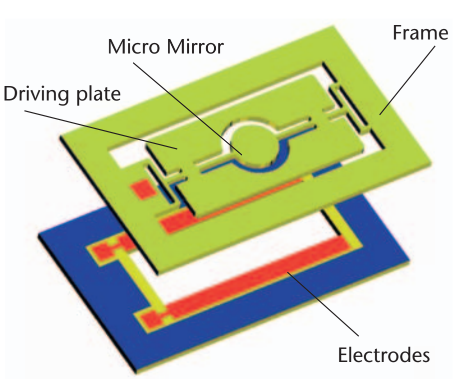


Figure 1: Construction of a micro scanner

To produce the mirrors, manufacturing technology from the electronics and semiconductor industry can be used. The dimensions of mechanically moving parts range between several microns and a few millimeters. By generating an electrostatic field between electrodes within this scanner, the small mirrors can be mechanically driven.

Simulation of MEMS Properties

During the design and development of these MEMS devices, numerous mathematical simulations must be made. The manufacturing processes are too expensive, too complex and too time consuming for experimental trial and error. The accurate prediction of system response in the design stage is only successful if suitable simulation models are available. Thus, in some cases, quite complex models are used to predict the interaction of electrical quantities with a multitude of physical quantities. Whether the MEMS components can reach the target specification after manufacturing primarily depends on the accuracy of the simulation, as it serves as a basis for dimensioning. It is therefore very important to test the validity of simulation models through comparisons with experimental data and then to fine-tune these models. For an undertaking of this kind, reliable measurement data on MEMS devices must be acquired and parameters that validate the simulation models must be extracted from the data.

Parameters Relevant to Manufacturing

Another task is to metrologically determine parameters which are relevant to manufacturing. Information on the process parameters currently available and their effects on geometric quantities and material parameters of the MEMS components are necessary for controlling the manufacturing process. The difficulty is that a wide range of measurement data needs to be reduced to the small amount of information necessary to control the manufacturing process. To solve this problem, processes to adapt model parameters are also still being developed and used. These can be used for example to determine the thickness of layers or the mechanical stress in the materials of the MEMS components. Prerequisite is a qualified measurement technology which also allows to obtain measurement data from wafer-level MEMS components at any stage of the manufacturing process.

Experimental Setup

The measurement data obtained from MEMS components mainly contains information on the dynamic deformation of movable components in form of time series or frequency response functions. A combination of a Polytec Laser Vibrometer and a Wafer Probe Station (Figure 2) has proven to be an excellent technique for optically detecting the mechanical movement of structures within MEMS components.

Because of the optical sampling, the measurement procedure very little influences the MEMS device. The diameter of the laser beam on the test sample is in the range of a few micrometers, so that even very small structures such as single cells of micro mirror arrays can be tested.

Simulation – Measurement – Parameter Adaptation

After an FEM analysis of the MEMS device , numerous simulation models are generated which describe the mechanical behavior at a large number of geometric locations. Since it is possible to allocate six degrees of freedom to each location, the results can reflect the behavior of a mechanical system with a large number of degrees of freedom and resonance points. Practically, for such an ensemble of points, only a few degrees of freedom have real meaning. To reduce the order of these models, techniques are used to make models with lumped elements that can be measured to verify the accuracy of the model.

In parallel, experimental data is taken on MEMS components excited to induce mechanical vibrations. The vibration amplitudes are typically between several hundred picometers and a few microns. Recording both the excitation signal and the resulting system response provides the input signals from which the frequency transfer functions is derived.

Finally, the parameters of the order-reduced model are adapted for a best fit to the measured system response data. To make the adaptation, the evaluation of resonance frequencies, the comparison with the model's eigen frequencies and the least squares

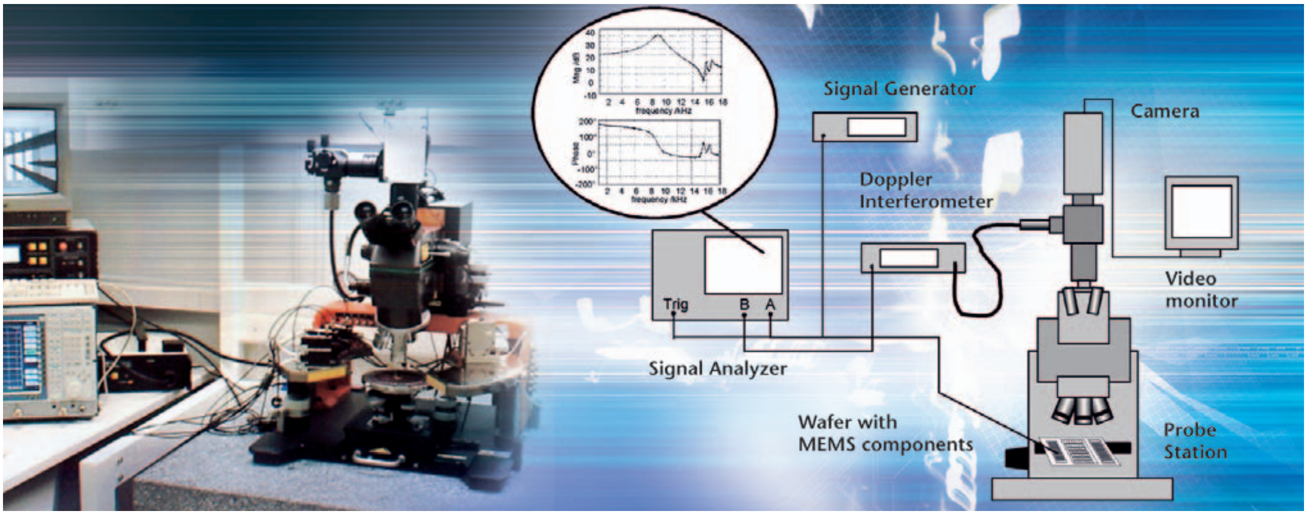


Figure 2: Probe station with Polytec Microscope Scanning Vibrometer

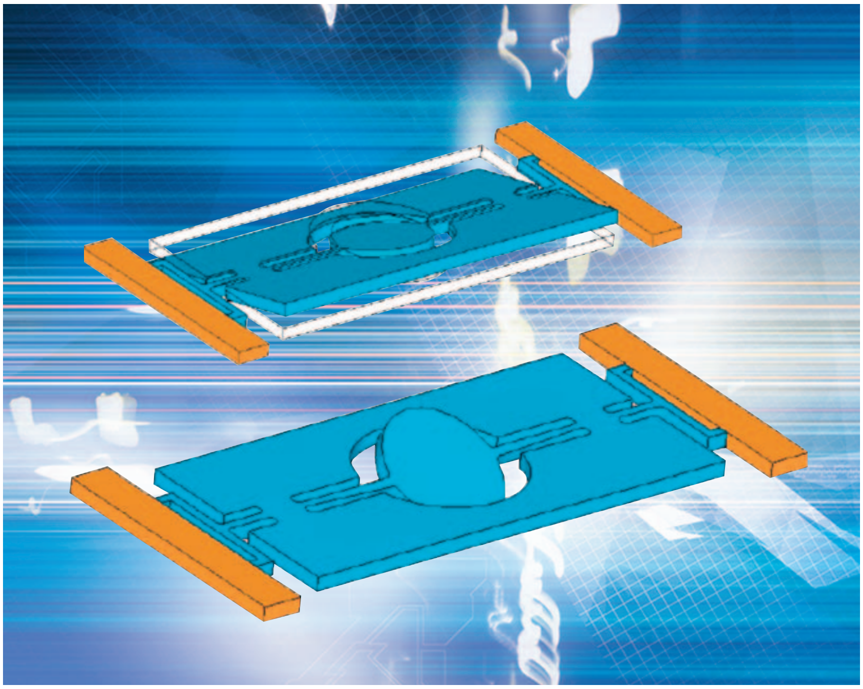


Figure 3: First (top) and second (down) natural deflection shape of the scanner

fitting method are used. The question regarding the accuracy of the simulation can be answered after a comparison between the calculated and the measured reaction, or by comparing the model parameters before and after adaptation. The adapted model can be used to simulate the behavior of the MEMS components, taking various outline conditions as a basis.

The material or geometry parameters can be determined quantitatively and can be referred to for process control.

Example: MEMS Scanner

The task is to experimentally determine the stiffness and geometry of the torsion bands which flexibly connect the micro-mirrors, driving plate and the frame with each other and to determine the mechanical damping caused by the air flow. As a first step, a finite element model of the scanner is set up (Figure 3) and the eigenfrequencies, deflection shapes and mechanical damping caused by the air flow are numerically analyzed (Figure 4).

A reduction of the model order leads to a simple model with lumped elements (Figure 5).

As a second step, the frequency transfer functions are measured at different locations on the MEMS scanner and the eigenfrequencies are read (Figure 6).

Finally the eigen value residuum is formed from the difference between the calculated and the measured eigenfrequencies and the stiffness matrix is corrected using the least squares method. After this procedure, it contains the stiffness of the torsion springs adapted by the behavior of the sample. The damping matrix can be adapted by referring to the calculated and the measured vibration amplitudes as a final step.

Summary

The geometry and material parameters of micromechnical components are determined by processing measurement data and simulation data using model parameter adaptation.
A Laser Doppler Vibrometer and a Wafer Probe Station allow efficient data acquisition. The researchers at the Fraunhofer IZM are working in cooperation with their colleagues at Polytec to fine-tune this measurement technique and adaptation of parameters.

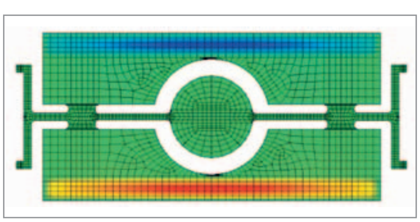


Figure 4: FEM analysis of damping by air flow, pressure distribution

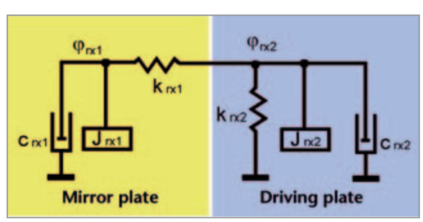


Figure 5: Model after reduction of order

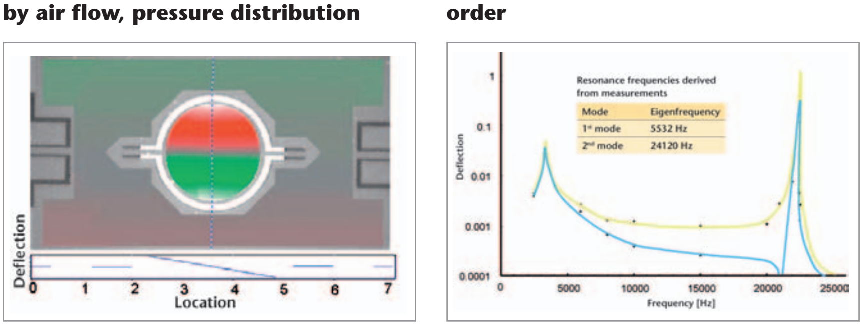


Figure 6: Measurement results with the Microscope Scanning Vibrometer, left: deflection shape; right: transfer function

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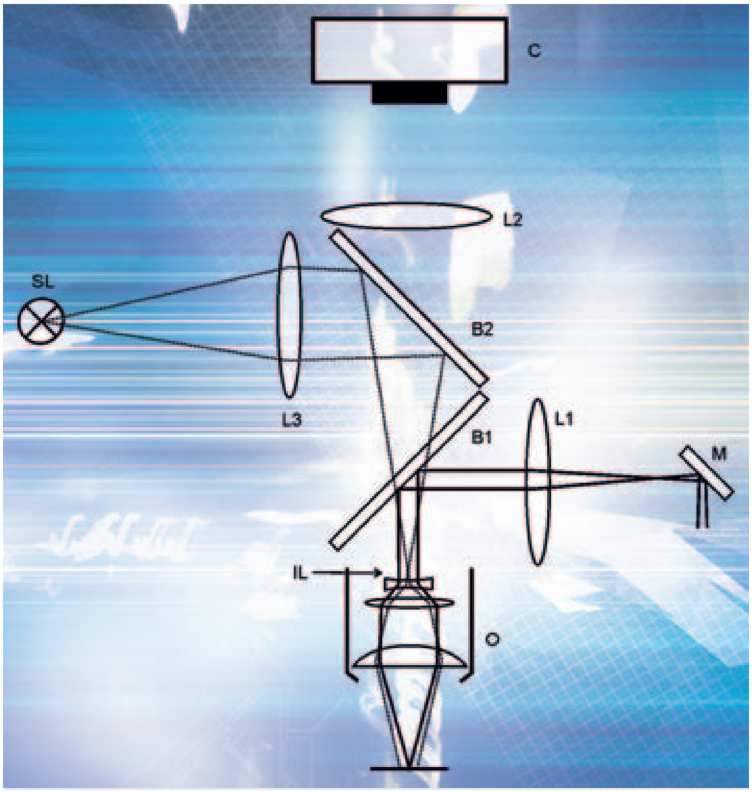


Figure 1: Schematic of an optics arrangement for a combined vibrometer and machine vision measurement.

L1 is the scanner lens, L2 the microscope tube lens that images the specimen on the camera chip C. Lens L3 images the strobe lamp SL to the backside focus IL of the objective O. B1 and B2 are beam splitters, and M is the scanning mirror.

A Smart Combination for Rapid Results

Normally, the highly sensitive laser-Doppler technique (picometer resolution!) is applied first to the device to rapidly find all mechanical resonances using wide-band excitation. "Pure" in-plane resonances will be detected because of small, parasitic coupling to out-of plane modes and the high sensitivity of vibrometry. A frequency signal that does not fall in a FFT line is distributed over the neighboring lines, and therefore even a narrow vibration peak, which falls between two FFT lines, can be discovered. One of the great advantages of this approach is that the in-plane analysis can be limited to the already determined resonance bands in the spectrum.

Optical Setup

The vibrometer's laser beams and the strobe illumination must be coupled into the beam path of the same microscope optics to integrate the two techniques in one setup. This can be realized by designing two beam splitters between the microscope objective and the microscope tube lens. The first beam splitter is used to couple the vibrometer laser beam into the microscope beam path. The second splitter couples the strobe light source into the microscope. A possible arrangement is shown in Figure 1.

Functional Principle

A stroboscopic video microscope measures in-plane motions of periodically moving structures with stroboscopic machine vision and can measure frequencies as high as 1 MHz. The camera used is typically a CCD sensor for video frame rates and not a high-speed detector; therefore, the stroboscopic principle must be applied to visualize rapid motions. A pulsed LED is used as a reliable light source that ensures constant illumination power of the strobe pulses. The time resolution of the system is defined through the pulse width of the strobe flash. No light is collected through the CCD sensor when the strobe light is off. Therefore, events can be recorded with a period time shorter than the exposure time of the camera.

The drive signal of the device is the timing reference and synchronizes the strobe flashes and the camera exposure. The timing diagram of the strobe synchronization is shown in Figure 2 for an example of three camera shots. The shots are recorded at three different phases of the periodic excitation for the specimen.

Two LED flashes are used in Figure 2 within the exposure time of the camera. The number of flashes per camera shot can be used to adjust the image brightness. The time between two shots is the cycle duration of the camera-framing rate. The phase delay of the strobe illumination with respect to the driving signal is adjusted by setting the duration T_{shot} between the shots to

$T_{shot} = nT_{excitation} + t_{phase\ delay}$.

Here, n is an integer, $T_{excitation}$ is the period length of the excitation signal, and $t_{phase\ delay}$ is the time shift that corresponds to the phase delay. The maximum frame rate F_c of the digital camera limits the shot frequency to $F_c \geq 1/T_{shot}$.

The procedure demonstrated in Figure 2 is completed when all images, necessary to derive the displacement response with image processing, are captured. Short strobe pulses are necessary to freeze a rapidly moving structure. Blur is generated if the device moves a longer distance than the distance that corresponds to the diameter of a camera pixel during the strobe illumination. It is necessary to use only a few flashes per shot (best is one flash) if the device does not perform a precise periodical motion but has a jitter. In this case, blur is generated if the jitter is higher than the distance that corresponds to one pixel.

Calculating Displacement: The Numerical Algorithm

Modern video-microscopy systems can automatically record frequency responses. Image sets are recorded for a number of frequencies to obtain a frequency response. Displacement-versus-phase-delay data is extracted for every measured frequency automatically by employing image-processing techniques. Phase and amplitude are computed through a sine-function fit from the displacement-versus-phase-delay data for every frequency record.

In-plane shifts *di* and *dj* between image 1 (I_1) and image 2 (I_2)) are computed with sub-pixel resolution by image correlation. Two images are matched if the displacement-dependent, normalized correlation coefficient

$$r_c(di, dj) = \frac{\sum_{k=1}^{K}\sum_{l=1}^{L}(I_1(k,l)-\bar{I}_1)(I_2(k+di,l+dj)-\bar{I}_2)}{\left[\sum_{k=1}^{K}\sum_{l=1}^{L}(I_1(k,l)-\bar{I}_1)^2\right]^{1/2}\left[\sum_{k=1}^{K}\sum_{l=1}^{L}(I_2(k+di,l+dj)-\bar{I}_2)^2\right]^{1/2}}$$

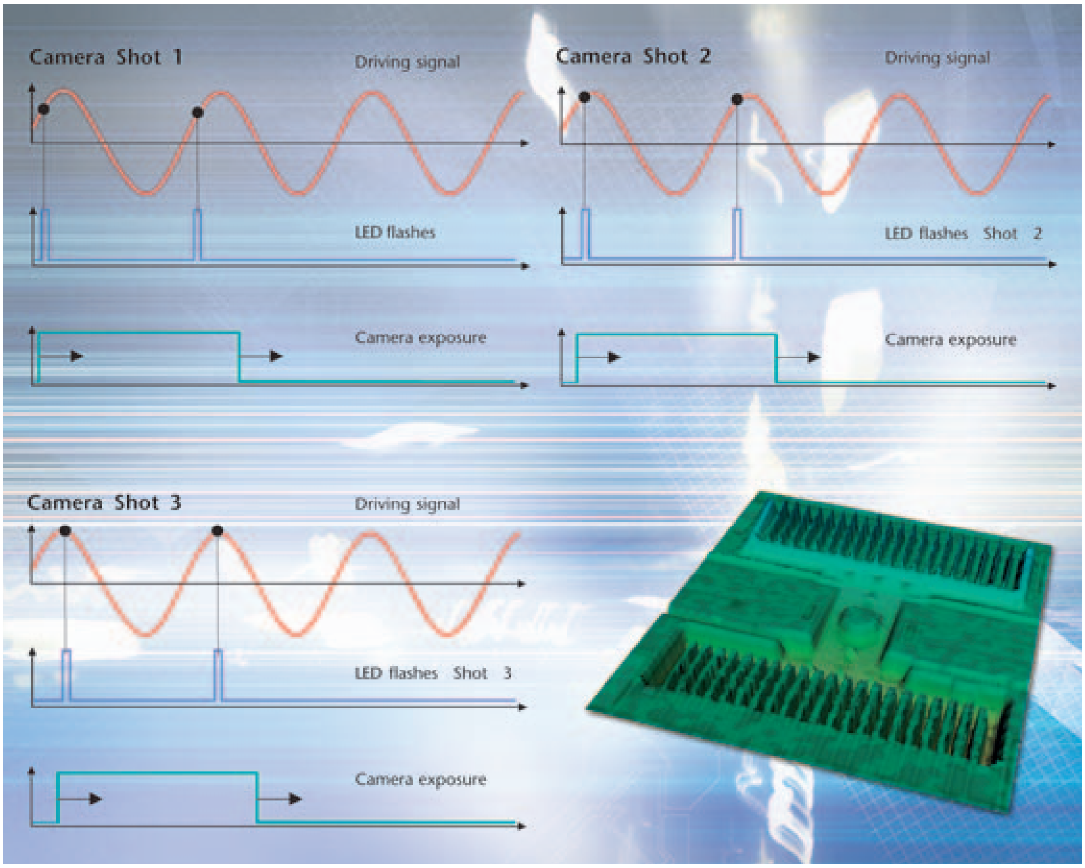
at (di, dj) is a maximum: max $(r(di, dj))$.

Here $\bar{I}$ denotes the average intensity value of the pixels in I and ($k, l \in \aleph$; $di, dj \in \Re$)*.
If r_c is maximum the difference between the image-pattern template $I_1(k, l)$ and the shifted image $I_2(k, l)$ is a minimum. Therefore, the displacements *di* and *dj* are the estimation parameters for an optimization algorithm that computes the maximum of r.

The in-plane-motion algorithm computes *di* and *dj* with sub-pixel resolution. The Nyquist-sampling theorem can be employed to calculate a resampled image $I_r(i, j)$ ($i, j \in \Re$) which is the key to understand the idea of sub-pixel-displacement computation.

* $\aleph$: integers; $\Re$: real numbers

Figure 2: Timing diagram of the stroboscopic method for in-plane analysis



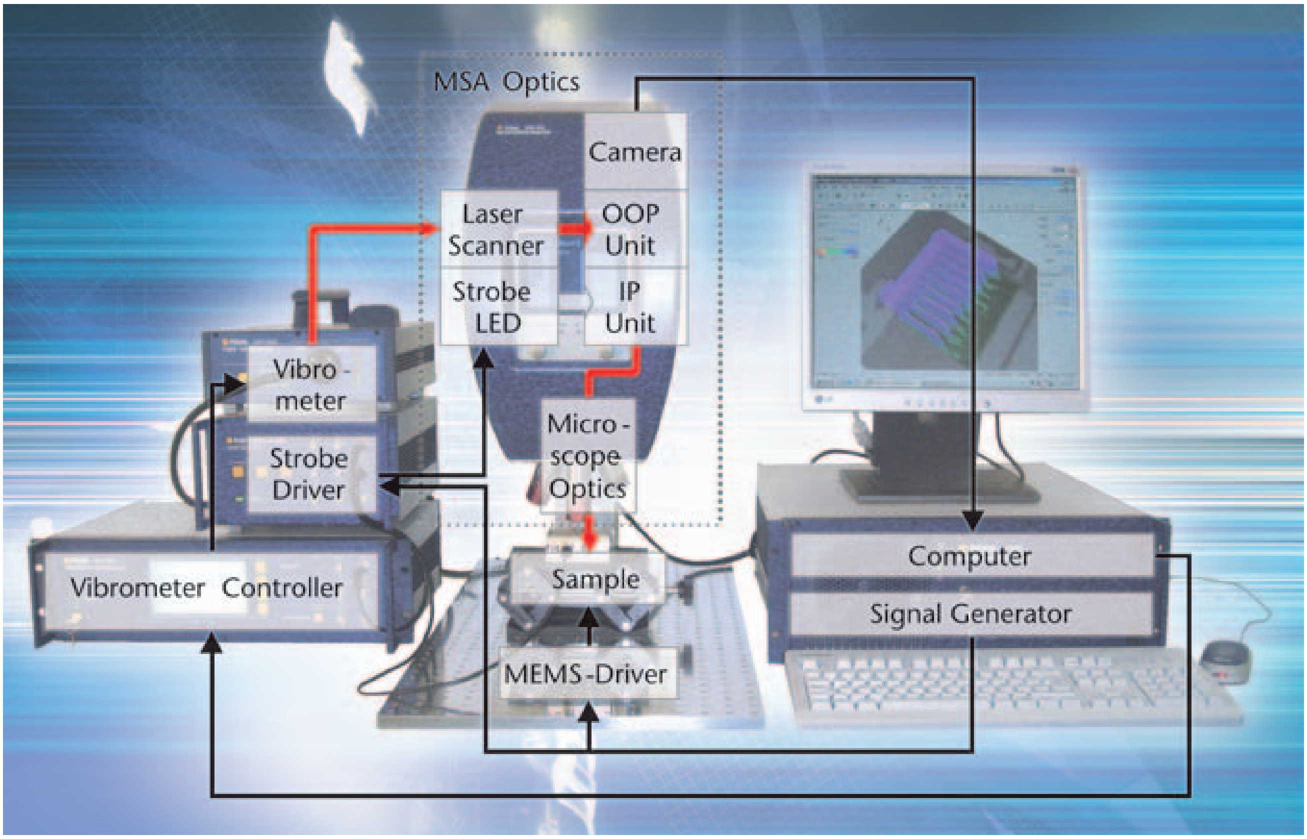


Figure 3: Schematic of the MSA-400 Micro System Analyzer. OOP: out-of-plane, IP: in-plane

Practical Implementation

In Figure 3 the schematic of the MSA-400 Micro System Analyzer is shown. The superimposed block diagram indicates how stroboscopic video microscopy and laser vibrometry have been combined. The strobe light and the vibrometer beam are coupled with modular units via the microscope C-mount into the microscope beam path. The computer in collaboration with the vibrometer controller and the signal generator controls the motion of the laser beam, the stroboscopic illumination, the processing of both the interferometric signals and the camera image, and the sample excitation. The acquisition, evaluation and presentation of the data is managed by individual PSV and PMA software programs that utilize the hardware differently.

More Info:
www.polytec.com/usa/microsystems

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Only advanced, non-contact measurement technology provides the required precision and reliability. Measurement accuracy is one of many aspects that must be considered when picking the right instrument; fail-safe, and maintenance issues are also extremely important.

Non-contact optical measurement is superior to conventional sensors in each case. In particular, the new LSV-300 Laser Surface Velocimeter retains the high-quality Polytec length and speed measuring technique and adds to it an extremely attractive price making the LSV-300 the optimum choice for many applications where cost-of-ownership is as important as accuracy.

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IVS-200/300 Industrial Vibration Sensor

The IVS is a ruggedized laser Doppler vibrometer for non-contact, on-line production vibration testing up to 22 kHz. Designed to be easily installed into existing manufacturing lines, the laser, interferometer optics and electronics are all contained within a single, compact and robust industrial housing (IP 64). IVS-300 uses digital signal processing (DSP) to ensure accurate and repeatable measurements from un-cooperative surfaces (speckle noise, dropouts).

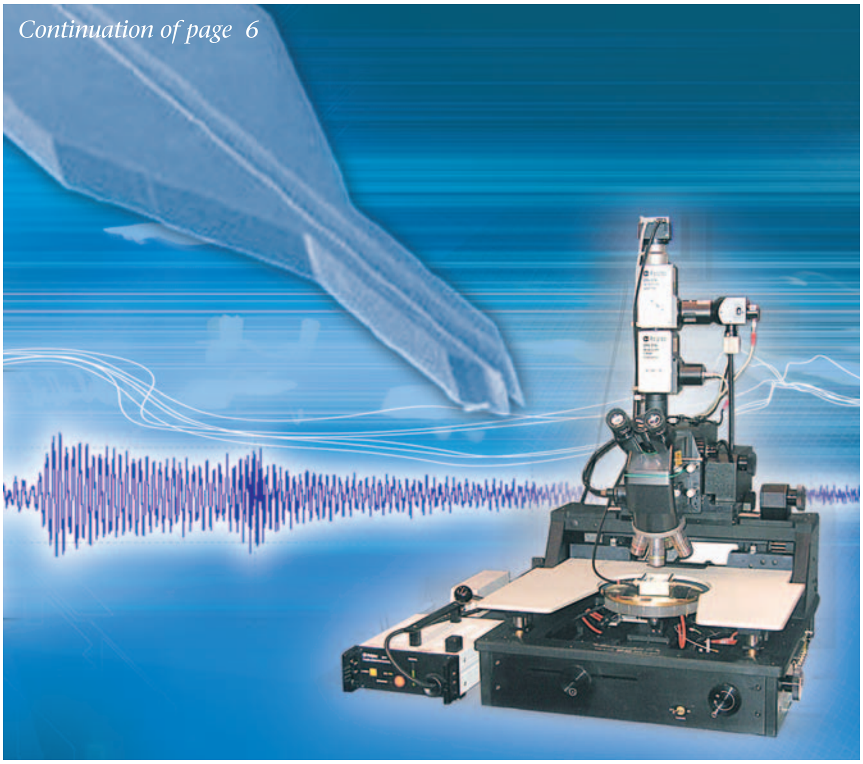
CLV Compact Laser Vibrometer

Designed for excellent velocity resolution and high optical sensitivity from a compact optical design, the CLV combines a robust (IP-64 rated), compact optical head with a modular controller. Ideal for precise non-contact vibration measurements up to 350 kHz in difficult-to-reach places or on production lines with limited space for adding a quality control sensor.

TMS-300/320 TopCam Interferometer

Designed as a high-resolution 3-D camera, the TopCam uses telecentric imaging to simplify precision topography and flatness measurements for on-line production part inspection. The TopCam is based on compact scanning white light interferometer technology that integrates image processing and 3-D coordinate acquisition to measure miniature relief structures, find distortions and uncover surface defects even on soft materials.

Technologies Unite *for Success*



Continuation of page 6

MEMS Workstations: Micro-Motion Analysis, Assemble, Test and Repair

Probe Station Advantages

By combining Polytec's motion analyzer systems with a probe station the user can concentrate on the dynamic test rather than on sample holding, positioning and contact issues already addressed by probe station technology. These solutions were found for the early semiconductor and microbiology applications and are easily adapted to MEMS testing.

Well designed probe stations come with simple sample mounting techniques and sufficient vibration damping of the microscope, sample holder and platen which holds the probes and MEMS tools. Manual stations provide for quick, convenient mounting and testing of wafer pieces, single dies and packaged parts; while semiautomatic stations can automatically step to each selected die on a wafer. A large, stable platen is important as it must hold and move in unison a wide variety of electrical probes and MEMS tools. Micro-tweezers, micro-scalpels, mini-vacuum wands, optical fiber holders, micro-injection systems, ultrasonic cutters and sample holders are available to test, assemble or repair MEMS devices. In addition, thermal chucks, light and EMI/RFI shields and environmental chambers can provide controlled environments needed to test MEMS functions under a wide range of condition.

Application Examples

Accelerometers/Gyroscopes

MEMS accelerometers are quickly replacing conventional accelerometers for crash air-bag deployment systems in automobiles. MEMS accelerometers are much smaller, more functional, lighter, more reliable, and are produced for 1/10th the cost of the conventional macro-scale accelerometers. Other automotive applications for MEMS include sensors for tire pressure, fuel pressure, air flow, headlight leveling, skid, tilt, shock and vibration to improve efficiency and safety. GPS positioning, navigation sensors and gyroscopes using MEMS technology are already available for use in land vehicles, watercraft and aircraft.

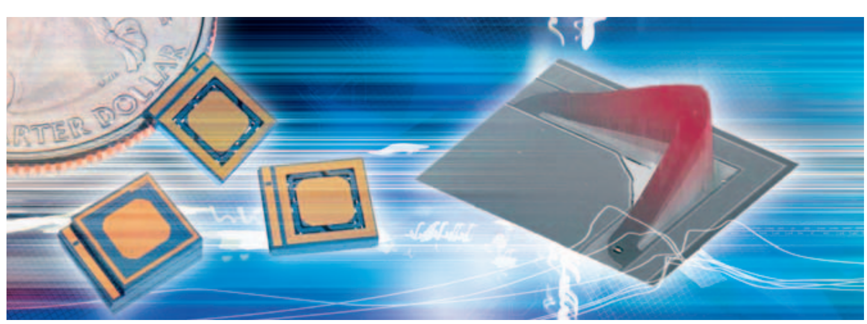
RF MEMS

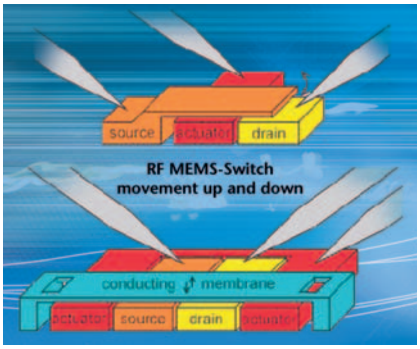
Discrete passives such as RF-switches, variable capacitors, micro-inductors, micro-antennas, high-Q resonators and filters have been identified as components that can be replaced by RF-MEMS equivalents. RF MEMS may be integrated into semiconductor circuits replacing larger discrete components, offer lower power consumption, lower losses, higher linearity and higher Q factors than conventional communications components.

Example: RF Switch

RF switches open and close electrical contacts by moving a cantilever or membrane up and down to complete an electrical circuit.

Test system requirements may include a Polytec out-of-plane motion analyzer to determine the total displacement of the cantilever or membrane and the speed of switching, and a probe station to provide a clean, controlled atmosphere and the convenience of step-and-repeat testing of switch arrays or die on a wafer. Also this may include a vacuum probe station which can test the switch under



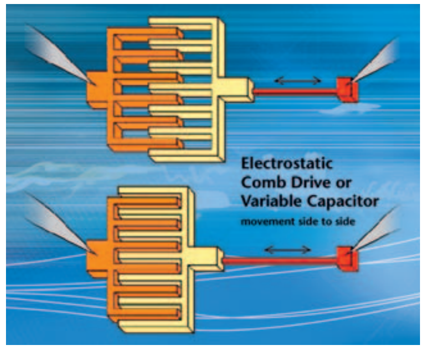


vacuum conditions. The probe station can be equipped with a thermal chuck for bonding experiments, environmental tests and accelerated failure tests; a laser cutter to trim cantilever or membrane materials; micromanipulators to position electrical probes; a micro-syringe system to apply adhesive; and several probes to provide high frequency signals, actuator power, UV-curing light and others.

Example: RF Variable Capacitor

Variable capacitors have a number of designs one of which is to use a comb structure which is moved in-and-out to alter the capacitive properties. A similar structure may be used as an electrostatic comb drive to move the variable capacitor parts.

Such structures may be tested by a combining Polytec's in-plane and out-of-plane motion analyzers to determine the total displacement of the comb structure and identify design or manufacturing problems which result in an out-of-plane motion. The probe station may need to be a vacuum probe station which can test MEMS devices under both vacuum or partial pressure and which is similarly equipped to the RF MEMS switch testing setup shown above.



Optical Network Components (MOEMS)

Even though the optical network industry recently experienced a major contraction, this industry still uses a wide range of optical MEMS devices. Switches, multiplexers and splitters are some of the MEMS devices which are used in standard optical communication systems.

Example: Optical Fiber Switch

Optical fiber switches are used in communication systems to route optical transmissions from one fiber to another. The design shown in Figure XX allows two input and two output ports. The micro-mirror may be moved into position by a comb drive.

System requirements may include a Polytec in-plane and out-of-plane motion analyzer to determine the total displacement of the comb structure, stability of the micro-mirror and identify design or manufacturing problems which result in unexpected out-of-plane motion. The probe station should provide a tilt/tip stage and a large platen to support multiple tools (laser cutters, optical fiber holders, micro-tweezers) to test and assemble the optical switch.

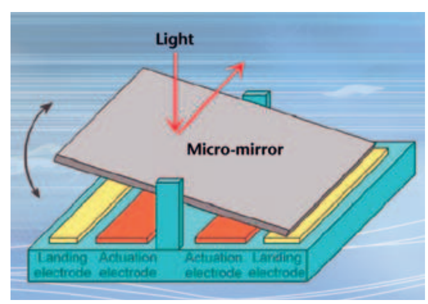
Video Displays

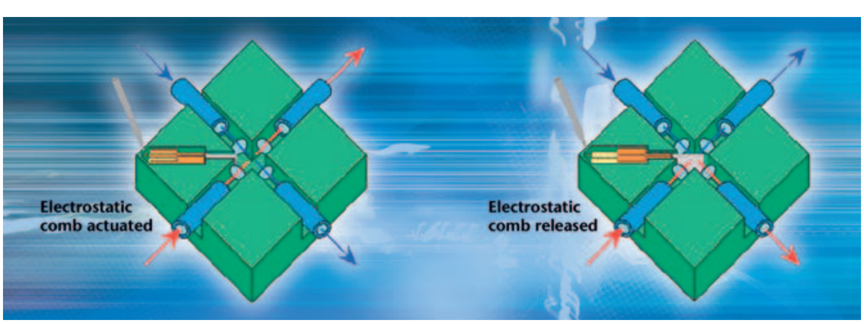
Video projection chips with a million moveable micro-mirrors are a significant MEMS application. The ability to independently control each micro-mirror allows for image control not available in traditional optical systems.

Micro-Mirrors

Micro-mirrors, activated by capacitive attraction or piezoelectric motion, are an important commercial application for MEMS, as they allow light to be manipulated at the micro-scale for use in micro-scanners and optical switches. Texas Instruments recently produced a capacitive micro-mirror for a Digital Light Processing technique used in new digital cinema projectors.

The combination of Polytec's in-plane and out-of-plane motion analyzers is able to determine the total displacement and stability of the micro-mirror, and identify design or manufacturing problems. The probe station should be equipped similar to the optical fiber switch testing setup described above and should provide multiple tools to test and repair the micro-mirror.





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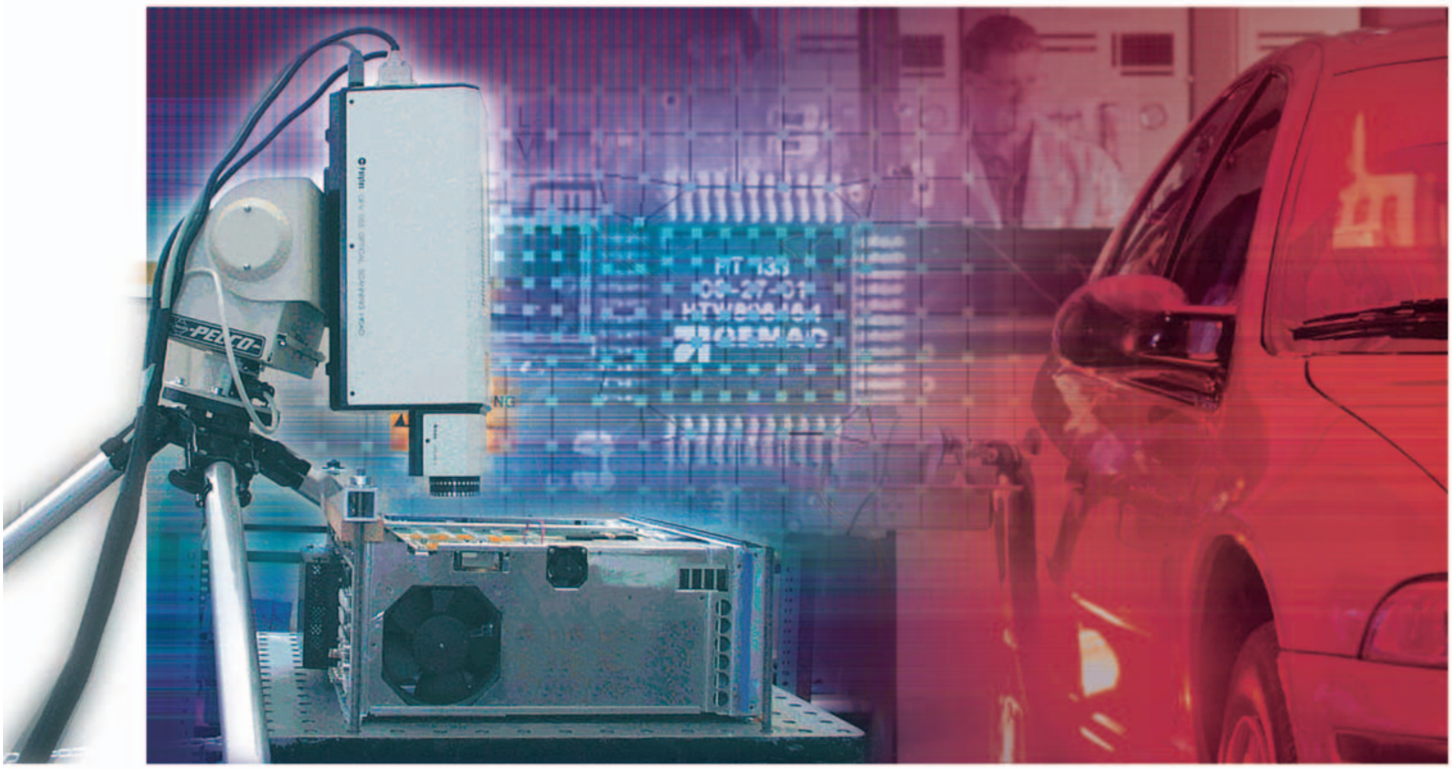

Characterizing the Thermomechanical Properties of Sensors Using Laser Vibrometry

Over the last few years, micromechnical sensors have become ubiquitous in every day technology. Their failure-to-perform can adversely affect simple products as well critical, safety-related automobile technology. The long-term reliability of sensors is of increasing importance through all stages of development and production and is characterized using sophisticated measurement procedures

Thermomechanical Sensor Properties

Depending on the application, micromechanical sensors are designed with different superstructures, materials and joining technologies.

Integrated together to form the sensor, these components determine the device's elastic, dynamic and thermomechanical properties.

Specific deformation under thermal and static load as well as mode structure, vibration amplitude and resonance spectra are also a direct result of these components. The long-term stability of these components is critically important for the long-term reliability of the sensor.

Measurement Procedure

The thermomechanical properties are measured using various non-contact methods and tools. To measure deformation, ESPI methods or image-correlation methods are used.

The vibration characteristics of micromechanical sensors can be identified with the aid of laser vibrometry.
For this purpose, AMITRONICS uses a single point vibrometer and a scanning vibrometer. The lateral resolution of these vibrometers and thus the smallest measurable structural size is defined by the size of the laser focus of approx. 30 µm. The scanning vibrometer is particularly good for thermomechanical characterization of electronic subassemblies because it shows the results as animated 2-dimensional vibrations.

Basics

Characterization of the dynamic behavior of a subassembly is based on the spectral position of significant eigenfrequencies, the associated deflection shapes and the amplitudes measured. If for example the properties of the joints change as a result of aging, fatigue or environmental influences, then the dynamic properties of the sensor often show a change which can be measured by the vibration characteristics.
For example, if vibration-relevant structural elements get "softer", then

the eigenfrequencies become lower (Figure 2). Alternatively, if the stiffness increases, then the eigenfrequencies become higher. Tears and fractures not only reduce the frequency but also change the deflection shapes, particularly in the upper frequency range.

Typical Sequence of a Characterization

Characterization begins with a properly designed measurement setup. Components can be self-excited or externally excited. Switching sensors, for example, are self-excited and do not require any external excitation. In contrast, acceleration sensors are excited externally using piezo ceramic elements. The title illustration shows the measuring setup with the PSV Scanning Vibrometer equipped with a close-up unit. The measurement grid is defined for scanning the surface of the sensor and follows the geometry of the component, taking into consideration vibration-relevant stiffness steps. Based on significant peak amplitudes or coupled eigenfrequencies, the measurement results can show possible vibrational weak points. This is a useful approach to characterize a variety of parts and samples for defects and potential failure points.

Applications

The tilt sensor shown in Figure 1 was examined before and after thermal cycling tests between – 40° C and 150° C (500 cycles). In Figure 2, the frequency response function of an undamaged tilt sensor is compared to a damaged sensor, both under exter-

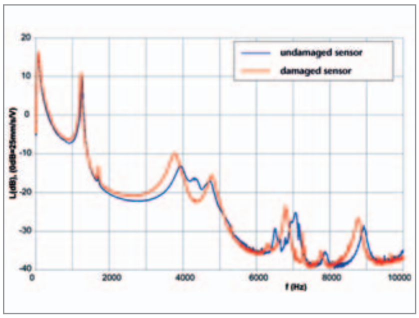

Figure 2: Frequency response function for the tilt sensor

nal excitation. The frequency shift to lower frequencies is clearly visible.

The vibration characteristics of a HF-MEMS switch were also examined (Figure 3). The switching process (electrostatic) is identified by self-excitation. The sensor can also be excited externally using a piezo shaker. The behavior of the bridge structure is of particular interest for thermo-mechanical characterization.
The initial results from this kind of investigation are plotted in Figure 4 and can be used to validate an FE model.

Sensor Properties and Long-term Reliability

The vibration characteristics of an intact sensor measured across a wide frequency range forms a baseline response. By sampling the sensor's vibration characteristics over time and comparing them back to the baseline, early changes in the sensor can be detected often prior to any functional impairment. The long-term reliability of sensors can be correlated to these changes and thus checked through suitable monitoring of the sensor itself or subassemblies critically related to reliability. Hence monitoring can be done externally or by observing the self-excitation through driving the actual sensor function (for example the switching function).

Summary

Non-contact laser vibrometry makes it possible to characterize the thermo-mechanical behavior of sensors through the spectral position of significant eigenfrequencies, the corresponding deflection shapes and amplitudes. Tears and fractures not only cause a frequency shift but also change the deflection shapes. The long-term stability of the thermomechanical behavior of sensors can be monitored through external measurements as well as by monitoring the self-excitation, for example with switching functions.

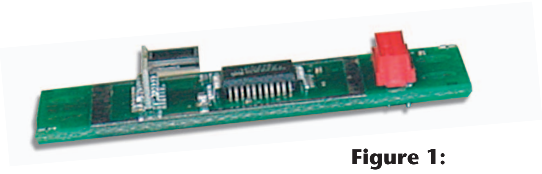

Figure 1: Tilt sensor (GEMAC mbH)

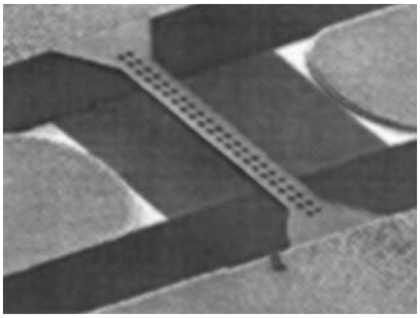

Figure 3: HF-MEMS switch (Picture: R. Bosch GmbH)

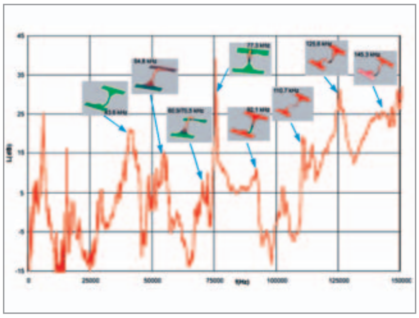

Figure 4: Frequency behavior and corresponding mode shapes

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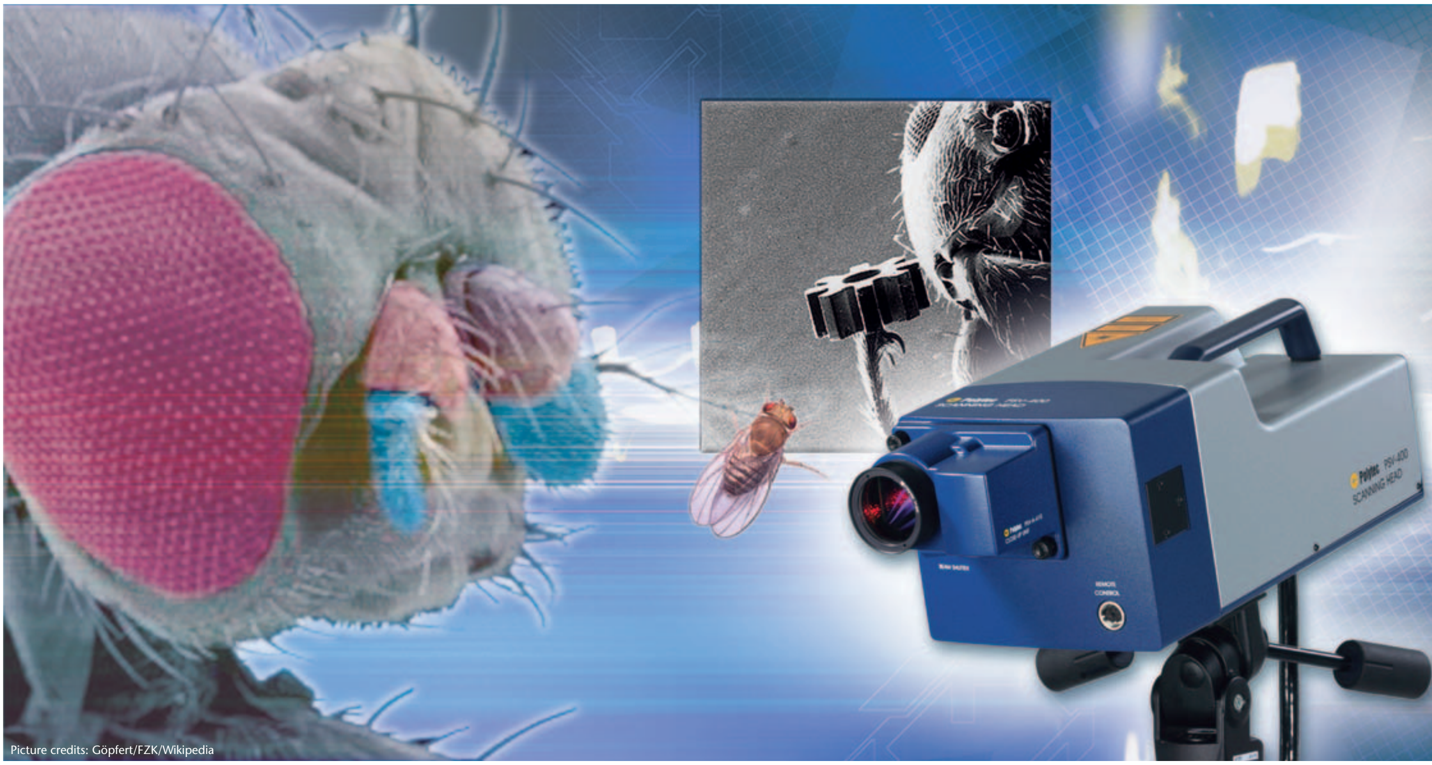
Molecular Motors *on the Fly*


Picture credits: Göpfert/FZK/Wikipedia

Laser Doppler Vibrometry Brings Insight into the Functioning of Fruit Fly Ears

Ears are complex micromechanical machines that amplify tiny acoustic vibrations and convert them into electrical signals. Which kind of structures and processes are responsible for the signal processing inside the ear? Laser Doppler vibrometry brings insight into the sophisticated mechanisms of hearing.

The Auditory Mechanism

Fruit flies have ears as well. These insects hear with their tiny antennae. The antenna itself forms a sound-receiver, like a human eardrum. Sound-induced vibrations of the antenna are funneled to sensory cells at the antenna's base causing the opening of ion channels that convert vibrations into electrical signals. The general functioning of human ears is similar, yet the ears of fruit flies provide an important experimental advantage: While a human eardrum is buried in the auditory duct, the antenna of the fruit fly sticks out from the body and is freely accessible to mechanical examination.

Measurements and Results

Using the PSV-400 Scanning Laser Doppler Vibrometer, the vibrations of the tiny, hardly visible fruit fly antenna can be assessed at defined measurement points. This procedure allows for the systematic study of the vibrational behavior of the sound receiver. (Figure 1 and 2).

The antennal vibrations contain more information than just the mechanical response of the receiver. Because the antenna, the sensory cells, and the ion channels are intimately linked to each other, the vibrations of the antenna also reflect the cellular and molecular processes inside the ear. Just like a stethoscope gives insight into the workings of the heart, the laser vibrometer thus provides access to the hidden, cellular and molecular processes of hearing.

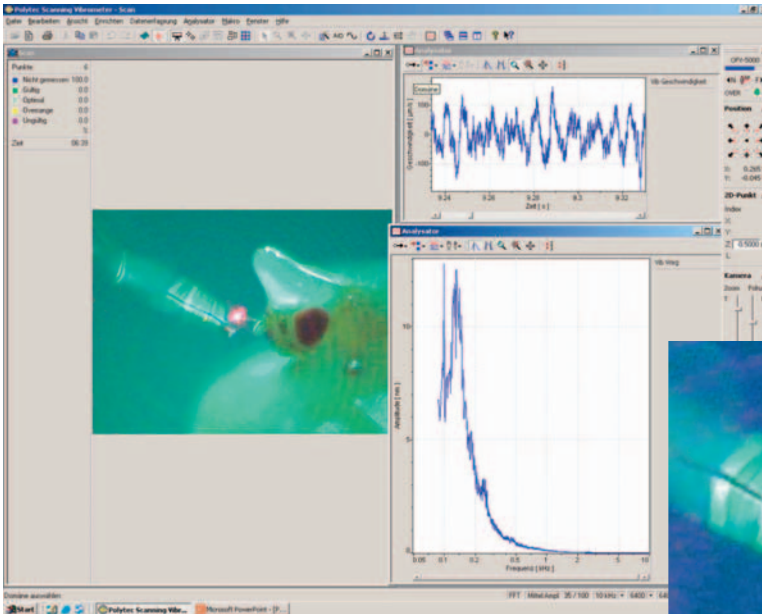


Figure 2: The measurement screen from PSV Software shows the antenna vibration (velocity versus time) in the upper analyzer window; the lower window displays the frequency dependence of the vibration displacement in nanometers

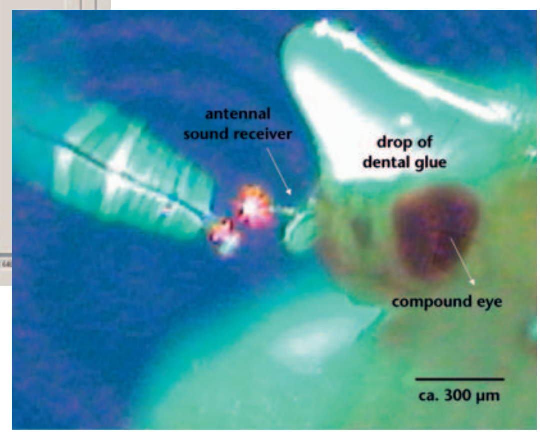


Figure 1: Drosophila head with sound receiver and laser spot focused onto the antenna, as seen by the video camera of the PSV-400 Scanning Vibrometer

Molecular Motors

Recent measurements show that besides ion channels, the sensory cells also house molecular motors that pump mechanical energy into the antennal vibrations providing amplification for weak signals. These motors amplify much like pushing a swing augments its amplitude when the push is in phase with the motion. The energy required for this amplification is very small. Fluctuation analysis based on laser vibrometric measurements shows that the motors lift the Brownian motion of the antenna by an average 20 zepto Joules (20×10^{-21} Joules).
This is twenty times less than the energy of a single green photon!

Conclusion

The PSV-400 Scanning Vibrometer enables non-contact measurements of mechanical vibrations even on delicate biological objects. The vibrational characteristics of the antennal sound receiver of the Drosophila fruit fly could be systematically analyzed. The high sensitivity of the method allows for a deep insight into the cellular and molecular processes behind.

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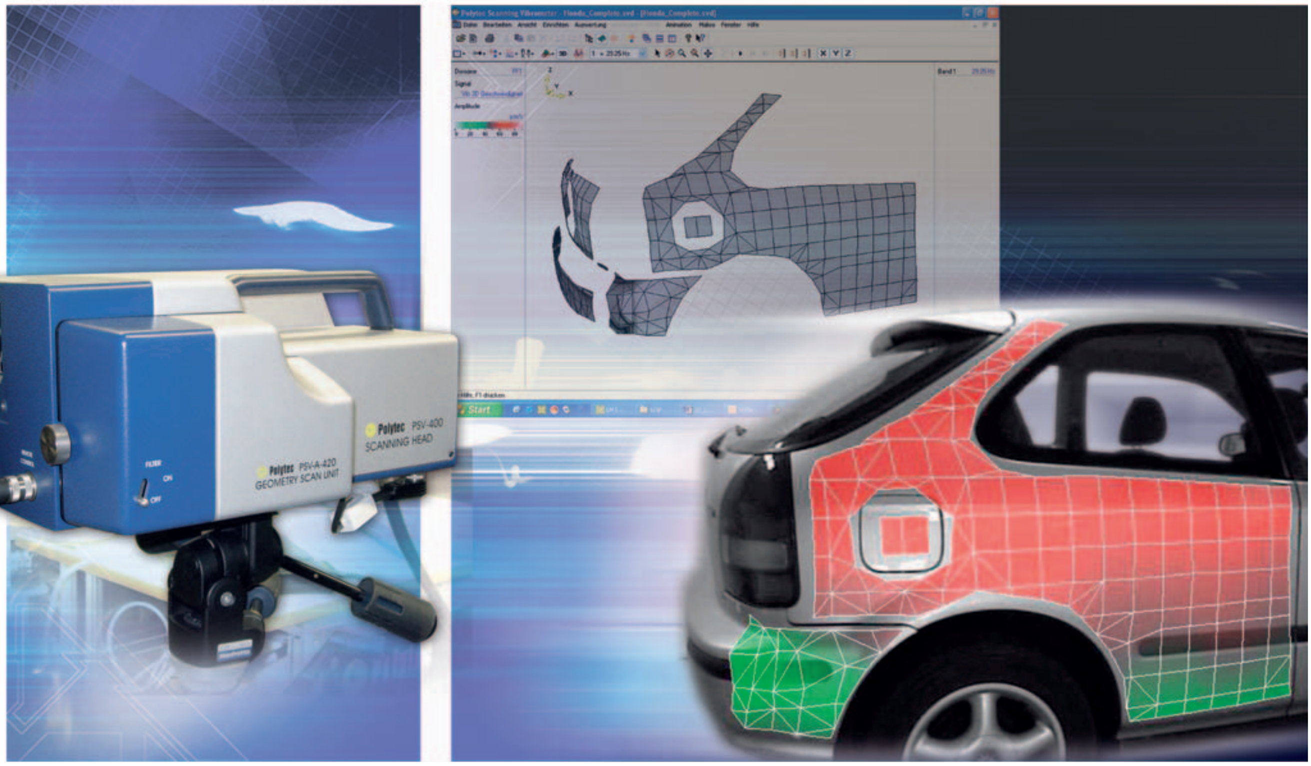
About the Project

The research project "Active auditory mechanics in insects" is currently underway at the zoological institute of the University in Köln, Germany and is funded by the German Foundation VolkswagenStiftung. Exploiting specific advantages provided by the ears of Drosophila and mosquitoes and combining biophysical, neurobiological, and genetic approaches, the mechanisms that bring about mechanical amplification are investigated on the systemic (auditory performance), cellular (motility of mechanosensory neurons), and molecular (transduction and motor machineries) levels. The highly interdisciplinary project features a unusual combination of biomechanics, acoustics and genetics.

http://www.uni-koeln.de/math-nat-fak/zoologie/tierphysiologie/goepfert

Achieve Even More *with the PSV-400*



Measurements with the PSV-400 become even easier, more effective and more versatile with the right accessories and powerful software tools. Find up-to-date information at ***www.polytec.com/usa/psv400***

Small Objects Can Appear Big

Using the PSV-400 Scanning Vibrometer to measure millimeter-sized structures and objects is no problem with the PSV-A-410 close-up unit. As seen in the picture, it is simply mounted in front of the laser and camera optics of the PSV-400 sensor head and can be adjusted to different working distances with various lenses. Block filters to reduce backscatter intensity and a ring light for illumination are helpful options. For example, a 1 mm x 1 mm sample can be measured from a 160 mm working distance using a micro-scan lens.

For convenient vertical positioning of the sensor head, the precision, motor-actuated, PSV-A-T18 vertical test stand is recommended.

Acquire Spatial Coordinates Quickly: PSV-A-420 Geometry Scan Unit

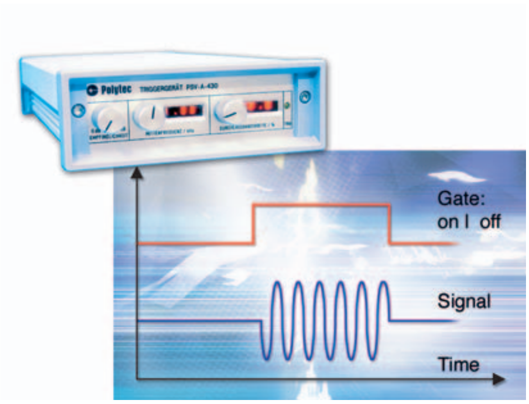
The PSV-400 system is now able to experimentally measure the geometry of test objects in terms of X, Y and Z coordinates. The standard PSV sensor head views the world of vibrating objects with a video camera in two dimensions. More realistic results are attained with the PSV-A-420 geometry scan unit sampling the test object and displaying a 3-D image. This advance makes the every day work with the PSV system considerably more efficient and has already proven itself extremely valuable.

The geometry scan unit is mounted on the side of the PSV-400 sensor head. Incorporating a laser range finder with the sensor head scan mirrors allows the acquisition of the three dimensional geometry of the object. The measurement grid generated for vibration measurement is sampled, the data for the X, Y and Z direction is measured and saved. This data forms the baseline geometry for displaying and for comparing to the deflection shapes measured with the Polytec Scanning Vibrometer.

The vibration information is superimposed on the 3-D measurement grid and can be animated.

If you export the data in UFF format, the 3-D geometry data can also be used in downstream programs, for example in modal analysis software.

The responsible Regional Sales Manager can give more details and advice or demonstrate a geometry scan with subsequent vibration measurement on a user supplied test object.



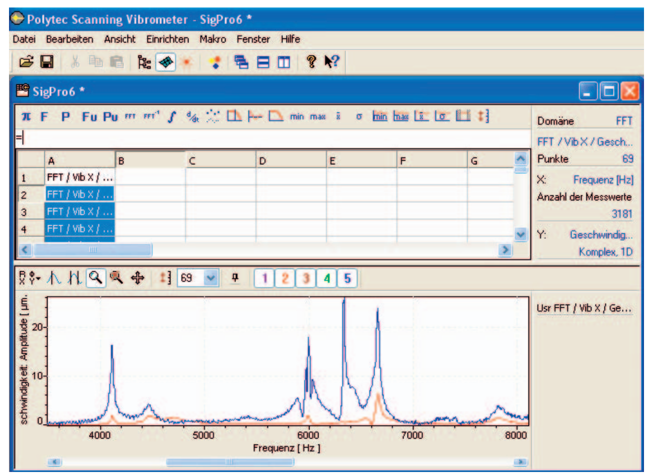
Electronic Watchdog for Measurements: PSV-A-430 Acoustic Gate Unit

Only make measurements when there is something to measure. The PSV-A-430 Acoustic Gate Unit waits for an acoustic signal in a predefined frequency and amplitude range and does not start taking measurements with the PSV-400 until triggered. If the signal disappears, the measurement is interrupted until the signal comes again. This function is particularly helpful when examining events that are difficult to reproduce, such as spontaneously squealing of disc brakes.

Analyzing and Processing Measurement Data by "Drag & Drop": The Polytec Signal Processor

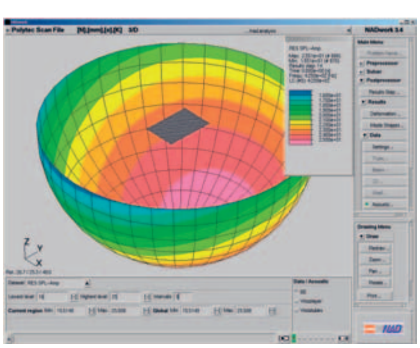
As already described in issue 2/2004, the current version of the PSV software has a whole range of new user-friendly functions. A review of the Polytec signal processor follows in great detail. It opens up the mathematical functions library of the PSV software in the simplest way.

The signal processor was designed as an easy-to-operate table calculation tool similar to MS Excel, It can be used to collate measurement data from different sources by a simple "drag & drop" technique. Present several measurement series in a diagram, calculate the differences, or apply a different mathematical function: basic arithmetic operations, FFT, inverse FFT, digital filters, limitations, integration, differentiation, resampling or statistical evaluation. These operations can be applied to all the scan data; the results can be included in the source file as User Defined Data Sets (UDDS) and be animated and saved there.



Acoustic Measurement Simulation: NADwork® Polytec® Connection

For more than 30 years now, the Finite Element Method (FEM) and Boundary Element Method (BEM) have been used successfully.Today they represent the state of the art for computer-supported prototype development. Properties of new products can be identified quickly and efficiently. FEM and BEM with NADwork® Simulation Suite make up the logical progression from CAD to Computer Aided Engineering (CAE): Constructing with CAD products, calculating the product properties in advance with NADwork® Simulation Suite.

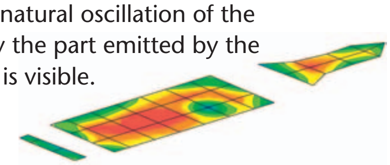


NAD and Polytec have common customers, who, for example, verify FEM and BEM acoustic simulations using Laser Scanning Vibrometers. The product NADwork® Polytec® Connection was developed as an interface which can be used to directly compare simulated FRF's with measured FRF's in the same display window. NADwork® Polytec® Connection thereby directly accesses the Polytec Scanning Vibrometer files. Above and beyond that, the "Advanced" version can automatically make emittance calculations on the basis of structure-borne noise measurement using the Polytec Laser Scanning Vibrometer. Find more info on this product on **www.NADwork.at/pdf/infos/polytec_eng.pdf**.

The automobile industry is repeatedly faced with the problem of characterizing the emittance behavior of individual components in hot exhaust systems. The solution has been found in a measurement simulation with NAD and Polytec.

Using the Polytec Scanning Vibrometer, the structure-borne noise from the component being examined is initially acquired and the noise-emittance calculation is made using NADwork® Polytec® Connection. The example image below shows the distribution of the noise energy intensity on the surface of the converter.

Another example is the development of loudspeaker systems. The question as to how much of the total emitted noise comes from housing vibration can not be answered by measurement or simulation alone. For this reason, the Polytec Scanning Vibrometer is used again to acquire the structure-borne noise from the housing. Then the noise-emittance calculation is made using NADwork® Polytec® Connection. The image (left) shows the sound pressure level on a hemisphere in the proximity of the lowest natural oscillation of the housing. Only the part emitted by the housing itself is visible.



Team Up – *Meet Polytec Worldwide*

North American Tradeshows

Polytec, Inc. closed out 2004 with three important tradeshows: DiskCon (Santa Clara, CA), Automotive Testing Expo (Novi, MI) and RD&D (Anaheim, CA). The new PSV-400-3D Three-Dimensional Scanning Vibrometer and MMA-400 Micro-Motion Analyzer were shown to enthusiastic audiences concerned with analysis of macro and micro structures. Also, Polytec introduced the new TMS-300/320 TopCam industrial, scanning white light interferometer, a new product line for North America that monitors "static" surface topography for on-line dimension and tolerance monitoring for improved manufacturing process and quality control.

The new year started with an intense event schedule that included three very important tradeshows: Photonics West MOEMS/MEMS 2005 in San Jose, CA; International Modal Analysis Conference (IMAC) in Orlando, FL and MEMS 2005 in Miami Beach, FL. At a Polytec-hosted IMAC reception, the new Geometry Scan Unit was demonstrated with the PSV-400-3D.

Interested attendees exceeded 100 IMAC participants. Of singular importance at MEMS 2005 was the introduction of the innovative MSA-400 Micro System Analyzer (see page 4) to the international research and development community.

2004 North American Vibrometer Users Meeting

On October 25 – 26, Polytec, Inc. hosted a two-day Vibrometer Users Meeting in Birmingham, Michigan, a suburb of Detroit. This annual meeting brought over 60 engineers together to discuss vibrometer applications, listen to invited speakers and learn about the newest Polytec Vibrometer technology. Participants covered applications and solutions to problems in the automotive, defense, aerospace and MEMS markets.
Nine invited talks addressed new applications of vibrometry including "NVH Analysis of Driveline Components Using laser Vibrometry" by Bob Lytkowski, Veri-Tek and "Testing Micro-Drillers for Next NASA Mars Mission" by Prof. Hanagud, Georgia Tech.

Some of these presentations can be reviewed at **www.PolytecUsers.com**.

In addition to the invited speakers, a Polytec member gave a detailed introduction to the new PSV-400-3D Three-dimensional Scanning Vibrometer.
A hands-on product workshop completed the Users Meeting, allowing participants to try Polytec's newest products.

The 2005 Users Meeting is already scheduled for September 21– 23.

"Successful Solutions to Challenges of Vibration Measurement"

8th German Vibrometer Seminar at Polytec Headquarters

Theory and practical applications of vibrometry were the focus of the Vibrometer Seminar on Oct 27 to 28 in Waldbronn, which attracted about 70 vibrometry users from all over Germany and featured sophisticated application reports on successful solutions to challenges of vibration measurement.

Twelve invited presentations covered a broad range of vibrometry applications, from acoustics, production testing, medical diagnostics and metrology to structural and failure analysis. Polytec engineers followed the presentations with live demonstrations, examples of macro programming in PSV and VibSoft Software, and suggested applications of the new Polytec signal processor. A final discussion gave an opportunity for the users to communicate their needs and wishes to the Polytec staff. We thank the participants for this invaluable information.

"The Whole World of Measurement Technology"

MeasComp 2004 in Wiesbaden, Germany

The leading German tradeshow for test and measurement instrumentation, MeasComp drew 230 exhibitors and over 6000 visitors in Sept 2004. Automotive and production test engineers and scientists came to the Polytec booth to learn more about products for non-contact measurement of vibration, length, speed and surface topography.
Of particular interest was the PSV-400 Scanning Vibrometer with integrated Geometry Scan Unit which had its world premiere at the show.

"A Very Successfull Event"

Polytec Yokohama: Grand Opening Seminar

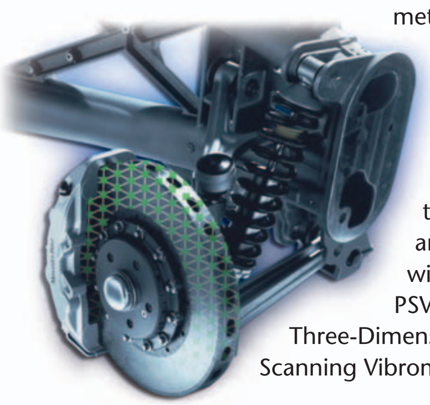
Polytec K.K. was incorporated during the summer and soon thereafter established at facilities in the German Centre for Industry and Trade in Hakusan High Tech Park in the city of Yokohama. To help celebrate this unique event, a Grand Opening Day was held on October 1st with the participation of scientists and engineers from leading companies serving the automotive, data storage, micro technology, civil engineering and industrial engineering markets. The celebration began with the management team of Polytec GmbH giving personal statements to commemorate the event. The second part of the day focused entirely on products and applications. The highlight was the demonstration of the PSV-400-3D Three-Dimensional Scanning Vibrometer and it's inherent promise of unique

measurement capability, providing not only scanning but a new level of precision, accuracy and fidelity for 3-D vibration measurements. The Grand Opening Day was a very successful event that provided a unique way to inaugurate Polytec K.K. (**www.polytec.co.jp**) and to introduce itself to customers.

Automotive Development in India

SIAT 2005 – SAE Conference

The biannual SAE conference on Automotive Technology held in Pune highlighted current developments and tends in international automotive design. It was also an excellent opportunity for Techscience Services Pvt. Ltd., Chennai to showcase the latest Polytec Vibrometers at the companion SIAT expo.



Non contact modal analysis with the PSV-400-3D Three-Dimensional Scanning Vibrometer

equipped with the Geometry Scan Unit was introduced with the SAE paper "A New Tool for Three Dimensional Non-contact Vibration Measurements in Automotive Applications."

The conference was hosted by the Automotive Research Association of India (**www.araiindia.com**), the center of research and development in one of the fastest growing automotive markets in the world. ARAI just recently expanded their capabilities in NVH by purchasing a new PSV-400 Scanning Vibrometer.

ARAI and Polytec took the opportunity to offer a workshop on Scanning Vibrometry for modal analysis right after the SIAT conference.

Polytec in Far East

Laser Vibrometry Seminars in Taiwan and Korea

The first ever Vibrometry Seminar in Taiwan was held on Sept 23, 2004 in Taipei and focused on semiconductors and data storage applications. On the following day in Taichung a second seminar focused strictly on automotive applications.
Both events were very well organized by our representative Samwells (**www.samwells.com**) and attracted about 40 participants each, predominantly from industry.

The 2nd Korean Vibrometry Seminar took place in Taechong City on Oct 5, 2004. It was arranged by our new representative HYSEN Corp. (**www.vibrometry.co.kr**) and featured high level presentations and demonstrations of all new Polytec products. A comprehensive CD-ROM covering the seminar was handed out to the 25 participants.

Polytec

Trade Fairs *and Events*

Experience *"Advancing Measurements by Light"* and Meet Polytec at the Following Events and Trade Fairs!

Apr 19 – 21, 2005	Quality Expo	Chicago, IL, USA	www.quality-expo.com
Apr 26 – 27, 2005	IOMAC	Copenhagen, Denmark	www.iomac.dk
May 09 – 12, 2005	AISTech 2005	Charlotte, NC, USA	www.aist.org/convexpo/2005_aistech.htm
May 16 – 19, 2005	SAE Noise and Vibration	Detroit, MI, USA	www.sae.org/events/nvc
May 18 – 19, 2005	MEMS Workstation and Tools Seminar	Dallas, TX, USA	www.polytecusers.com/seminar1.html
May 31 – June 02, 2005	Automotive Testing Expo Europe	Stuttgart, Germany	www.testing-expo.com
June 01 – 03, 2005	DTIP 2005	Montreux, Switzerland	tima.imag.fr/conferences/dtip
June 07 – 08, 2005	Information Storage Week	Tokyo, Japan	www.idema.gr.jp/isw2005
June 13 – 16, 2005	Laser 2005	Munich, Germany	www.laser.de
June 29 – 30, 2005	MEMS Workstation Seminar	Boston, MA, USA	www.polytecusers.com
July 11 – 14, 2005	12 ICSV International Conference	Lisbon, Portugal	www.icsv12.ist.utl.pt
July 12 – 14, 2005	SEMICON West	San Francisco, CA, USA	www.semi.org
July 23 – 28, 2005	Mechanics of Hearing	Portland, OR, USA	www.ohsu.edu/hearingmechanics
Aug 10 – 11, 2005	MEMS Workstation Seminar	Detroit, MA, USA	www.polytecusers.com
Aug 29 – Sept 02, 2005	Forum Acusticum Budapest	Budapest, Hungary	www.fa2005.org
Sept 20 – 21, 2005	MEMS Workstation Seminar	San Jose, CA, USA	www.polytecusers.com
Sept 21 – 23, 2005	US Vibrometer Users Meeting	Santa Clara, CA, USA	www.polytecusers.com
Sept 22 – 23, 2005	Diskcon 2005	San Jose, CA, USA	www.idema.org
Oct 05 – 06, 2005	Japan Modal Analysis Conference	Tokyo, Japan	www.mech.chuo-u.ac.jp/~toilab/JMAC/
Oct 26 – 28, 2005	Automotive Testing Expo US	Detroit, MI, USA	www.testing-expo.com/usa
Nov 08 – 10, 2005	Aerospace Testing Expo US	Long Beach, CA, USA	www.aerospacetesting-expo.com
Nov 09 – 11, 2005	Micromachine 2005	Tokyo, Japan	www.micromachine.jp/en

Reference the web for the most up-to-date information on trade fairs and events!

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What is missing? ______

Suggestions for improvements: ______

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For all other regions please refer to the list of Polytec representatives on the reverse side.