

## NATURE AND TECHNOLOGY: VIBRATIONS EVERYWHERE!

*Polytec's Vibrometers are Indispensable Tools to Investigate Natural Dynamic Processes and to Optimize Parts and Goods.*

The heart beats, wings flap, sounds are sent out and received – life would be much too quiet without vibrations. To investigate vibrating systems in nature requires sensitive and flexible measurements that don't disturb the specimen. Originally developed to characterize manmade products, technology and systems, non-contact Laser-Doppler Vibrometry is now exploring measurements that unravel the mysteries of biological structures.

In this issue discover how complex biomechanical processes in the middle and inner ear can be elucidated by Polytec vibrometers (pages 5, 8 and 11). Another biological application involving insects is highlighted on page 14 with the research on vibration-based communications in a beehive. Besides looking at bio-structures, the PSV Scanning Vibrometer can help maintain our health by optimizing dental ultrasonics (page 16) and other medical devices.

There are numerous other research applications in mechanical and civil engineering. For example, please find an article about the Rotational Vibrometer applied to engine development (page 18), and a companion tutorial about measurement of rotational vibrations. All this and much more are included in this edition.

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**EDITORIAL**



**Michael Frech**

Dear Reader,  
At one of our recent seminars, the participants asked the speaker which objects he would investigate with his vibrometers. He replied: "Anything that hasn't taken to the trees on the count of three!"



**Dr. Helmut Selbach**

We'd like to add that even on moving objects the speaker would have a sporting chance. Laser vibrometry is easily adapted to difficult measurement tasks and can record data even when the object is distant, delicate, rotating or very hot.

Polytec's non contact vibration measurement technology can solve problems in many different markets including automotive, aerospace, industrial production, data storage and micro systems (MEMS). In these core markets our vibrometers help to improve the quality of products and processes.

Recently, the technology comprising our MSA-400 Micro Structure Analyzer received the 2005 Sensor Award for Innovation – a valuable acknowledgment of Polytec's exceptional, application-related research and development activity in the field of light-based sensor technology.

Besides our core markets mentioned above, there are many more fields of application. In this issue, we have assembled interesting articles that apply Polytec technology to biology, medical research and mechanical engineering.

Have fun reading!

**Michael Frech**  
Vice President  
Laser Measurement Systems

**Dr. Helmut Selbach**  
Managing Director Polytec GmbH

## New Polytec US Midwest Office and Representatives

Polytec is continuously improving its worldwide sales network. With a third US office just opened in Ann Arbor, MI, Polytec is ready to expand its support for the automotive industry. Also, new local representatives have been chosen in Israel, South Africa, Norway, and, for the Laser Surface Velocimeter product line, in the Peoples Republic of China. Please see back page and inside of the tear-off form for a complete list of our world-wide offices and representatives or visit [www.polytec.com](http://www.polytec.com).

## New Corporate Video on Vibrometers

Advancing Measurements by Light – Just what does this slogan really mean? How does a laser vibrometer work? What are the features and benefits of the technology?

Now you can get answers to these questions with a short video journey into vibration measurement and Polytec's innovative solutions. Please find the new Polytec video on the CD attached to this issue, or view or download it at [www.polytec.com](http://www.polytec.com)



## Polytec Wins Sensor Award 2005



The AMA Fachverband für Sensorik e.V. sponsors the Sensor Innovation Award for extraordinary applied research and development in the field of sensor and measurement technology. Its intention is to highlight outstanding R&D projects which have a promising market potential. Recently, at the Sensor+Test 2005 tradeshow in Nuremberg, the fifth Sensor Innovation Award was given to Polytec for developing the innovative MSA-400 Micro System

Analyzer. The MSA-400 is a unique all-in-one instrument for quick and precise 3-D dynamic measurements on MEMS devices (see page 4). It greatly enhances efficient development and cost-effective manufacturing of reliable micro systems.



# Polytec *Partners*



## ANOVIS Makes Full Use of the Laser Vibrometer Bandwidth

The MEDAV group of companies concentrates on innovative signal analysis and classification methods for measurement data taken from different industrial applications. For more than 10 years, MEDAV's employees have been working on End of Line (EoL) testing of gearboxes and engines. Their consistently high level of performance has established their position as one of the leading suppliers of intelligent monitoring systems.

Signal analysis covers a wide range of processes used to identify decision-relevant information in the recorded data. In MEDAV applications such as combustion engine or crack testing, wide signal bandwidths are often necessary.

This is one good reason why MEDAV relies on laser vibrometry by Polytec. MEDAV solutions make full use of the laser vibrometer bandwidth to optimally fulfill the most important requirements from the EoL environment: Failsafe fault identification.

The Acoustic Noise and Vibration Signal Analyzer (ANOVIS) from MEDAV supports a direct connection to laser vibrometers under production conditions. On the ANOVIS platform, MEDAV offers Black Box systems for test bench operation, analyzers for the QC/QA laboratory as well as a mobile system for vehicle measurements.

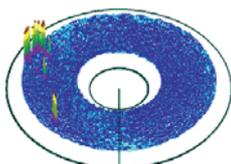
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## THÔT/Polytec Photonic Force Microscope Enables Picometer Measurements

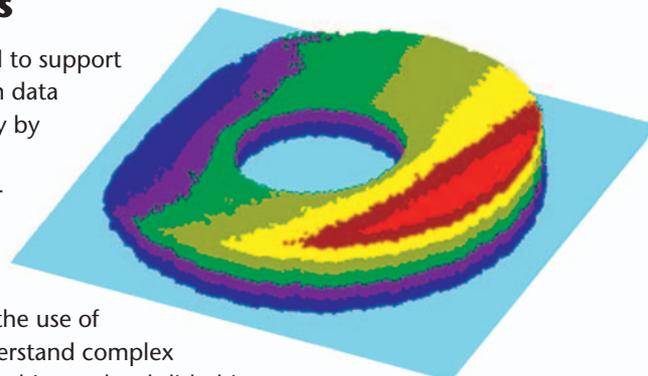
THÔT manufactures optical media inspection and measurement equipment to monitor vibrations at the atomic level for the data storage and semiconductor industry. THÔT testers use Polytec's vibrometer technology for automated production, process control, process development and R & D applications. These test systems provide state-of-the-art measurements that can be adapted to a specific customer's need.

With a total system noise floor below 2 pm and phase differential detection of 0.6 pm, THÔT's new LDV based Photonic Force Microscope (PFM) provides the picometer



resolution required to support further advances in data storage technology by characterizing the head/media mechanical interface.

To learn more about THÔT Technologies and the use of vibrometry to understand complex mechanical relationships on hard disk drives, please read THÔT's article featured in the LM INFO Special issue 2/2004 found in PDF format at [www.polytec.com/usa/LM-INFO](http://www.polytec.com/usa/LM-INFO) or visit [www.thot-tech.com](http://www.thot-tech.com).



# Characterization of Micro Systems



## 3-D Topography Measurement is Now Available for the MSA-400 Micro System Analyzer

*In addition to its unique capability to measure MEMS and microsystem dynamics, Polytec's MSA-400 Micro System Analyzer can now perform high resolution topography measurement on MEMS and micro-components.*

### The All-in-One Optical Instrument for Measuring MEMS Dynamics and Topography

The award-winning MSA-400 Micro System Analyzer uses light for non contact measurement of three-dimensional motions in microstructures. Equipped with internal, precision microscope optics, the MSA-400 combines scanning laser Doppler vibrometry to measure out-of-plane vibrations orthogonal to the component's surface with stroboscopic video microscopy to capture in-plane displacement parallel to the component's surface. Taken together, these techniques allow fast and complete dynamic characterization of microstructures.

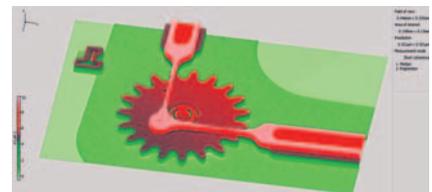
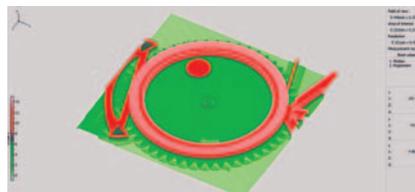
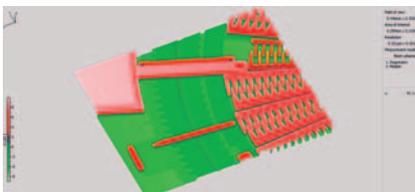
In addition, static 3-D topography measurements can now be made using white light interferometry to determine structure heights and shape on both rough and specular surfaces. This is also a non-contact measurement procedure, free from any impact, feedback or surface preparation to the sample.

The MSA-400 Micro System Analyzer is the ideal MEMS measurement technology for determining the essential static parameters – profile, shape, critical dimensions and roughness – as well as dynamic parameters – resonance frequencies, deflection shapes, damping, settling response and decay time. The MSA-400 is designed to mount to popular MEMS probe sta-

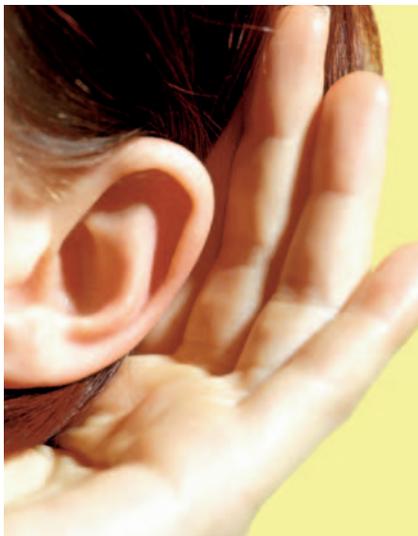
- All-In-One-instrument for measuring both dynamic response and static topography of MEMS
- Rapid, non-contact measurement procedure
- Sub-nanometer resolution
- Rough and specular surface compatibility

tions and is suitable for both laboratory R&D measurements and production line, quality control applications.

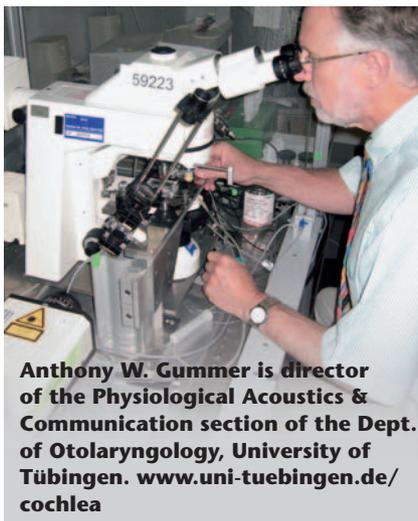
Please visit [www.polytec.com/usa/microsystems](http://www.polytec.com/usa/microsystems) for detailed information or contact our product specialists and regional sales managers to arrange a complete demonstration.



# We Can “See” How the Patient Hears



## Interview with Professor Anthony W. Gummer about the Use of Laser Vibrometers for Hearing Research and Clinical Diagnostics



**Anthony W. Gummer is director of the Physiological Acoustics & Communication section of the Dept. of Otolaryngology, University of Tübingen. [www.uni-tuebingen.de/cochlea](http://www.uni-tuebingen.de/cochlea)**

*Professor Gummer, how has Laser-Doppler-Vibrometry (LDV) found its way in to hearing research and diagnostics?*

The first experimental vibration measurements on the eardrum were in the seventies and eighties. Some years later, the LDV started to provide insight into the micromechanics of the inner ear with an article by Nuttall et al in 1991. Since the nineties, the application of LDV in clinical diagnostics has been continuously reviewed. At that time, the experimental setup was cumbersome

and the measurement time prohibitively long. In 1995, our research group succeeded in combining a highly sensitive Polytec vibrometer with all other components to produce a so-called Laser Audiometer that provides full diagnostics within a couple of seconds.

*Which pathologies can be diagnosed by LDV measurements, and which are the regions of the ear that can be accessed via eardrum measurements?*

Measurements on the eardrum can be used to diagnose pathologies of the middle ear, such as luxations of the ossicles, otosclerosis or dysfunctions of middle-ear implants and prostheses. It also allows us to investigate the micro-mechanical function of the inner ear. The active amplification process inside the cochlea, which generates an oto-acoustic emission, can be assessed non-invasively by the highly sensitive single-point vibrometer as a vibration of the ear drum. We can “see” how well or poorly the patient hears. This could have important applications in screening infants for dysfunctional hearing.

*Can you outline the advantages of LDV compared to other methods?*

I just mentioned the benefits to clinical diagnostics. Regarding our fundamental research on biophysical processes in the cochlea, there is no other measurement technology providing appropriate sensitivity and a resolution below 1 pm.

*What are the clinical practice requirements for a LDV-based diagnostic device?*

The system must be simple to operate by a technical assistant, the measurement time short so as not to unnecessarily inconvenience the patient, and the laser power must be below 1 mW, as in the case of Polytec vibrometers.

*How would you rate the performance of the current Polytec product line?*

We are extremely satisfied with the capability of Polytec’s single-point vibrometers. The depth-of-field is in the  $\mu\text{m}$  range, enabling well-focused high-resolution measurements. Our current experimental setup for the investigation of hair cells involves an OFV-505 Sensor Head and our newly developed AFM cantilever and has a 100-fold better sensitivity than the previous combination (see article on page 8).

# I Can Hear *the Grass Grow...*

*Laser vibrometry can answer many questions: How do ears work? How do insects communicate? Where Is the vibration source?*



*In our world, vibrations are everywhere. Did you know about honeycomb vibrations, silo honking, bridge resonance failure and remote voice detection? Read on to learn more about vibrations in nature and in man-made products and processes. Discover how these vibrations are detected and studied using laser vibrometry.*

*To download previous issues of the LM INFO Special quoted in this article, please visit [www.polytec.com/usa/LM-INFO](http://www.polytec.com/usa/LM-INFO)*



## Biology

For every living species on our planet there are corresponding biological applications of laser vibrometry. One of the most prominent is insect communication. Some insect sounds are quite loud, such as the singing of the cicada; while others are supersonic and can't be heard. Some insects are so small that their songs are transmitted mainly through a plant rather than air. Entomologists can use vibrometers to record this unheard noise for later study. Consider honeycomb vibrations in beehives; these signals can only be measured with highly sophisticated equipment (see page 14).

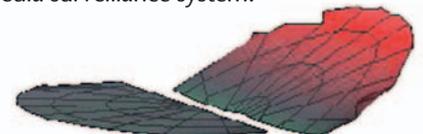
Other bio applications include measuring communication between elephants, fruit ripeness, spider web motion, and the hearing mechanism in frogs and fruit flies (see issue 1/2005, page 18).

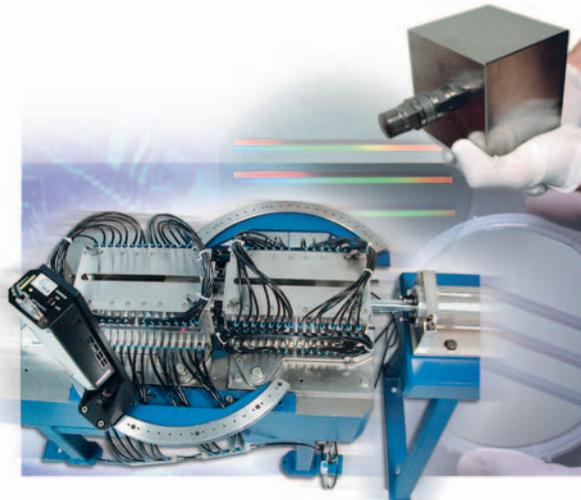
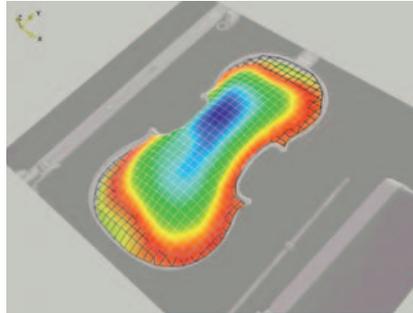
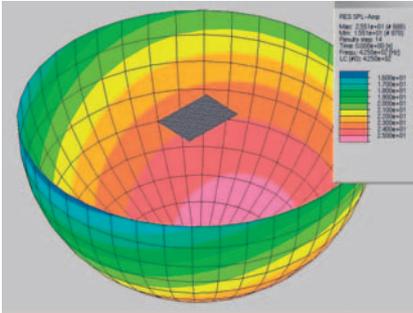


## Medical and Health Care

In this issue you will learn how laser vibrometry can assist with eardrum diagnostics and research on the middle and inner ear. In addition, vibrometers have been used for vibration measurements on artificial heart valves, mechanical properties of tendons, analysis of vibrations while bone drilling or medical laser ablation, and detection of bone crack propagation. Medical, safety and health care devices like tooth brushes,

dental scalers (see page 16) and respirators have been investigated using Polytec vibrometers. The vibrometer can also function as a non-contact polygraph by measuring muscle vibrations, or as a remote voice detector as a part of a multi-media surveillance system.





## Acoustics

Musical instruments generate wonderful, inspiring sounds through their vibrations. Polytec vibrometers can help us understand how this happens with early work already done on violins, cembalos and dulcimers. Vibrometers are also indispensable tools for loud-speaker design, identifying diaphragm resonances that are deleterious to the sound quality. Vibrometer measurements provide an experimental basis for sophisticated acoustic investigations like structural-acoustic response (sound field) predictions, acoustic imaging and anti-sound research. Acoustics are also increasingly im-

portant in product design. The focus is on how and where are undesired noises generated and at which point or location can countermeasures be taken. Please read the article about the joint project between Polytec and HEAD acoustics on "Binaural Transfer Path Analysis" (See issue 1/2004, page 10).



## Metrology and Calibration

Primary calibration of vibration and shock sensors by laser Interferometry has the unique advantage that measurements of surface acceleration, velocity or displacement are made with a precision that is traceable directly to the wavelength of laser light (see issue 1/2003, page 8). Also, laser vibrometric velocity measurements offer the possibility to perform traceable impulse calibrations of transducers subjected to known impulse loads (see issue 1/2004, page 16).

## Industrial Research

There are many areas of industrial research where vibration issues are encountered. In the automotive and aerospace industry there are undesired vibrations of parts and bodies that must be eliminated.

Laser vibrometry gives the opportunity to optimize dynamic automotive FE models by matching the parameters derived from vibration measurements on prototypes to the FE model. Similarly, for small moving or vibrating components in electronic circuits, data storage devices, and microelectromechanical systems (MEMS), FE model verification is essential for rapid cost effective micro component designs. See issue 1/2004 for automotive applications, issue 2/2004 for data storage applications and issue 1/2005 for MEMS applications.

## Materials Research, Mechanical and Civil Engineering

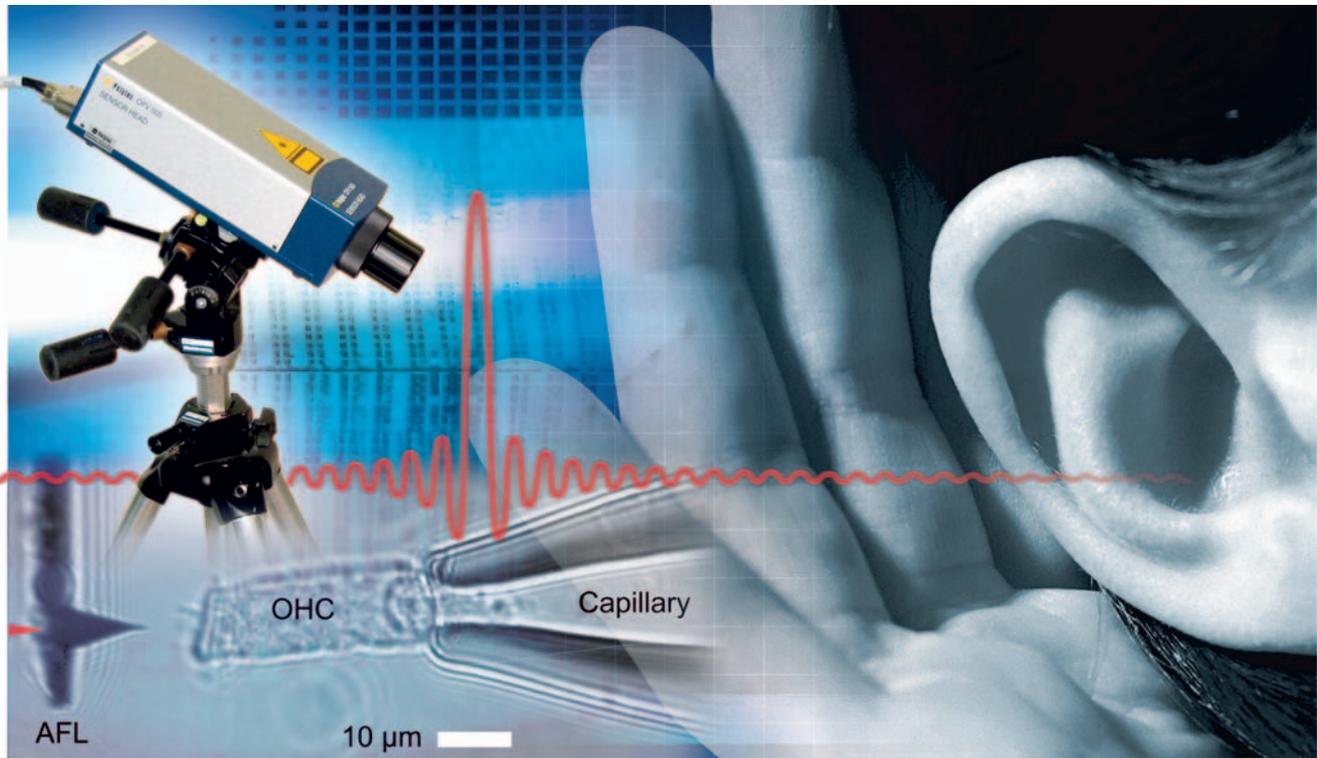
Laser vibrometry is an ideal tool for the measurement of structural dynamics and for non-destructive flaw detection (fracture, delamination, fatigue) in all kinds of materials, parts and components. For instance, we reported on non-linear scanning vibrometry for non-destructive testing (see issue 1/2004, p. 20) and on the investigation of ultrasonic wire bonding (see issue 1/2004, p.18). Regarding buildings and industrial plants, there are many applications for in-the-field structural health monitoring on wind turbines, building vibration and displacement, and cable-stayed bridges to prevent bridge resonance failure. Even curious effects like the loud

"honking" noise (up to 110 dB) that occurred while discharging grain from a silo could be resolved by using a Polytec vibrometer. Geological applications include detection of land mines, rock failures and earthquake-induced defects in concrete.



More interesting applications on [www.polytec.com/usa/research](http://www.polytec.com/usa/research)

# Tiny Sensors – Accurate Ear



## Laser-Doppler Vibrometers Probe the Basic Mechanism of Hearing

*Intensive medical, molecular and biomechanical research activities have provided much insight into the function of signal processing inside the ear. However, we are still far from a comprehensive understanding of the hearing mechanism. Current research work deals with the details of electro-mechanical signal transduction occurring in the cochlea of the inner ear. For the investigation of the inner ear biomechanics, Laser-Doppler Vibrometers have proven to be highly sensitive vibration sensors that don't affect the specimen.*

### Ears and Hearing – Biological Miracles of Signal Processing

Our ears are the most critical sensory organs with regard to interaction with the environment and to communication. They process various spatially resolved signals in real time featuring a remarkable spectral resolution and a tremendous dynamic range. From a biomechanical point of view, the ear is a highly sophisticated acoustic sensor converting sound pressure waves into electrical signals.

There are three sections to the human ear (Figure 1):

- The outer ear (A) includes the auricle, the earlobe and the ear canal.
- The middle ear includes the tympanic membrane or eardrum (B) and the ossicles (C), the three tiny bones of the middle ear known as the malleus, incus, and stapes. These bones transfer the tympanic membrane motion to the inner ear through the oval window.
- The inner ear (D) comprises both the cochlea (the organ of hearing) and the labyrinth or vestibular apparatus (the organ of balance). Inside the cochlea and labyrinth is

a fluid medium and hair cells with their cilia either free-standing in the fluid or in contact with a covering membrane. Moving the fluid or membrane, the cilia are deflected generating nerve impulses.

The perception of acoustic signals depends essentially on how acoustic vibrations are transmitted and converted on their way from the outer ear via the middle ear to the hair cells in the inner ear.

The details of biomechanical signal processing in the cochlea are a current topic of medical research.

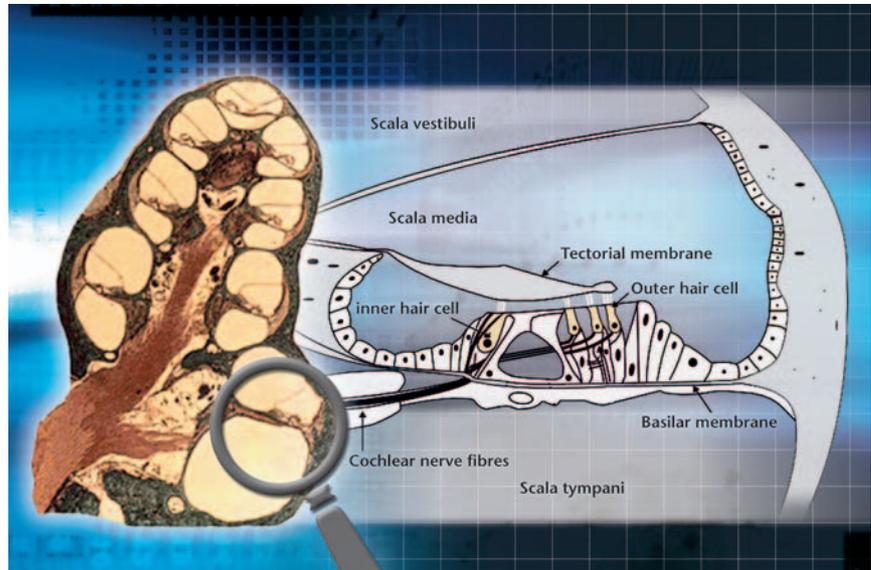
### Structure of the Cochlea

The cochlea is a spiraled, hollow, conical chamber of bone (for a cross-section see Figure 2, left) and consists of three fluid-filled chambers (Figure 2, right). Its core component is the Organ of Corti, the sensory organ which supports the receptors of hearing.

Vibrations transmitted from the stapes to the cochlea generate a wave traveling along the basilar membrane. The basilar membrane separates the scala media and the adjacent scala tympani. A certain sound frequency generates a displacement maximum at a corresponding location on the basilar membrane. The stiffness of the basilar membrane decreases from bottom to top of the cochlea. Thus high frequencies cause a maximal displacement at the base of the basilar membrane while lower frequencies maximally affect more distant positions. The wave propagation inside the cochlea is influenced by active mechanical amplification processes that are responsible for the extraordinary dynamic range and the frequency selectivity of hearing.

### Transduction in the Cochlea

The hair cells are arranged in four rows across the Organ of Corti and along the entire length of the cochlear coil.



**Figure 2: Cross-section of the cochlea (left) and enlarged view of the Organ of Corti with hair cells (right)**

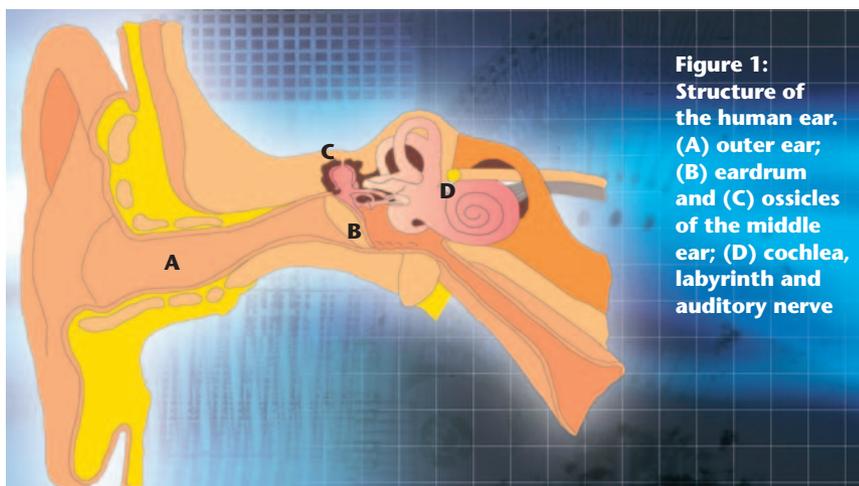
Three rows consist of outer hair cells (OHCs) and one row consists of inner hair cells (IHCs).

- The inner hair cells (IHCs) provide the main neural output of the cochlea and generate nerve impulses from the mechanical vibrations induced by the sound wave.
- The outer hair cells (OHCs), however, are responsible for mechanical amplification within the cochlea. These are the object of current research.

### Electromechanical Transduction in Outer Hair Cells

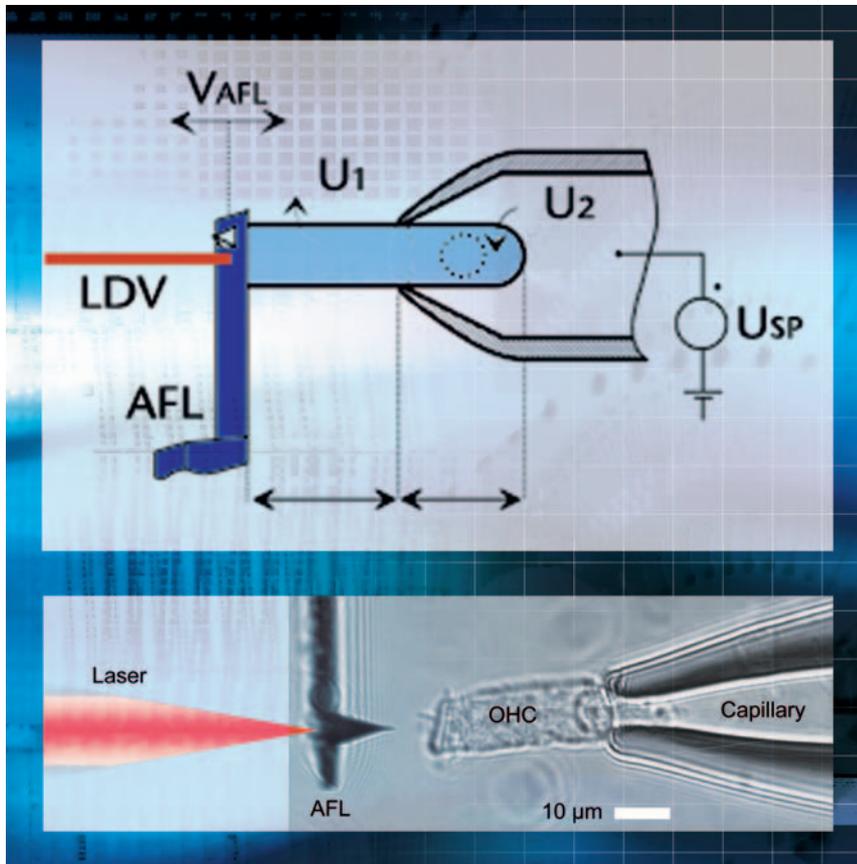
How can the outer hair cells influence the traveling wave?

A change of membrane potential of the outer hair cell (OHC) causes the cell body to contract and elongate. This electrically induced motion, called somatic electromotility, is believed by many researchers to be the basis of the exquisite frequency selectivity, sensitivity and dynamic range of the cochlea. The electromechanical force produced by the cell is thought to counteract damping forces in the cochlea, such as those inherent to the motion of fluids and cells, to produce the extraordinary mechanical tuning of the cochlea. The motor molecule responsible for somatic electromotility is called prestin. There are at least 6,000 of these molecules per square micrometer of cell surface. It is not known how the motion of all these molecules is coupled to the cytoskeleton, to generate the somatic electromotility. The process is exceedingly fast and works up to ultrasonic frequencies. Destruction of this transducer leads to deafness.



**Figure 1: Structure of the human ear. (A) outer ear; (B) eardrum and (C) ossicles of the middle ear; (D) cochlea, labyrinth and auditory nerve**

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**Figure 3: Layout and micro image of the experimental setups for electro-mechanical force (upper) and impedance (lower) measurements of an outer hair cell (OHC)**

The electromechanical transduction process was investigated employing laser Doppler vibrometry together with atomic-force spectroscopy. Using the vibrometer the somatic electromotility was found to follow changes of the membrane potential cycle-for-cycle up to at least 100 kHz. The soma of the OHC turned out to have the necessary molecular machinery to generate electromechanical responses – with little attenuation and time delay – well above the frequency limit of hearing. Since these measurements were completed, an innovative method to measure the mechanical properties of biological structures up to at least 40 kHz has been developed. This technique employs an atomic force cantilever and has general applications outside the area of hearing research;

it is particularly attractive for investigation of biological structures in a fluid. It was also applied to investigate mechanical and cell biological properties of cellular and membranous structures in the cochlea.

#### Dynamical Measurements of an Outer Hair Cell

To investigate the dynamics of the OHC, a portion of the cell is sucked into a glass capillary (Figure 3). For determining electromechanical force, the transmembrane potential of the cell is modified by applying a voltage ( $U_{SP}$ ) to the pipette solution inducing voltage drops,  $U_1$  and  $U_2$ , across those sections of the cell membrane excluded from and contained in the pipette, respectively (Figure 3, upper). The somatic electromechanical force was

determined by placing a high-impedance mechanical load, the reverse side of a lever used in atomic force microscopy (AFL), against the apical end of the cell. The velocity of the AFL,  $V_{AFL}$ , in response to electrical induced force by the excluded section of the cell was measured with the Laser Doppler Vibrometer (LDV) focused on the AFL. The force is then calculated from  $V_{AFL}$  and the known mechanical impedance of the AFL.

To measure the axial impedance of the cell, the tip of an AFL was placed against the apical end of the cell (Figure 3, lower) and a known force applied to the AFL using a magnetic field. The impedance is then computed from the resulting velocity  $V_{AFL}$  measured by the LDV and the known mechanical impedance of the AFL.

Velocity measurements were performed using a contemporary OFV-505 Sensor Head and an OFV-5000 Vibrometer Controller.

#### Results

The experiments show that isolated OHCs can compensate for fluid forces with nearly constant displacement amplitude and phase up to frequencies exceeding their local frequency on the basilar membrane. From this it follows that electromechanical transduction in the OHCs provides the high frequency capabilities that are necessary to amplify the traveling wave within the whole acoustic range.

#### CONTACT

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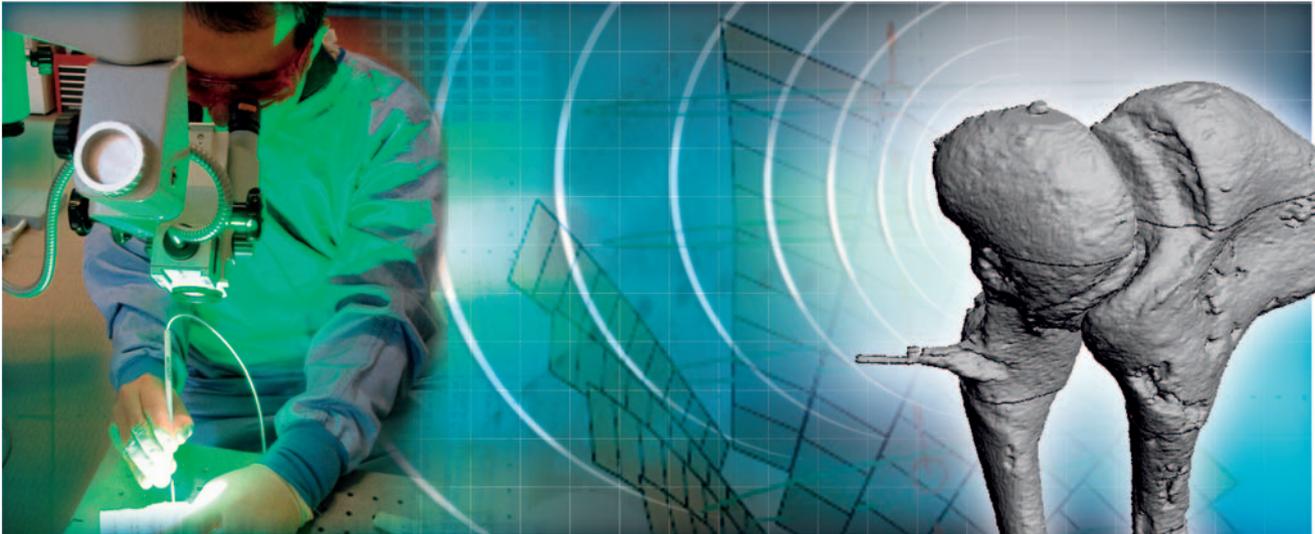
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[www.uni-tuebingen.de/cochlea](http://www.uni-tuebingen.de/cochlea)

Visiting this address you will also find a comprehensive glossary about the structure and function of the inner ear.

# Illuminating *Sound Transmission*



## Motion and Biomechanics of the Human Middle Ear

*Significant advances are being made in our understanding of the structure and functional relationships of normal and pathological middle ears. One reason for the enhanced understanding has been the use of non-contact laser Doppler vibrometers to measure motions of the middle ear both in-vitro (cadaver in laboratory) and in-vivo (patient in operating room).*

### Introduction

In the physiological range, motions of the middle ear are typically less than 100 nm. Thus, accurate measurements with good signal-to-noise in the acoustic hearing range of 20 Hz to 20 kHz are necessary to characterize the response of the human ear, and at higher frequencies for similar measurements on animals.

We are now on the verge of understanding the relationship between human middle ear morphometry, tailored to individual ears, and the biomechanical processes that lead to physiological responses in individual subjects. Yet, despite all of the recent advances, there exists a significant lack of knowledge about the relationship between middle ear structures and sound transmission. The goal of our new study is to make precision measurements that result in a better understanding and model of the middle ear and thus improved middle ear repairs and better

clarity in interpreting otoacoustic emissions that travel from the cochlea through the middle ear and are measured in the ear canal.

### Experimental Approach

The Stanford OtoBiomechanics group uses the approach of deconstructing middle ears of cadaver temporal bones into sub systems that are each characterized through a combination of physiological and morphological measurements as well as three-dimensional mathematical analyses. The subsystems are mathematically reconstructed for comprehensive analyses representing the intact middle ear of each individual. The sub systems are:

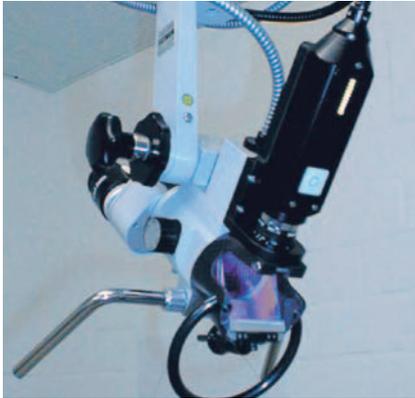
- the tympanic membrane coupled to the ear canal and isolated by removing the incus
- the malleus-incus complex (Figure 1) isolated by dissecting the eardrum and the stapes from the temporal bone
- the isolated stapes footplate

### Measurement Setup

Dynamic measurements using a Polytec HLV-1000 Laser Doppler Vibrometer (Figure 2) are made in order to determine the biomechanical parameters of the morphologically based sub models. Without an eardrum or stapes the malleus-incus complex (Figure 3) cannot be driven with sound.



**Figure 1: Isolated malleus-incus complex (microCT image) without suspensory ligaments.**



**Figure 2: Polytec HLV-1000 Hearing Laser Vibrometer**

A magnet attached to the tip of the malleus is driven by a coil around the tympanic annulus. The magnitude and phase-angle of the velocity are measured at several points on the malleus and incus. Each point is measured from five or more unique angles to allow decomposition into three vector components: in-plane (X,Y) and out-of-plane (Z)).

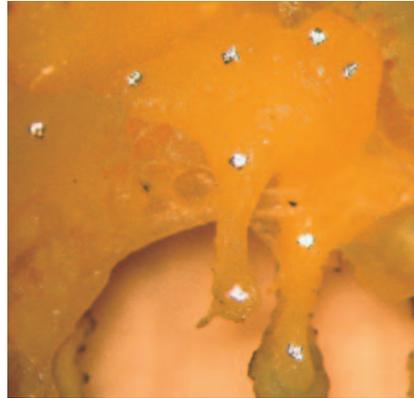
Once a cadaver middle ear preparation is mounted with the medial side facing the laser, two stacked goniometers are used to provide two orthogonal axes of rotation around a common fixed rotation point 17.5 mm above the goniometer. Each goniometer has an angular range of  $\pm 15$  degrees around one-axis, and  $\pm 20$  degrees around the other. Angular resolution is 5 arc minutes. Care is taken to choose an xyz coordinate system which is a body-axis system, that is, fixed in the temporal bone and rotated with it. Alignment of the y-axis should be along the incus handle with the x-axis in the plane of eardrum. The z-axis is along the laser measurement direction.

### Geometry Model

components of velocity are related as follows:

$$v_i = -\sin(\beta_i)v_x + \sin(\alpha_i)\cos(\beta_i)v_y + \cos(\alpha_i)\cos(\beta_i)v_z$$

The relation between measured velocities and xyz components of velocity



**Figure 3: Preparation of the middle ear ossicles, with reflective material**

can be compactly expressed in matrix form as:

$$\mathbf{v}_m = \mathbf{A} \cdot \mathbf{v}$$

where  $\mathbf{v}$  is a vector with calculated xyz components,  $\mathbf{v}_m$  is the measured velocity and  $\mathbf{A}$  is the matrix determined from the measurement angles. The method of least squares is used to calculate  $\mathbf{v}$ . For each sub system and for the intact middle ear, high resolution micro-CT images are used to describe individual temporal bone ears. The micro-CT images are segmented and combined to obtain three-dimensional volume reconstructions of the ear canal, eardrum, ossicles, ligaments and tendons, which are further analyzed to obtain the desired morphometry.

### Mathematical Model

A mathematical model is formulated, incorporating anatomical features of the eardrum, including its angular placement in the ear canal, conical shape and its highly organized circumferential and radial fiber layers. The dynamic motion of the ossicular chain is modeled by methods of the multi-body system:

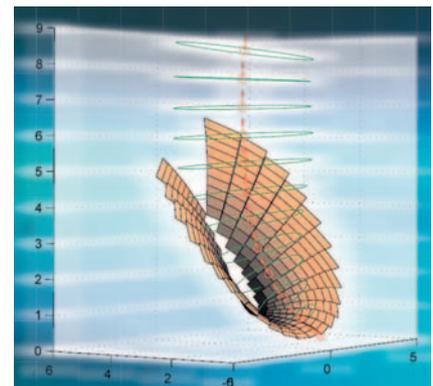
$$\mathbf{M}\ddot{\mathbf{x}}(t) + \mathbf{C}\dot{\mathbf{x}}(t) + \mathbf{K}\mathbf{x}(t) = \mathbf{F}(t),$$

where the vector  $\mathbf{x}(t)$  denotes the displacement at time  $t$ , and the vectors  $\dot{\mathbf{x}}(t)$  and  $\ddot{\mathbf{x}}(t)$  are the corresponding velocity and acceleration. The force vector  $\mathbf{F}(t)$  is the force generated by the

magnet/coil system. The mass matrix  $\mathbf{M}$ , the damping matrix  $\mathbf{C}$ , and the stiffness matrix  $\mathbf{K}$  are obtained from the basic relations from the methods for linear systems. The challenge in the above description is to estimate the viscoelastic parameter values of each ligament and tendon. These estimates are obtained by 3-D velocity measurements using the laser Doppler vibrometer.

### Conclusion and Outlook

By combining each of the sub models, these studies result in anatomically-based biocomputational models of the intact middle ear. Furthermore, the studies will provide a solid foundation for the structural basis for middle ear sound transmission and will have applications in many areas of hearing health care including surgical reconstruction of the middle ear, otoacoustic emissions and passive and active prostheses. Laser Doppler vibrometers are a critical component in the battery of tests used to understand structure/function relationships of the ear.

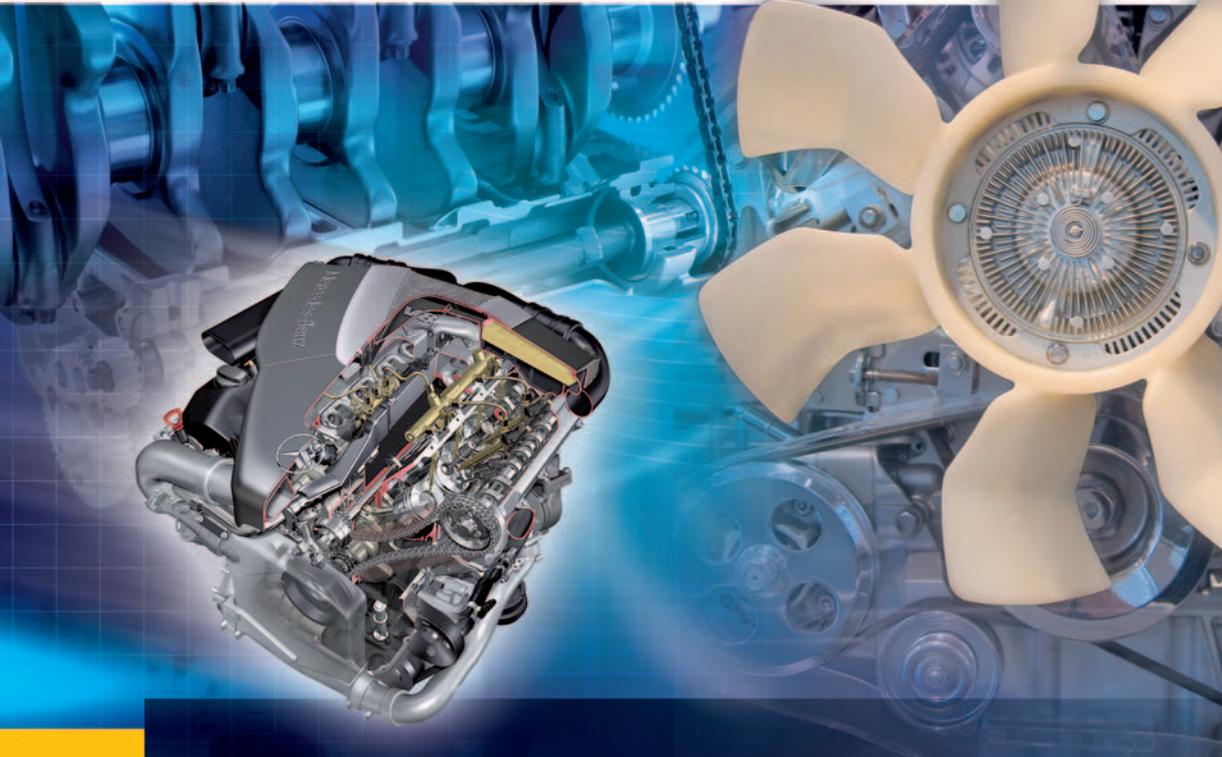


**Figure 4: Mathematical model of the eardrum**

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## Basics of Rotational Vibration Sensing



### FOR BEGINNERS AND EXPERIENCED USERS

*Polytec laser vibrometers are proven instruments for non-contact measurement of surface vibrations. The 4000 Series Rotational Vibrometer is a variation on a standard vibrometer that allows engineers to measure rotational vibration directly. The instrument uses two non-contact laser probes for dynamic acquisition of the angular vibration of rotating parts. Each laser probe is a separate laser interferometer. A special differential technique uses both measurement beams and allows only the rotational component to be acquired, independent of the shape of the measurement object. At the same time translational vibrations are virtually eliminated. The 4000 Series has a frequency range of 0.5 Hz to 10 kHz, providing enough bandwidth for even the most demanding measurement tasks.*



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### Applications

Many familiar mechanical systems such as engines, power trains and gearboxes are significant sources of rotational vibrations. These systems generate rotational motion and mechanically transmit the torque, movement, speed and acceleration from one place to the other. Besides creating torsional and bending vibrations in the generation of the rotation motion there are many vibrations created in its transmission to the point of usage. Additional vibrations are generated by mismatched gearing, unbalanced shafts, and poorly aligned articulate joints. All of these unwanted vibrations result in undesirable noise and premature fatigue of the mechanical systems.

### Measurement Challenges

To minimize the rotational vibrations and their harmful effects in the engineering design, measurements are made to discover how torque and kinematics are carried across the drive system, and to describe the nature of the deviations in terms of elasticity, inertia, torque and contact. Traditional measurement of torsional and rotational motion is not easy because the system components are continually moving relative to the sensor platform and large portions of the system reside in inaccessible places.

There are both invasive and non-invasive sensing techniques. Invasive methods use devices mounted to the rotating part that transmit a signal to an opposing receiver or sensor, for instance RF telemetry combined with shaft mounted strain gauges or accelerometers. While these techniques give direct physical measurements, they are skill

and maintenance sensitive. Conventional contact transducers are also subject to wear and slippage. In comparison, non-contact technologies, like laser interferometers, are easy to mount even in crowded places and are ideal for monitoring purposes. The vibrometer's large standoff distance makes repositioning the laser probe fast and convenient and enables the precision measurement of operating machinery at several locations without interruption. A specific advantage of the Polytec design is its ability to measure anywhere within the range of -7,000 RPM to +11,000 RPM including directional changes, torsional transients and rotational vibrations around the rest position.

### The Rotational Vibrometer System

The 4000 Series Rotational Vibrometer includes the OFV-400 Optical Sensor Head and the OFV-4000 Controller. Polytec's long-standing experience in the development of laser vibrometers has been applied to the design of the OFV-400 Measuring Head, with a compact dual interferometer whose high optical sensitivity enables precision measurements on untreated surfaces. Signals from the OFV-400 are processed by the OFV-4000 Controller/Power Supply. The controller bandwidth is large enough to handle fast transients such as sudden accelerations of a shaft during gear changes. All instrument settings are shown on the OFV-4000's backlit display including signal strength from both laser beams and RPM.

### Principle of Operation

The 4000 Series Rotational Vibrometer uses two parallel laser beams which exit the OFV-400's front lens and strike the rotating surface. Each back-scattered laser beam is DOPPLER shifted in frequency by the surface velocity vector in the beam direction. This velocity is made up of rotational and lateral components. Raw velocity information from each beam is independently sent to the OFV-4000 for processing. The difference between the two velocity components is a direct measure of the pure rotational velocity of the object and eliminates lateral vibrations. Polytec's dual interferometer design has significantly greater optical sensitivity than competing designs using only one interferometer operating in an optically differential mode. This optical sensitivity advantage allows measurements on poorly reflecting surfaces, thereby increasing the range of applications and ease of use. For measuring positive and negative rotations as well as vibrations around zero RPM, a BRAGG cell is incorporated into the dual interferometer.

The Bragg cell produces a constant angular velocity offset by frequency shifting the laser beams.

### Optical Setup

The OFV-400 Sensor Head contains two independent laser interferometers cleverly designed into a compact, lightweight package, utilizing several shared components. Each of these two interferometers emits a measurement beam through the OFV-400 front lens. The two beams are parallel and come to a focus at a specified distance from the sensor head, where they strike the rotating object with a separation,  $d$ . One beam strikes the rotating object above the axis of rotation while the other strikes it at an approximately equal distance below.

Each point on the circumference of the rotating part, with angular velocity  $\omega$ , has a tangential velocity  $v_t$  which is dependent on the rotational radius  $R$ . This tangential velocity can be broken down into two orthogonal translational velocity components. In the figure, the vectors are shown for one such break down of velocity for two points  $A$  and  $B$ , where one of the velocity components is arranged to point along the direction of the measurement beam ( $v_A$  and  $v_B$ ).

As shown in the following, it is possible to determine the angular velocity  $\omega$  by measuring two parallel, translational velocity components. By projecting the tangential velocity vectors along the measurement beam, the following formulas were determined:

$$v_A = v_{tA} \cos \alpha = \omega R_A \cos \alpha$$

$$v_B = v_{tB} \cos \beta = \omega R_B \cos \beta$$

As described above, the velocity components along the direction of the measurement beam produce the Doppler frequencies  $f_{DA}$  and  $f_{DB}$  in

the back scattered beams. According to the drawing in the figure, the lower beam measures a Doppler shift from the surface moving towards the sensor head. The upper beam measures a Doppler shift with opposite sign from the surface moving away from the sensor head.

Here the following formulas apply:

$$f_{DA} = 2 v_A / \lambda = 2 (\omega R_A \cos \alpha) / \lambda$$

$$f_{DB} = 2 v_B / \lambda = 2 (\omega R_B \cos \beta) / \lambda$$

The geometrical relationship between the beam separation distance  $d$  and the angles  $\alpha$  and  $\beta$  at given radii  $R_A$  and  $R_B$ , is given by:

$$d = R_A \cos \alpha + R_B \cos \beta$$

and thus the following formula is obtained for the frequency difference between the two Doppler-shifted beams that depends on the system constants  $d$ ,  $\lambda$  and the angular velocity  $\omega$ :

$$f_D = f_{DA} + f_{DB} = 2 d \omega / \lambda$$

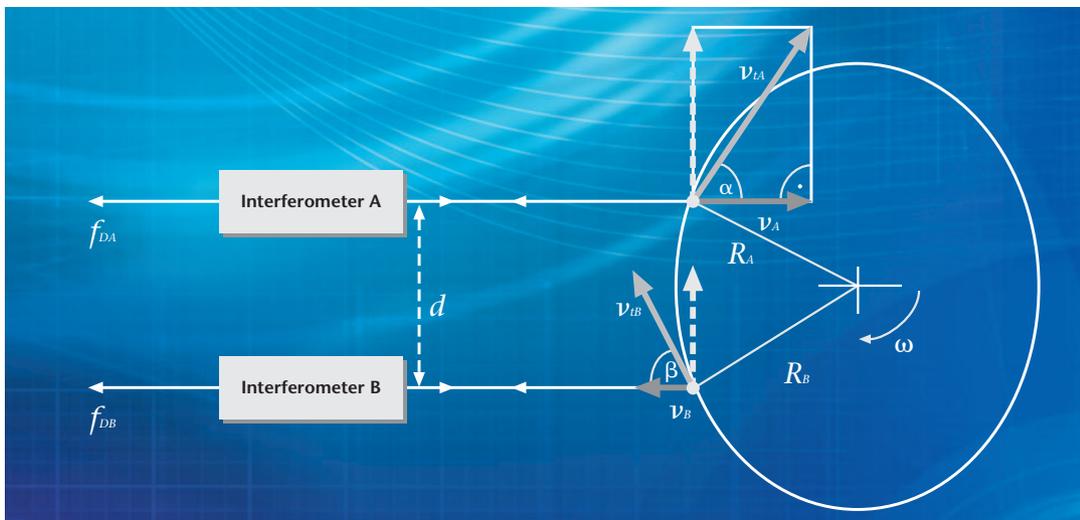
Hence, the angular velocity is

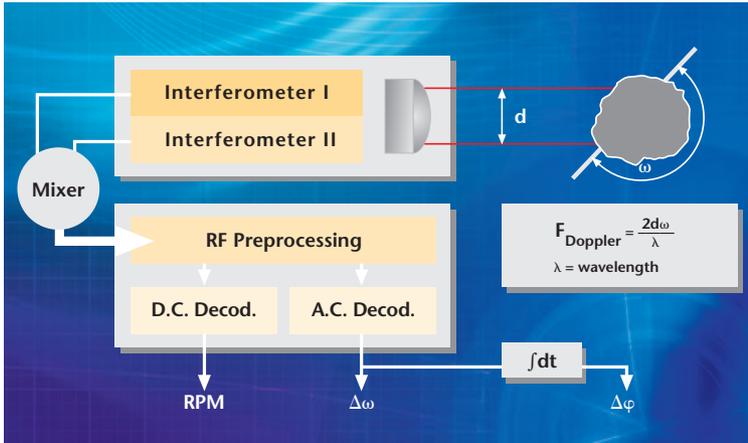
$$\omega = f_D \lambda / 2d$$

### Signal Processing

Signals from the OFV-400 are processed by the OFV-4000 Controller to obtain the complete angular velocity information from the frequency of the analog output signals of both interferometers and to separate the static component (DC fraction) from the dynamic component (AC fraction) of the rotational speed.

After separate signal conditioning, the output signals of both interferometers are merged in a mixer stage, followed by a preprocessing block. Here static and dynamic frequency components are separated and supplied to separate decoders, which operate as frequency-to-voltage converters.





Thus, measurements with a Polytec Rotational Vibrometer, enhanced by data processing software like VSI Rotate, can help identify individual vibration frequencies solving problems in noisy signals with closely spaced and crossing orders, and creating impressive plots and tables to use in reports and presentations.

For more information about VSI Rotate from Vold Solutions please visit [www.vold.com](http://www.vold.com). For more information about Polytec Rotational Vibrometers, please visit [www.polytec.com/usa/rotvib](http://www.polytec.com/usa/rotvib).

After decoding, the static RPM and the dynamic signal ( $\Delta\omega$ ) are fed to separate outputs:

- DC stationary rotation  $\omega_{DC}$ :  
A constant component of the tangential velocity which is proportional to the speed or RPM. The combination of both beams yields the correctly scaled RPM information, independent of radius.
- AC rotational vibration  $\Delta\omega$ :  
The fluctuating component of the shaft rotation, which indicates the angular or rotational vibration.
- The vibrational velocity signal ( $\Delta\omega$ ) is also sent to an integrator block to provide the angular displacement  $\Delta\phi$ .

The gross, lateral movement of the shaft towards or away from the sensor head is not measured because it is common to the two laser beams, that cancel in the differencing process.

### Data Processing

Angular vibrational velocity, angular vibrational displacement and RPM are provided as analog outputs via three BNC jacks. These outputs can be examined further with signal processing software, such as an order tracking analyzer.

VSI Rotate is such a software package, provided by our partner company Vold Solutions, for analyzing noise and vibration from time waveform and tachometer signals. It is able to post-process vibration data and provides high-resolution spectral and order-based analysis that enable a detailed diagnosis of machinery problems. VSI Rotate features spectrograms, color contour plots, phase plots, order tracking, 2-D and 3-D plotting, and bode diagrams.

### POLYTEC TUTORIAL SERIES

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(Issue 1/2004) E5 – E8

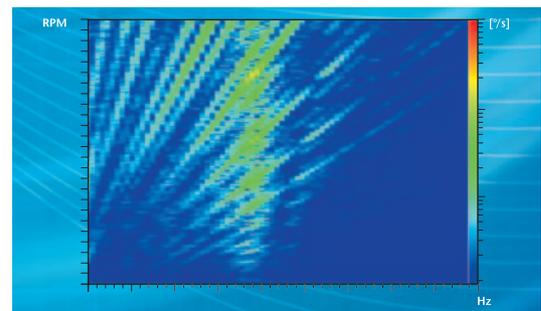
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Each LM INFO Special contains a pull-out tutorial section written to educate those interested in the basic technology and application of non contact laser Doppler vibrometry and other light-based measurement techniques.

Please download previous issues at [www.polytec.de/usa/Lm-download](http://www.polytec.de/usa/Lm-download)



# For Vibrations at 20 m/s And Beyond



## New Modular to Formula 1 Proven High Speed Vibration Measurement Systems

*Optimized for high vibrational velocities:*

### Modular 20 m/s Vibrometer

The new OFV High Speed Vibrometer series expands the number of options known from the proven OFV-5000 Modular Vibrometer System. Now you can make vibration measurements at vibrational velocities up to 20 m/s (previously 10 m/s), for highly demanding applications such as engine development. The new High Speed System is composed of the OFV-5000-S Vibrometer Controller and the OFV-525 High Speed Sensor Head.

The OFV-5000-S is based on the OFV-5000 Vibrometer Controller and can likewise be configured with a wide range of decoders and decoder combinations for very different tasks.

This means that vibration frequencies up to 1.5 MHz or vibrational displacements that range from sub-nanometer to meters can be measured.

The OFV-525 single-point Sensor Head is based on the OFV-505 standard model. Like the basic model, the OFV-525 adheres to an eye safe laser output performance < 1 mW (Class 2) and offers a very high optical scatter

light sensitivity, a remote focus control function, auto focus as well as the option of locking the focus position. With an OFV-5000-S and OFV-525 combination, it is possible to upgrade to a Polytec PSV-400-H4-S Scanning Vibrometer.

*Scanning extremely high velocities:*

### PSV-400-H4-S Scanning Vibrometer up to 20 m/s

The high velocity scanning system is based on the PSV-400-H4 and allows vibration measurements up to 20 m/s with a vibration frequency of up to 80 kHz. This, for example, allows simple and intuitive operational deflection shape analysis of engine components or other parts and aggregates in the high velocity range.



*The specialist for developing Formula 1 racing engines:*

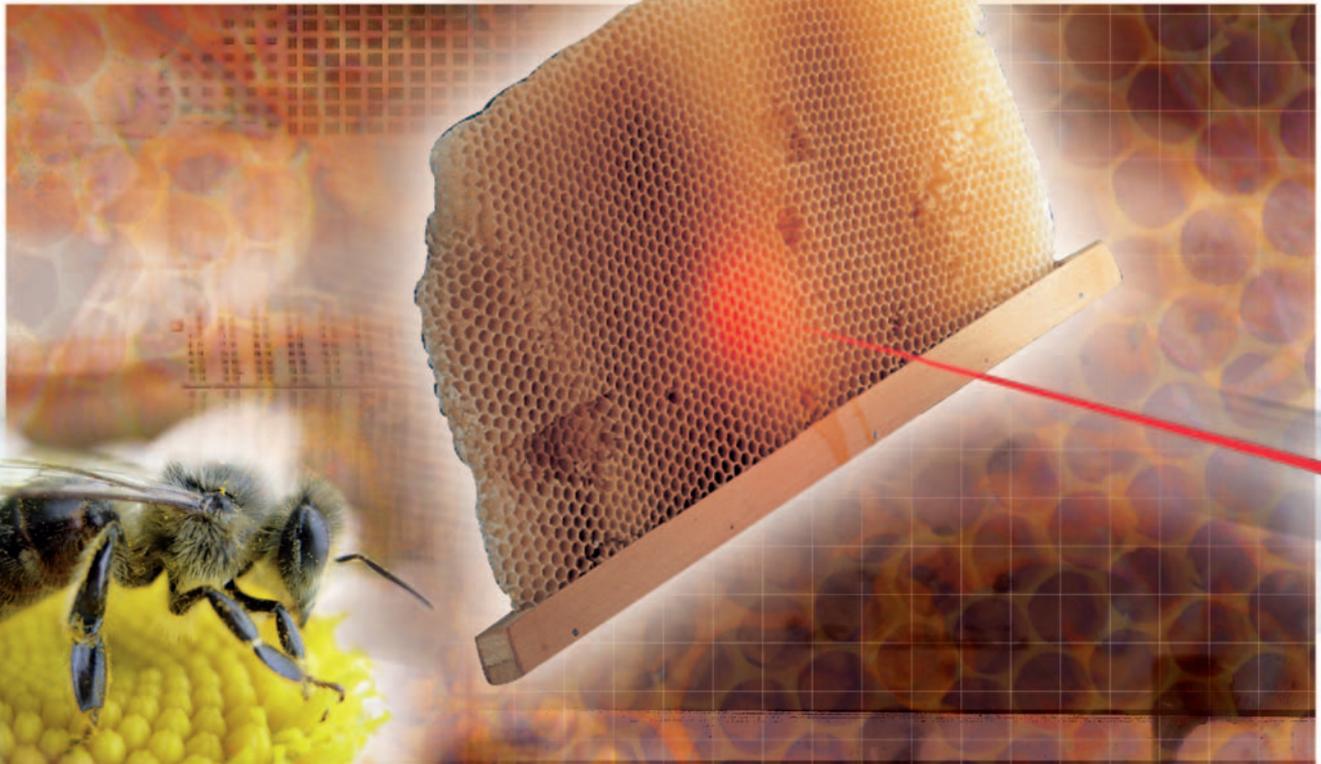
### HSV-2000 High Speed Vibrometer up to 30 m/s

The HSV-2000 system allows single point and differential displacement as well as velocity acquisition up to  $\pm 30$  m/s. Typical applications are valve train measurements as well as examining shock, impact and other high velocity effects. This system is widely used in Formula 1 racing to optimize their high performance engines. Using a special microscope adapter, high velocity measurements are also possible on small objects, e.g. droplets of ink in bubble jet printers.

You will find more information at [www.polytec.com/usa/highspeed](http://www.polytec.com/usa/highspeed)



# Good Vibrations



## Dancing Bees Generate Vibrations in the Honeycomb as a Means of Communication

*Honeybees live in colonies containing about 50,000 individuals. We are just beginning to understand the wealth of information exchange in this “super organism”. Modern measurement methods allow us to significantly extend our understanding of the use of mechanical signals for communication between honeybees.*

### Feeding Ground Recruitment among Honeybees

Collecting bees which have discovered a new feeding ground perform the so-called bee dance or waggle dance in the dark hive. The information on the geographical position of the feeding ground is in the time-space construction of the dance move. This information is transferred during the dance movements from the dancer to the follower bees which are dancing in direct body contact with her.

The highly complex chain of information transmission starts in the hive by the other bees noticing a dancer and going to her. Often several dancers are

moving a few bee lengths apart from each other, whereby different feeding grounds can be shown at the same time. The enticing signals which these dancers emit should only have a short range so as to minimize disruptions to each other and so as not to attract too many bees.

### The Dancer as a Source of Honeycomb Vibrations

This function is fulfilled by honeycomb vibrations which are generated by the dancers. Measuring these honeycomb vibrations has proved to be extremely difficult, as an active colony generates an incredible continuous level of noise. Using non-contact laser Doppler vibrometry, we managed to make a measure-

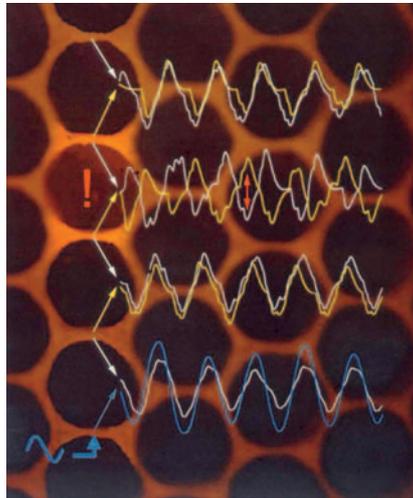
ment directly on the honeycomb next to a dancer, providing we aligned the movement phases of the bee and the time window of analysis very precisely.

The frequencies caused by the dance which can thereby be measured are in the range between 200 and 300 Hz and produced in pulses of approx. 30 – 50 milliseconds in length. These pulses are generally in the time sequence of the abdominal movement so that the reverse phase of the abdominal movement is emphasized. This leads to the assumption that an important role of the movement of the abdomen we can see is to effectively couple the vibration pulse of the flight muscles to the honeycomb.

## How Well do Honeycombs Conduct Vibrations?

Subject to a few simplifying assumptions, it has been calculated that a dancer exerts a force of a maximum of 1 mN on the edges of the cells during the waggle phase. On this basis an experiment was conducted in which the edges of the cells of an empty honeycomb were examined while being excited with this force and the frequency and time pattern as measured for the dancers to see how, which and how well vibrations are conducted via the honeycomb.

In doing so, it could be seen that the honeycomb best conducts the vibrations in the frequency range examined as a horizontal shift of the net made up of the edges of cells. A problem appears if one considers that in a noise-type excitation as occurs through the activity of all the bees on a honeycomb, vibrations of the honeycomb also occur in the transmission range of the dancers. The signal can thus be hidden in the noise. The behavioral reaction of the bees standing or walking near a dancer on the honeycomb however shows that the dancer is very reliably recognized. Apart from the high probability that in parallel to the "dance" there are other information channels used such as air movement, higher body temperature of the dancer, and chemical stimulants, the honey-



**Figure 2: Measurement results from a row of adjoining cells. The opposite walls of the individual cell marked with "!" are vibrating in the opposite beat**

comb vibration itself also offers options to solve this signal/noise problem.

Bees are standing on six feet on the edges of the cells and thus have six sensors working simultaneously. With the aid of two identical Polytec OFV Laser Vibrometer single-point Sensor Heads, the vibration of the cell edges were measured on empty honeycombs in two places at the same time. Thus, it was possible to duplicate what at least two of the six bee legs can perceive at the same time.

It was apparent that at the frequency transmitted best, in a whole row of cells across the entire honeycomb, all

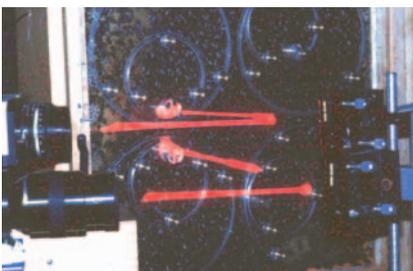
opposite walls of every individual cell are vibrating in the same direction. However, in every row of cells, there is a single cell whose walls vibrate precisely in the counter-phase (vibration node). Depending on the position of the excitation point, this cell is between one and seven cells away from the point of excitation. It is plausible that the bees standing or walking in the edges of the cells recognize this particular cell and know it indicates the proximity of a dancer. Because the maximum distance from which follower bees are still attracted to the dancer is precisely seven cells.

## Conclusions

Social insects are excellent subjects for study. Understanding their mechanical systems and the evolution of differentiated meaningful communication signals is important. The use of innovative methods for quantitative acquisition of signals and their transmission has shown how brilliantly the honeybees have utilized the vibration signals they produce, the way in which they transmit such signals via the honeycomb and the respective size of the audience for each dancer.

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**Figure 1: Test setup. The colony is covered with a clear plastic window with moveable circular panes. With the aid of other moveable and transparent elements and 90° deflecting mirrors, almost every position on the honeycomb can be measured without bees walking into the measurement beam.**



# Perfect Teeth



## Laser Vibrometry Helps to Improve Efficacy in Dental Ultrasonics

*Visualizing the motion of dental ultrasonic scalers is challenging due to their high frequency vibrations and small associated displacement amplitudes. Laser vibrometry has made it possible to study, in detail, the vibration patterns of dental ultrasonic scaling equipment, and to determine which may be the most effective designs.*

### Introduction

Dental plaque is a major factor in the initiation of gum disease. Plaque may be removed easily through regular tooth brushing but, if allowed to grow undisturbed, may become mineralised, forming a deposit known as calculus. This is a much harder substance, requiring professional intervention by a dentist for its removal to help prevent gum disease. Whereas early gingivitis may be reversed by improved oral care

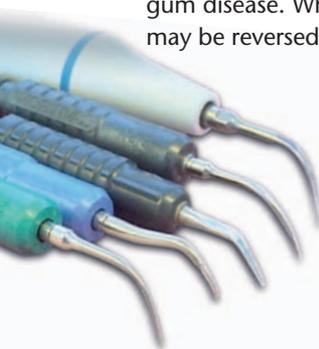
of the patient at home, treatment of periodontitis is only possible through the thorough cleaning of teeth by a clinician using hand curettes and antimicrobials. Another instrument available to the clinician for tooth debridement is the ultrasonic scaler.

Ultrasonic scaling units are present in almost every dental practice in the UK. Generators drive scaler tips (Figure 1), using magnetostriction or piezoelectricity, to produce tip vibrations in the lower kilohertz range (usually 20 – 30 kHz).

### Laser Vibrometry and Dental Ultrasonics

Ultrasonic scalers remove deposits from tooth surfaces via the mechanical chipping action of the scaler tip as it is

maneuvered over the tooth surface. Because of this, the magnitude of the vibration displacement amplitude has regularly been used as an indicator of the efficacy of the ultrasonic scaling system. The motion of dental ultrasonic scalers is difficult to visualize due to their high frequency vibrations and small associated displacement amplitudes. Therefore it is not simple to determine whether or not the instruments are working correctly or which may be the most effective designs. However, laser vibrometry has made it possible to study, in detail, the vibration patterns of dental ultrasonic scaling equipment. The laser vibrometer used in our investigations is a PSV-300-F/S Scanning Vibrometer system, which



**Figure 1.**  
Selection of ultrasonic scaler tips used for removing plaque and calculus.

enables us to evaluate the vibration characteristics of the whole scaler probe. Initial scans (Figure 2) were performed on scalers oscillating in an unloaded environment (in air). The effect of water flow rate and generator power setting on tip displacement amplitude was then evaluated for a range of instruments. To make investigations more clinically relevant, scaling instruments were then scanned while in contact with tooth surfaces under known loads.

### Results

In Figure 3 the displacement data is shown as a color map and in Figure 4 a snapshot from an animated deflection shape is superimposed over a video image of the scaler tip. The computer-generated animation of the vibration allows tip motion to be assessed quickly and easily. From the data the maximum vibration displacement amplitude of a scaler tip is seen to occur at the unconstrained end of the tip. Furthermore, the scanning laser vibrometer enables the evaluation of how water flow, generator power and tip/tooth contact load affects scaler oscillation characteristics.

### Clinical Implications

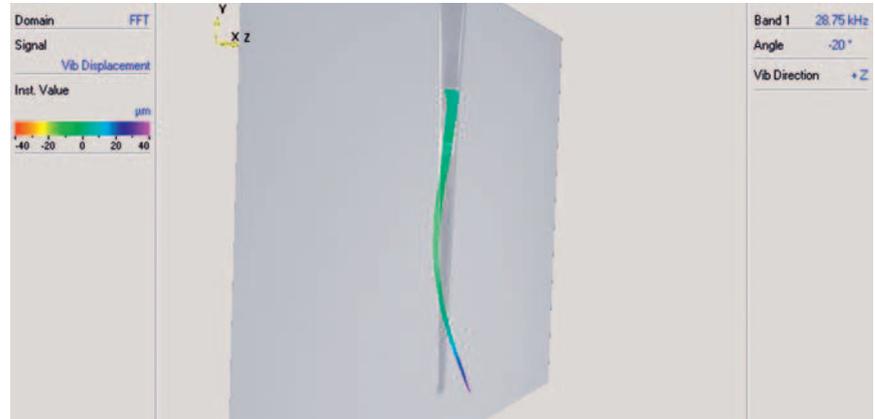
One of the most significant results of this work is the high degree of variability that was observed between tips of the same design. New and unused scaler tips of the same style will respond differently in response to applied load, an adjustment in water flow rate or generator power setting.



**Figure 2. The laser from the Scanning Vibrometer is scanned over the surface of a dental ultrasonic scaler.**



**Figure 3. Ultrasonic scaler tip vibration data mapped over an image of the scaler.**



**Figure 4. A snapshot from an animated deflection shape of the vibration data, superimposed over a video image of the scaler.**

It is clear that vibration data acquired using laser vibrometry can highlight to manufacturers that the current range of ultrasonic instruments exhibit a high degree of variability. The lack of standardized instrument response makes it difficult for a clinician to familiarize themselves with the instruments properly and this may affect clinical procedures. An improved scaler tip design, based on the evidence gained through laser vibrometry, may lead to the manufacture of instruments with more consistent operational characteristics, leading to improved patient treatment and care.

### Conclusion

Laser vibrometry has increased current knowledge in the field of dental ultrasonics. In particular, this research has highlighted the significant variability of these instruments.

Future use of the laser vibrometer in this field may enable new scaler tips to be designed whose vibrations are better understood, improving clinical efficacy. Following the successful characterization of dental ultrasonic scalers, the scanning laser vibrometer has found further application for measuring the response of endosonic files, ultrasonic retrograde tips and even powered toothbrushes.

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# Rotational Vibrations *Unraveled*



## Using Rotational Vibrometers to Make NVH Measurements on Combustion Engines

*An engine's combustion process induces rotational inhomogeneity and torsional vibrations in the drive shaft resulting in unwanted vibrations and noise emission. By examining the rotational movements of the different components, the drive train for the motor vehicle can be optimized to reduce the unwanted vibrations. Rotational vibrometers using non-contact measurement procedures allow for a quick and simple examination of the torsional vibrations during operation.*

### Components in the Combustion Engine

A combustion engine contains a large number of rotating parts, starting with the crankshaft, the camshaft, the drive shafts and differential shafts to the auxiliaries such as the starter, electric generator and turbo charger. In the following examples, measurements on the crankshaft pulley are shown.

### Comparison of Measurement Procedures

The traditional method for measuring rotational vibrations uses the angular displacement encoder mounted to a pulley using an adapter. Apart from

the mechanical effort involved, this technique loads the pulley causing a change in its mass and the moment of inertia. At best, these changes diminish the accuracy of the measurement; at worst, they can lead to completely false results.

The Polytec OFV-4000 Rotational Vibrometer makes a simple, non-contact measurement that preserves the original mass and moment of inertia. As a general rule, the surfaces to be measured do not need to be prepared, only on material which is highly light-absorbent (black) it is necessary to

increase the light scatter by applying reflective sticky tape (negligible mass).

### Measurements with the Rotational Vibrometer

Rotational vibrometers measure angular vibrations on surfaces rotating from  $-7,000$  to  $+11,000$  RPM. They sense the rotation using the Doppler shifted laser light. The basic principles of rotational vibrometry are explained in the detailed insert contained in this booklet.

The example in Figure 1 shows simultaneous measurement of two movements of the pulley: the rotational vibrations are acquired using the OFV-4000

Rotational Vibrometer and the axial movements of the shaft are acquired with a Polytec Single-Point Vibrometer.

The measurement data is used to perform an order analysis. The orders are multiples of the rotational speed. If the engine is turning at 3000 RPM (50 Hz) then the first order is at 50 Hz, the second order at 100 Hz and so on.

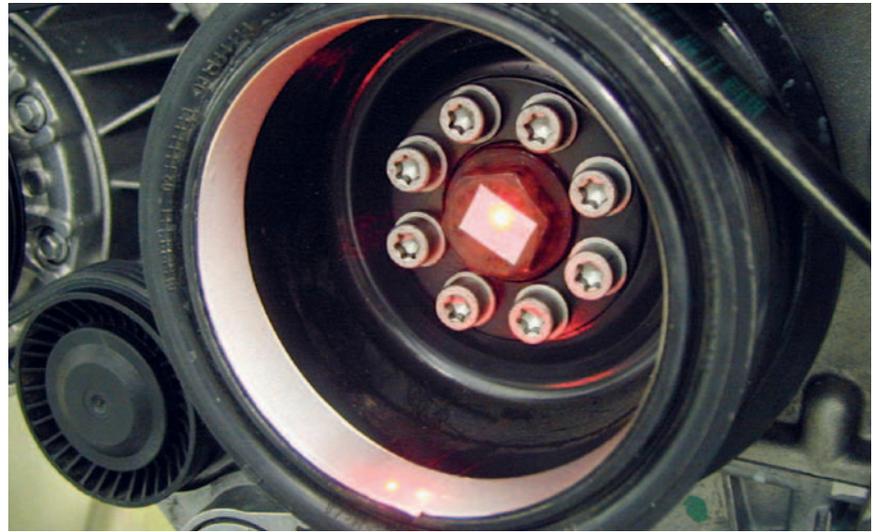
If the signal power of the rotational vibration is plotted against the rotational speed and frequency (spectrogram shown in Figure 2), then you can see that the maxima occur primarily at a resonant frequency of 490 Hz.

The corresponding order spectrum (Figure 3) shows that in the RPM range between 1000 RPM and 6000 RPM, primarily resonances of the 6th, 8th and 10th order are excited.

### Signal Quality

The OFV-4000 Rotational Vibrometer offers you the option of conditioning the input signal using a tracking filter to improve the high-frequency carrier signal. It is particularly suitable for bridging short dropouts which can occur during rotational measurements due to the speckle effects of the reflected light. This effect is in principle better with a larger time constant (SLOW) but when tracking highly dynamic signals you have to switch to FAST. The most favorable setting is often found by trial and error and varies from case to case.

In Figure 4 the right picture shows how a smoother signal progression is



**Figure 1: Measurements of rotational vibrations and out-of-plane vibrations on a crankshaft pulley**

attained using the filter setting FAST in which the discontinuities and disruptions shown in the example on the left side (Filter setting SLOW) are filtered out.

### Summary

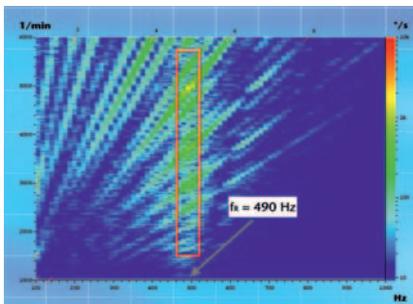
The Rotational Vibrometer is very easy to use, has a high optical sensitivity and maintains a large dynamic range. No adapter or flange is necessary for making measurements, leaving the object under examination unaffected. The Rotational Vibrometer prevents stoppage time which occurs when using contact processes. In the car industry it supports the development of torsional vibration dampers and helps solve all kinds of rotational vibration problems.

### CONTACT

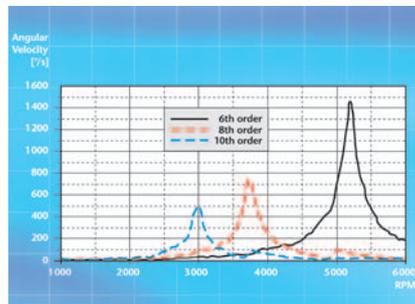
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### About IAV Group

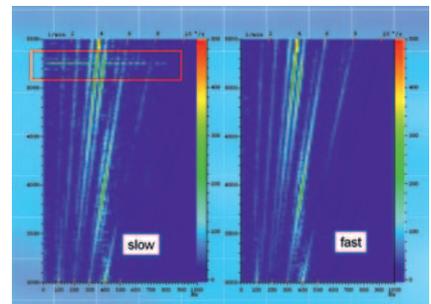
Ingenieurgesellschaft Auto und Verkehr offers the automotive industry the full spectrum of hi-tech engineering. IAV's activities encompass production vehicle development, advanced engineering as well as in-company basic research. In addition to its headquarters in Berlin, IAV also operates from other locations in Europe, USA and Brazil. See [www.iav.de](http://www.iav.de) for further information.



**Figure 2: Spectrogram graph of the measurements on the crankshaft**

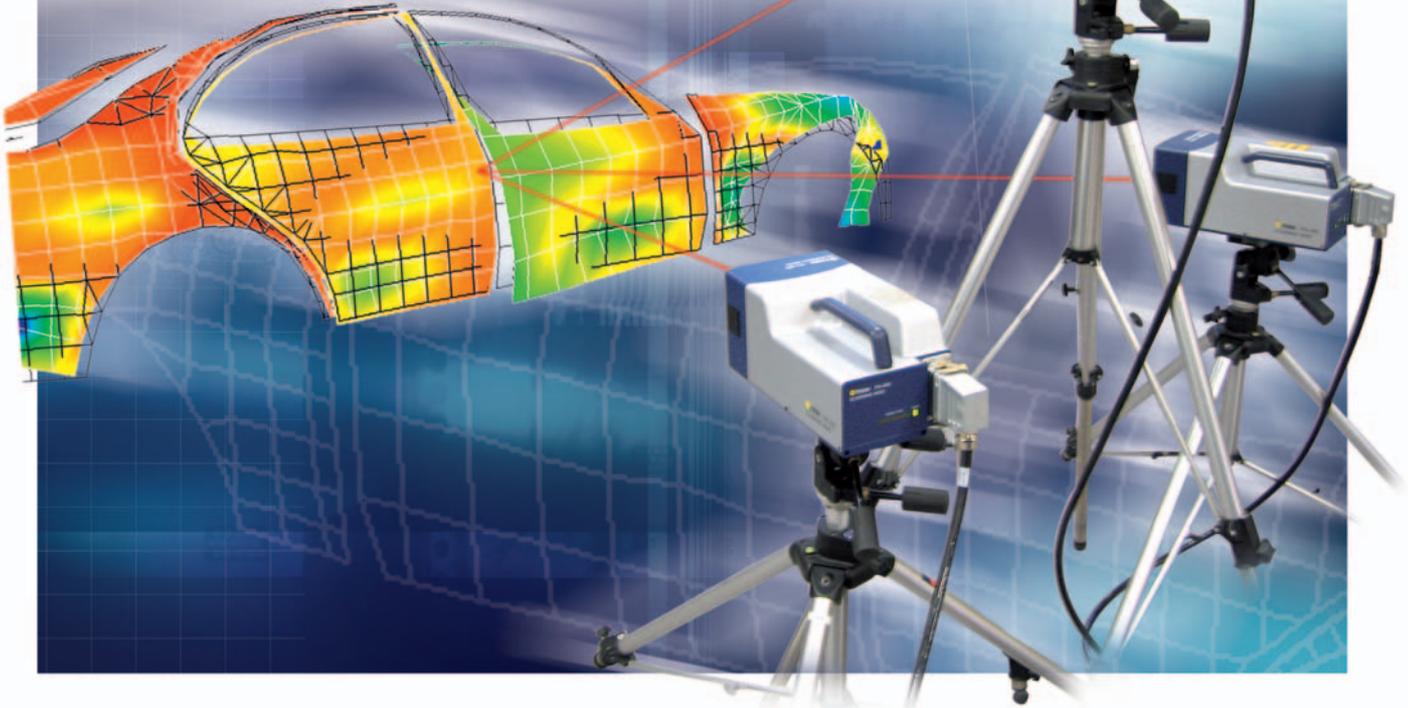


**Figure 3: Order spectrum of the rotational vibrations**



**Figure 4: Application of the tracking filter**

# Scanning Vibrometry: New Milestones



## Enhanced Hardware and Software Open Up New Possibilities in the Area of Surface Vibration Measurement

*The new eight-channel PSV-400 data acquisition system and the greatly enhanced PSV Scanning Vibrometer Software are powerful tools that simplify experimental modal analysis. With newly designed, intuitive and simple handling of geometry data MIMO measurements can be significantly improved. For large objects, 3-D measurement of the vibration dynamics of the entire surface can be made in pieces, with different views, and then stitched together to make a global data set that can be visualized together. Once again, Polytec takes non-contact vibration metrology to the next level.*

### Eight-Channel Data Acquisition for MIMO Measurements

An 8-channel data acquisition system is now standard equipment on the PSV-400-3D Scanning Vibrometer and



optional for the PSV-400-H4 Scanning Vibrometer. Of these eight channels three are taken by each of the vibrometer heads leaving five measurement channels available for parallel acquisition of reference signals such as load cells (seven available for the PSV-400-H4). This provides completely new possibilities for Principal Component Analysis (PCA) within the framework of MIMO (Multiple-Input-Multiple-Output) measurements.

MIMO is a measurement method in which energy is introduced simultaneously into a test structure at multiple points (Multiple Input) while the system response is acquired at different sample points on the structure (Multiple Output). Thus, a matrix of transfer functions can be determined between all power flows and sample points. MIMO measurements are made

- on large structures to be able to couple more measurement energy into different areas of the structure,

- where resonances fall very close together (degeneration) so that superimposed modes can be uniquely identified.

Both the PSV-400-H4 and the PSV-400-3D have up to four different internal generator channels available and now have the required number of reference channels. Determining the FRFs (Frequency Response Functions) is done directly in the PSV software so that only the complete MIMO FRF matrix is exported into a downstream modal analysis system.

### PSVSoft Release 8.3

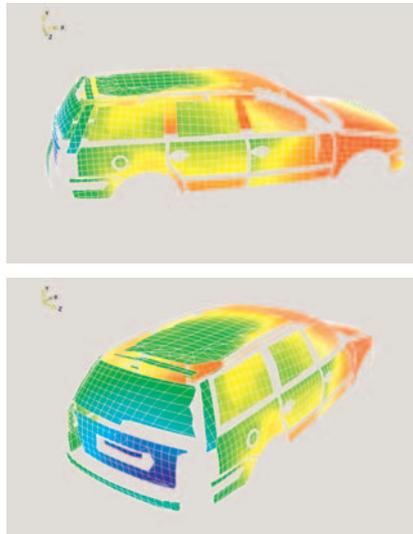
The Scanning Vibrometer Software represents the “Intelligence” of the vibrometer system and guides all measurement, control, regulation and analysis tasks in the data acquisition system.

The PSV software has significantly expanded and improved the data acquisition, analysis and presentation modes with the release of version 8.3. Numerous requests and suggestions from the user community have been incorporated in the new release to make surface vibration measurements even more powerful, easier and more user-friendly. Among other things, the following performance characteristics have been implemented in version 8.3:

#### Bringing measurement data together

The 3-D vibration dynamics acquired in several individual measurements on large spatial structures can now be grouped together directly in the evaluation mode of the PSV software to form a global data set (3-D geometry and 3-D vibration data). This can then be analyzed, visualized and exported, allowing simple and intuitive access to the whole 3-D structural dynamics and contributing towards simplified data analysis.

The example shows an operational deflection shape of a car body that has been stitched from 10 data sets and has about 3000 measuring points.



#### Simplified handling of geometry data and measurement points

The 3-D geometry view is now available in acquisition mode so that the measurement grid can be spatially visualized before making the vibration measurement (by using 3-D coordinates). Furthermore, by using specific color codes, the status of a geometry or measurement point can be clearly shown with regards to geometry acquisition, focus and vibration measurement. The sample points can now be selected according to their status and their point numbers and, then, modified through diverse processing methods. Thus, for example, certain points can be selected, blocked or renumbered for geometry acquisition, focus definition or vibration measurement.

#### Management of settings, browser upgrades

A project-oriented work sequence is made significantly easier by the newly designed filing system which places settings and measurement files in a common location (e.g. in a project folder). Settings can now be filed in any directory. The PSV browser uses a tree structure to allow the hierarchical access to the settings from settings and measurement files. In addition, the browser also shows the Frequency Band Definition in the tree structure of

.svd files. The Frequency Band Definition can be extracted (“Save As...”) or dragged using Drag & Drop into an open frequency band editor.

#### PDA remote control

As of now a PDA (mobile handheld computer) can be used to remotely control the PSV software. The PDA thereby supports the same functions as the handset PSV-Z-051. The connection with the PSV PC is made using WLAN.

#### Eight channel signal processing

The 8-channel data acquisition mentioned before is fully supported by the new software release, including user-friendly management and configuration options for all measurement channels.



### How do You Get the Most from the Enhancements?

As a user with a service agreement, Polytec will make the new software available to you directly. Please note that within the framework of the new Uni-Vib program, Polytec is also making the respective current releases of the PSV software available to users in university groups free of charge. Please contact us for specific details.

If you are an end user and want to use the attractive new performance features in the current software release, but do not yet have a service agreement with Polytec, then please contact us as soon as possible. As part of our commitment to you, we will outline the attractive advantages of our service concept and make you an offer tailored to meet your requirements.

For more information about Polytec Scanning Vibrometers please visit us on the Internet at [www.polytec.com/usa/psv400](http://www.polytec.com/usa/psv400)

# On the Spot with Cutting-Edge Products

*Polytec is there! – trade fairs, conferences, user meetings and road shows are opportunities where Polytec shares its unique expertise in vibrometry with customers and specialists all over the world.*

## 2005 MEMS Workstation Seminar Series

On April 6th, Polytec, Inc. and The Micromanipulator Co. (TMMC) began a six-stop seminar series to introduce the new MSA-400 Micro System Analyzer for dynamic MEMS characterization coupled to a high performance probe station from TMMC. This combination is known as a MEMS workstation and allows the user to characterize MEMS dynamics, position the device with motorized translation stages, work on wafer level or packaged devices, and utilize a variety of probes for electrical and mechanical stimulation. The first seminar was in Irvine, CA followed by Dallas, TX on May 18 and Boston, MA on June 30. The final three seminars will be September 23 in Sunnyvale, CA at the North American Vibrometer Users Meeting, October 25 in Detroit, MI and November 16 in the Baltimore/Washington D.C. area. For more info visit [www.polytec.com/usa](http://www.polytec.com/usa)



## North American Tradeshows

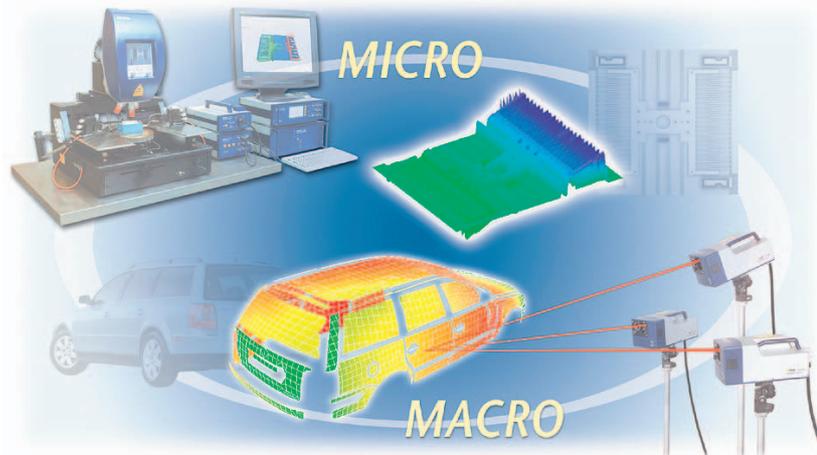
The intense 2005 event schedule included Smart Structures/NDE in March, Quality Expo in April, AISTech in May, SAE Noise and Vibration in May, Semicon West in July and Mechanics of Hearing Workshop in July. Polytec's outstanding products were enthusiastically received including new products such as the PSV-400-3D Three-Dimensional Scanning Vibrometer

with Geometry Scan for large object experimental modal analysis, the MSA-400 Micro System Analyzer for dynamic MEMS characterization, and the TMS-300/320 Scanning White Light Interferometer for precision machined part inspection.

Information on upcoming tradeshows is available on [www.polytec.com](http://www.polytec.com)

## 2005 North American Vibrometer Users Meeting

The North American Vibrometer Users Meeting will be held at the Four Points by Sheraton in Sunnyvale, CA on September 20 -23. This will be an exciting event featuring both a two-day software training class and a two-day technical seminar. The Users Meeting commences with the two-day scanning vibrometer software training class on September 20 – 21. This training is a first for North America. Often requested by our users, the training has become necessary due to the growing complexity and sophistication of the software and the intended applications. The technical seminar follows the software training and features many invited speakers discussing their applications on September 22 – 23. For complete info: [www.polytec.com/usa/users](http://www.polytec.com/usa/users)





## UK Vibrometer Users Meeting

On November 22nd and 23rd the UK Vibrometer Users Meeting will be held at the Photonics Cluster site on Aston Science Park in Birmingham. The first day will cover users' work with vibrometers in the fields of automotive development and testing, microstructures (including manufactured and natural structures), the analysis of acoustic and ultrasonic waves in fluids (including air), plus other vibrometry applications. Day two will be a technology day, covering the hardware and software, methods and practices that make Polytec vibrometers so powerful and useful in vibration measurement. [www.lambdaphoto.co.uk](http://www.lambdaphoto.co.uk)

## 2005 German Tradeshows and TechDays

Polytec's non-contact 3-D vibrometer technology attracted numerous automotive experts attending the Automotive Testing Expo in Stuttgart and the Laser 2005 Exhibition in Munich. In addition, Polytec visited four of Germany's best-known car manufacturers and presented special Automotive TechDays on-site. These events have become an important forum for our experts to learn about the requirements our current and future vibrometer users need in next generation products.

Polytec premiered the new MSA-400 Micro System Analyzer to Europe at Control 2005 in Sinsheim and received

the 2005 Sensor Innovation Award for developing this outstanding technology at Sensor+Test 2005 in Nuremberg (see page 2).

Also highlighting Sensor+Test 2005 was the new LSV-300 Laser Surface Velocimeter. Featuring high performance laser-Doppler based velocity and length sensing technology, the LSV-300 is offered at an extremely attractive price/performance ratio. Its versatile interfaces enable a simple and rapid integration into typical production processes.

[www.polytec.com/usa/lsv](http://www.polytec.com/usa/lsv)



## Third Vibrometry Seminar in Korea

In March, Polytec's Korean representative had its Third Vibrometry Seminar entitled "Advancing Laser Vibrometry". It attracted over 60 participants from industry and research including large computer and car manufacturers (GM Daewoo, Samsung, LG). Presentations covered the basics of heterodyne demodulation as well as live demonstrations of the PSV-400-3D Scanning System and the MMA/MSA product line. The success of this seminar has resulted in a planned 4th seminar entitled "Modal Analysis and Micro World". [www.vibrometry.co.kr](http://www.vibrometry.co.kr)

## Information Storage Week 2005 in Tokyo

Information Storage Week (ISW 2005) is the largest data storage conference and exhibition in Japan. It draws the top professionals in the data storage industry to the world-class sessions and exhibits. As a pioneering data storage test and measurement company, Polytec exhibited several innovative instruments including the PSV-400 Scanning Vibrometer, the MSV-400 Microscope Scanning Vibrometer and the VDD Digital Vibrometer, the latter operates at the threshold range of data storage performance by utilizing the latest technology in digital signal acquisition and processing. This exhibition was complemented by a corporate seminar named "Targeting the Limits of Laser-Doppler Vibrometry" which taught about 20 participants about the technology and the usage of Laser-Doppler Vibrometers. [www.polytec.co.jp](http://www.polytec.co.jp)

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For Polytec's Global Sales Offices please see Back Page

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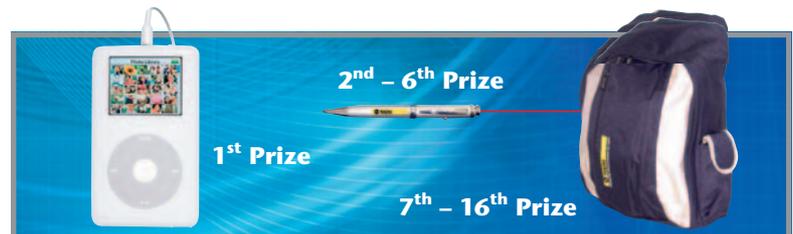
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**Yes, I want to participate in the Polytec contest.**

**What is the Maximum Vibration Velocity that can be Measured with the current Polytec Vibrometers?**

**The right answer is** \_\_\_\_\_ . (see back page)

# Watch & Win with Polytec!



## Win a 20 GB iPod Color, a Laser Pointer Pen or a CityBag!

All Polytec vibrometer users are winners – every day, creatively using our versatile, simple-to-use, high performance vibrometers – even the famed

iPod benefits from sophisticated hard disk drive technology made possible with Polytec vibrometers! Interested in an exciting chance to win an outstanding prize just for you? Here's the deal.

Watch our new corporate video and see if you can find the answer to the following question:

## What is the Maximum Vibration Velocity that can be Measured with the current Polytec Vibrometers?

You can find the video on the CD that is attached to your copy of the LM Info Special or you can view it on our web site.

Please use the fax feedback form inside this issue or our feedback web page [www.polytec.com/usa/contest](http://www.polytec.com/usa/contest) to send the answer to the question

and your comments. We will put the names of all respondents into a drawing for an Apple iPod, five Laser Pointer Pens and ten CityBags.

Please note the deadline for a response is December 1st, 2005. Thanks in advance for your comments!

## Trade Fairs and Events – Laser Measurement Systems

Reference our web site [www.polytec.com](http://www.polytec.com) for the most up-to-date information and links on trade fairs and events!

Sept 17 – 20, 2005	IEB Inner Ear Biology Workshop 2005	Tübingen, Germany
Sept 20 – 21, 2005	Diskon 2005	San Jose, CA, USA
Sept 20 – 23, 2005	US Vibrometer Users Meeting	Santa Clara, CA, USA
Sept 27 – 29, 2005	MesurExpo 2005	Paris, France
Sept 27 – 29, 2005	MeasComp 2005	Wiesbaden, Germany
Oct 05 – 06, 2005	Japan Modal Analysis Conference	Tokyo, Japan
Oct 05 – 06, 2005	Vibrometer User Meeting Sopemea	Vélizy, France
Oct 11, 2005	SIMTEC Journée Test & Mesure	Nancy, France
Oct 17 – 19, 2005	Noise-Con 2005 and ASA Meeting	Minneapolis, MN, USA
Oct 25 – 26, 2005	Astelab 2005	La Défense, France
Oct 26 – 28, 2005	Automotive Testing Expo US	Detroit, MI, USA
Nov 03, 2005	Engineering Integrity Society Meeting	Coventry, UK
Nov 05 – 11, 2005	ASME Congress and Exposition	Orlando, FL, USA
Nov 08 – 10, 2005	Aerospace Testing Expo US	Long Beach, CA, USA
Nov 09 – 11, 2005	Micromachine 2005	Tokyo, Japan
Nov 22 – 23, 2005	Vibrometry User Group Workshop	Birmingham, UK
Jan 21 – 26, 2006	Photonics West 2006	San Jose, CA, USA
Jan 22 – 26, 2006	MEMS 2006	Istanbul, Turkey

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