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Optical Metrology Enables New Energy Sources



Dr. Helmut Selbach



Eric Winkler

Dear Reader,

The market is growing for renewable energy such as geothermal, wind, solar, and ocean energy. The economic potential of their widespread deployment is very large, provided that innovative technology, advanced materials and, of course, sophisticated design and evaluation tools are available for their development.

Browsing through this issue, you will encounter several applications dealing with energy production or utilization. Consider the complexities of maintaining a wind power plant that is subject to heavy vibrations. Structural health monitoring is critical to its safe, efficient and cost effective operation. Discover how it can be done using Polytec's non-contact vibrometers (page 6). The same characterization and optimization is needed for new, fuel-saving vehicles like the prototype that won the 2008 Shell Eco-Marathon in the fuel cell category (page 8). Solar panels (page 15) must be tested prior to mass production. Even microsystems need innovative power sources that extract energy from their environment – read about energy harvesting MEMS devices on page 16.

Of course, this issue also contains interesting articles that address vibrometer, surface velocimeter and topography measurement system applications in our core markets – automotive, aerospace, industrial production, data storage and microsystems. Please enjoy and learn from the interesting articles, current news from Polytec, and up-to-date information about new products and events.

We appreciate your interest and look forward to assisting you with your next measurement task!

Dr. Helmut Selbach
Managing Director
Polytec GmbH

Eric Winkler
Optical Measurement Systems

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News from the Worldwide Polytec Family



This summer, more than 50 employees from Polytec subsidiaries around the world, as well as representatives from many countries, gathered at Polytec Headquarters in Waldbronn, Germany to share their experiences and to learn about new products and applications.

Polytec Ltd., the new Polytec Division in the UK, is located at the Harpenden site where it was previously part of Lambda Photometrics Ltd. Lambda still represents a wide range of companies and products, including the photonic products from Polytec GmbH. Customers in the UK and Ireland will continue to enjoy full technical advice, sales and service support for vibrometry, velocimetry and spectrometry systems.

However, we can now expand our product line up with the TopMap family of Topography Measurement Systems for R&D and production metrology tasks, including topography measurement services. By expanding and focusing our UK team, we expect to extend the level of service we provide and to better serve our existing and future customers.
www.polytec-ltd.co.uk

Polytec Inc., our US subsidiary, has strengthened its operation by setting up a fourth office in Austin, Texas complimenting the headquarters in Tustin, California, and the Hopkinton and Detroit offices.

Polytec France S.A.S., has established an additional office in Lyon to improve their regional sales force.

Polytec Sponsors New Automotive Research Facility

The new vehicle-in-the-loop test bench of the NVH/Driveability research group at the Institute of Product Development (IPEK) at the University of Karlsruhe was officially inaugurated in April with many interesting presentations/demonstrations from more than 60 guests from research centers and industrial contributors. Integrated into the test bench is Polytec's 3-D Scanning Vibrometer for non-contact and non-reactive acquisition of three dimensional vibration data from complex automotive structures. Polytec supported the research group by granting a free maintenance contract and three PSV software licenses.

www.ipek.uni-karlsruhe.de



Eric Winkler of Polytec and IPEK director Prof. Dr.-Ing. Albers

2008 Polytec Representative of the Year



Josef Wirthmüller



Arend von der Lieth

Josef Wirthmüller is now managing worldwide customer service, offering technical advice, repair and calibration support to our customers. He is the successor to **Arend von der Lieth** who has accepted a new position as the U.S. manager for Application Services and has moved to Polytec's Detroit office.



LB acoustics, our Austrian vibrometer distributor, received the 2008 Polytec Representative of the Year Award. In second place was HYSEN of Korea and in third place was BPS of Italy. **Helmut Ryback** of LB acoustics accepted the award in recognition of their excellent sales and marketing performance, covering Austria and a significant part of Eastern Europe. Adding to our growing list of local representatives, we welcome Mr. Mercury Kountouras from SYSSMA Environmental and Architectural Acoustics of Thessaloniki, Greece.

Please find complete and up-to-date contact information at www.polytec.com

Polytec News

RoboVib Structural Test Station is a Hit with Japanese Automotive Engineers



With the first installation of a fully automated RoboVib Structural Test Station at a Japanese customer already history, Polytec and KUKA robotics presented the system in May at the Japan Automotive Engineering Exposition, the largest trade show for the Japanese Automotive Society. The RoboVib was displayed at a joint Polytec/KUKA booth and consisted of the PSV-400-3D Scanning Vibrometer and the KUKA KR-60 industrial robot. The well

attended demonstrations, including a fully-automated 3-D vibration measurement on a shaker-excited transmission case, highlighted the convincing merits of RoboVib for product development, validation and quality assurance. The 3-day attendance resulted in significant interest in quotations, sales visits and information packages. For more information and to see a video of RoboVib in operation visit www.polytec.com/robovib

Laser Scanner Detects Nano-asperities and Makes 2008 Nano 50™ Award Winners

Nanotech Briefs, a web site and monthly email newsletter from the publishers of NASA Tech Briefs, has announced the winners of its fourth annual Nano 50™ awards competition. The 50 winners are the most innovative designs, people, and products that will move nanotechnology into key mainstream markets. This year's winners include Polytec LLC's Model 42000 Scanner with Nano-Scan defect detection. Built around a Polytec laser vibrometer, the

42000 Scanner is capable of measuring nano-asperities and morphology on hard-disk drive components helping manufacturers ensure data quality and increase the potential storage of their drives. This award is only given to technologies that incorporate nanotechnology in their design and/or operation, with significant current or near-term commercial applications.

www.nanotechbriefs.com



Polytec, Inc. Acquires THôT Technologies And Expands Hard Disk Drive Metrology

Characterizing disk morphology or finding nano-asperities in high density perpendicular magnetic recording media just got easier! Polytec, the



market leader in non-contact, laser-based vibration measurement, is pleased to announce the acquisition of THôT Technologies, a US-based supplier of sophisticated test instrumen-

tation for the disk drive industry. Effective September, 2008, THôT Technologies is fully integrated into Polytec LLC – Disk & Drive Measurement Solutions. This new company is dedicated to partnering with the disk drive industry to deliver critical and enabling metrology for next generation disk drives. Polytec customers always come first. Consequently, expanding engineering, manufacturing and customer support is vital to meeting increasingly complex metrology tasks.

Furthermore, Polytec's president, Michael Frech, has appointed a former THôT executive, Phil Maher, as vice president. He will run the day-to-day operations from Polytec's current facilities in Campbell, California, strategically located near Polytec's major disk drive customers including Seagate, Hitachi GST, Western Digital and Samsung. Polytec LLC headquarters will be collocated with Polytec, Inc. in Tustin, California. THôT's former customers will see a seamless switch to the new company and will continue to receive expert technical advice, sales, service and repair support.

www.polytec-LLC.com

See How the Wind Blows

Laser Vibrometers Make Non-contact Vibration Measurements on Wind Power Plants

The design specifications and maintenance protocol of wind power plants must assure that the mechanical limits of the components are not exceeded. In operation, the wind excites vibrations in these plants which can lead to dynamic deflections of the tower and the rotor blade of up to 1 meter with typical eigen frequencies of several Hz.

Wind power plant vibrations must be monitored during operation to optimize the simulation models used for design and construction, and to ensure faultless day-to-day operation by recognizing excessive material stress and fatigue prior to failure.

Such preventative maintenance, or condition monitoring, is often done with the aid of vibration sensors which are placed along various sections of the drive shaft. These sensors can then monitor vibrations and provide information on the status of

bearings in the power transmission. To monitor the rotor blades is much more difficult, particularly during operation, since measuring vibrations with contact sensors is only possible when using elaborate telemetry systems.

Laser vibrometry is a non-contact, optical technique for measuring vibration with zero-mass loading. The laser probe permits a long standoff distance (remote) from the measurement point, and, in the ideal case, there is little surface preparation prior

to the measurement. This investigation tested the suitability of using laser vibrometers for non-contact, remote measurement of vibrations in wind power plants. The study was within the framework of a much larger project to research sensor-enabled operational monitoring systems. This scientific work is part of the research network CEwind, in which the activities of many German universities are grouped together with the goal of elaborating and solving fundamental issues concerning future wind power plants, parks and infrastructure.

Experimental Issues

The wind power plant examined was an Enercon model E-30 with a nominal rating of 300 kW and a hub height of 50 m. Various vibrometer systems were placed at ground level and used for measurements on the tower shaft and on the rotor blades (Fig. 1).

In the experiment, apart from the eigen frequencies, the signal-to-noise ratio and transmission functions should be determined for both unprepared surfaces and those prepared with reflective film. Both a rotor blade and the hub had reflective film bonded in specified places in advance (Fig. 2).

For high resolution and reference measurements, an OFV-505 single point vibrometer was available. The OFV-5000 vibrometer controller was equipped with a high-resolution, digital VD-09 velocity decoder. Other measurement points were acquired using a PSV-400 Scanning Vibrometer. The scanner mirrors made it easy to align the laser to the measurement locations and with the aid of the integrated geometry scanner, it was possible to determine the coordinates automatically.

Results

Vibration measurements with a good signal-to-noise ratio can be made easily on the prepared surface, even at standoff distances of 90 m. The first eigen frequencies are at 0.47 Hz for the tower or the hub and at 1.85 Hz for the rotor blade. Without averaging, harmonics of these frequencies can be seen up through 50 Hz. On the surfaces that have not been prepared, good measurements are also possible using the OFV-505 sensor head with an SLR Super Long Range lens. The measurement values



Fig. 1: Measuring instrumentation – OFV-505 Single-Point and PSV-400 Scanning Vibrometers



Fig. 2: Laser spots on the reflective film on the rotor blade.

must be limited to less than 5 Hz with a low pass filter (Fig. 3). To align and monitor the measurement spot without reflective film, a telescope with a narrow band filter for the laser wavelength, or other optical aid, is strongly recommended (Fig. 4). To determine the transmission function (Fig. 5), measurements were carried out with several vibrometers at the same time on a fixed reference position, and on various points on the rotor blade. The measurements result in noise levels of 1 $\mu\text{m/s}$ for the velocity signal (at 4 mHz resolution), or respectively 0.1 μm for the displacement signal. Displacement amplitudes of up to 8 mm were observed, at moderate wind forces (12 ... 28 km/hr.) during the measurements.

The equipment worked well and first attempts to make measurements during operation (rotating blades) were successful. The tower vibrations are superimposed with the periodicity occurring as a result of the rotor rotation (Fig. 6, top).

After a Fast Fourier Transformation (FFT) of the signal and applying a low pass filter, the first eigen frequency of the tower can clearly be seen at 0.47 Hz (Fig. 6, bottom). To be able to acquire the vibrations of the rotor blades during operation as well, the measurement would have to be made closer to the hub. There, the duty cycle for the retention period of the laser spot on the rotor blade is more favorable. With the aid of a time resolved FFT, it would then be possible to separate the tower and rotor vibrations from each other.

Summary and Outlook

Laser vibrometers are a powerful tool for remote, non contact vibration monitoring of wind power plants or other large engineered structures. Equipped with the appropriate measurement technology and a suitable measurement setup, the measurements are easily made from the ground with the plant operating or stationary even without applying reflective film.



Fig. 4: OFV-505 sensor head with super long range SLR lens (200 mm focal length) and telescope.

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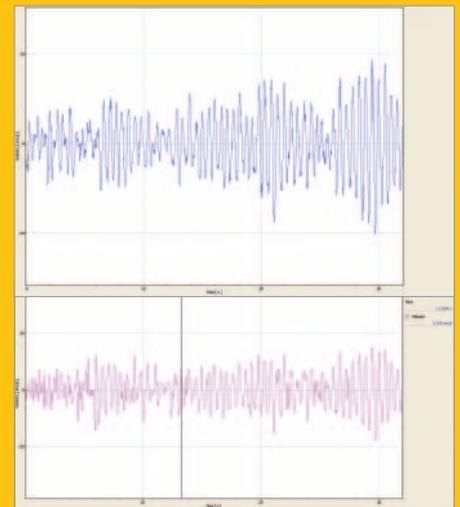


Fig. 3: Time progression of the vibrational velocity on the rotor blade; Top: PSV-400 with reflective film; Bottom: OFV-505 with SLR lens, without reflective film, with low pass filter applied (5 Hz).

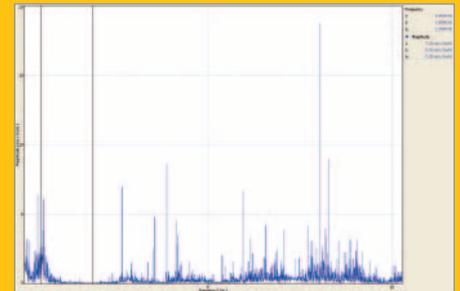


Fig. 5: Transmission function.

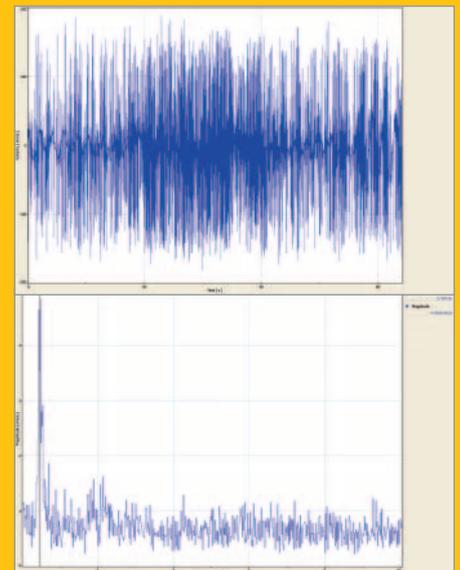
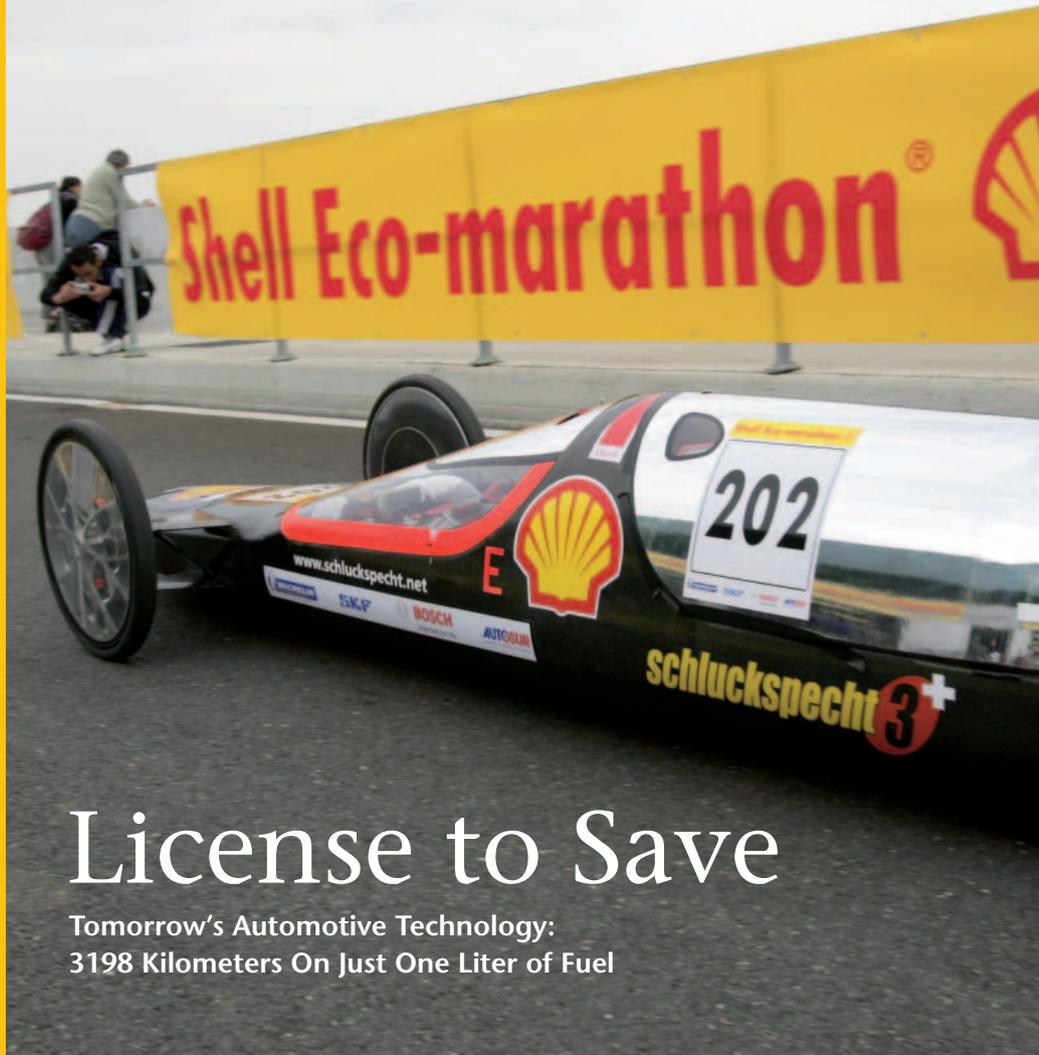


Fig. 6: Measurement during operation, time signal (top) and frequency spectrum after FFT and low pass filtering (bottom).

How far can you get with one liter of gasoline? With soaring fuel prices worldwide, this question is more topical than ever. A group of students at the University of Applied Sciences Offenburg has been working with team leader Prof. Dr. Ulrich Hochberg for ten years on making the answer as large as possible. They have developed several generations of an energy saving car, ironically called "Schluckspecht", German for "The Guzzler". Entered in the Shell Eco-Marathon in May 2008, the vehicle won 1st place in the fuel cell vehicle category and 2nd place in the overall standings, breaking through the fuel efficiency barrier of 3000 kilometers per liter for the first time.



License to Save

Tomorrow's Automotive Technology:
3198 Kilometers On Just One Liter of Fuel

Formula for Successful Energy-saving Vehicles

The recipe for success: economical, innovative drive, low weight, low air resistance, energy efficient driving manner. Although the eco-vehicle is a purely experimental car, these economy measures are equally as applicable for an environmentally friendly, commercial car. From this point of view, the concepts and ideas developed for the "Schluckspecht" are of great interest to the automobile industry.

There is a great deal of know-how in the development of the newest prototype. A single fuel cell powers a university-developed hub engine that drives the rear wheel. Using 1.2 kW, the vehicle attains speeds of nearly 50 km/h. The self-supporting chassis of the eco-vehicle weighs only 25 kg and was fabricated from carbon fiber reinforced plastic. The body has excellent aerodynamics with an overall drag coefficient

(c_w) of 0.17, originally calculated with a simulation program (ANSYS CFX) and confirmed in wind tunnel measurements at the University of Applied Science Offenburg. The structural dynamics of the chassis is also of interest. To assess dynamic properties, such as how the chassis reacts to the driver's weight or external influences while traveling, both simulations and experimental tests were performed.

Measurement of Chassis Vibrations

Laser vibrometry is an excellent measurement tool to perform modal and resonance characterization of the car quickly and without contact. The "Schluckspecht" design engineers contacted Polytec to arrange such a measurement.

In May, at the Automotive Testing Expo, the leading European trade fair for automotive test and measurement technology, the measuring setup with the eco-vehicle

was shown with a robotically positioned 3-D Laser Vibrometer known as RoboVib (Fig. 1), thus featuring two high-technology exhibits at one booth. The RoboVib Structural Test Station allows for robotic scanning and automated measurement of the vibration characteristics of a complete



Fig. 1: Polytec stand at the Automotive Testing Expo Europe.

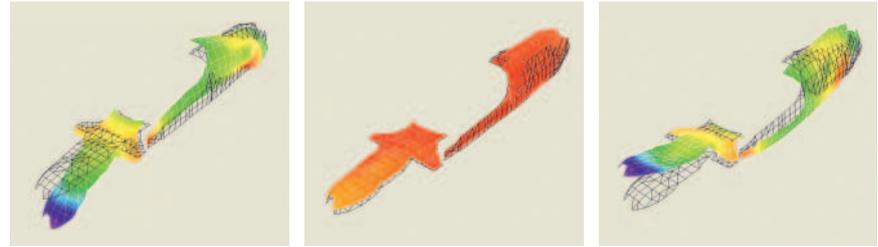


Fig. 4: Three snapshots (phases) of the chassis deflection shape at 120 Hz.

tions determined by the software. At each location, the vibration response of the corresponding measurement surface was measured and stitched to prior locations, forming a complete data set for the structure (Fig. 3). The evaluation of the measurements showed that the chassis exhibited a first order natural vibration along the center line at 120 Hz (Fig. 4). Other vibrations can also be seen, for example in the cabin. The deflections measured were only in the range of a few microns and the accelerations in the range of several m/s^2 .

Conclusions and Outlook

The natural vibrations of the chassis were in the acoustic range. Such vibrations could, for example, be excited by vibrations of the engine or by road noise. However, the measured deflections were minimal. With the aid of precise measurements and calculations, it is possible to determine elasticity parameters and the stress and strains of the chassis during operation. This allows a more in-depth analysis of the dynamic

stability. Investigations of this kind are extremely useful for CAD manufactured prototypes and are quite common in automobile development and manufacture where Polytec laser vibrometers are the best choice for non-contact vibration measurement. They are established and proven measurement tools and in connection with the automated RoboVib structural measurement station, offer great potential to further minimize vehicle development times and costs.

chassis (Fig. 2). For this purpose, the car was excited on the underside by an electrodynamic broadband shaker to initiate vibrations. The applied power was measured by a load cell and used as the reference signal. The 3-D sensor head was moved sequentially by the robot to various posi-

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Fig. 2: Vibration measurements on the vehicle using the RoboVib Structural Test Station.

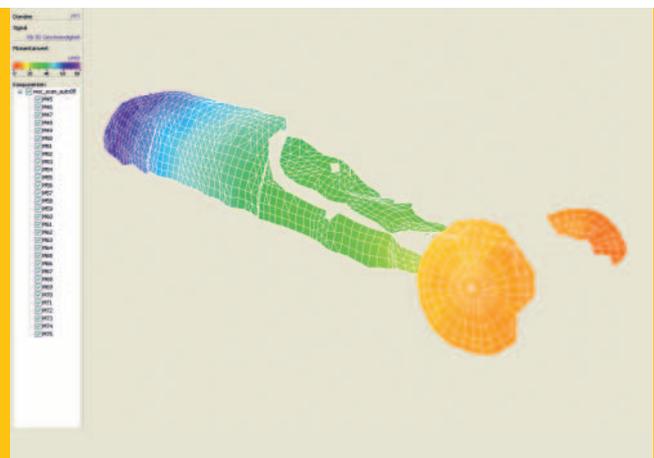


Fig. 3: Combined data set for all measurement points.



High-Revving Motorcycle Engines

Acquisition of Irregular Rotational Speed Patterns in a Four Cylinder Sports Motorcycle Engine

Because of a combustion engine's discrete firing process, irregular rotational speed patterns of the crankshaft occur. These excite components of the driveshaft, causing rotational vibrations which in turn can cause undesired noises and vibrations. On typical motorcycles, the engine and driveshaft are not acoustically encased. Consequently, analysis to reduce undesired noises and vibrations is given high priority. Acquiring the rotational vibrations induced on motorcycles can be done directly on the vehicle when placed on a roller dynamometer. For the special case of high-revving motorcycle engines ($>10,000$ cycles/min), it is best to use Polytec's RLV-5500 Rotational Laser Vibrometer.

Introduction

The design goal of modern, high performance motorcycle engines is to optimize efficiency and lightweight construction. At the same time, there is the customer's desire for smooth power delivery and comfortable characteristics from the driveshaft. This means a drive that is free of resonances and does not jerk. In addition, the stress caused by irregular rotational speed patterns, hard load and gear changes, and misuse requires precise calibration of the individual components in the vibrating driveshaft. Using dynamic simulation, the spring and damping elements of the driveshaft (Fig. 1) are designed to suit the type of vehicle – from giving a sporty to giving a comfortable ride. As however,

there are lots of things that influence the drive of a motorcycle, it is vital to analyze and test the whole driveshaft in detail. This is done by making measurements and correlating to real test drives which are especially important for determining subjectively perceptible and annoying vibrations and knocks. The vibration behavior of the total driveshaft can be examined in detail with the aid of special rotational vibration measuring setups.

Experimental Setup

The analysis of the vehicle's drive vibrations on an acoustic roller dynamometer has many advantages, apart from the rotational vibrations, the acoustic radiation can be examined at the same time. The vehicle

setup on the dynamometer reflects real conditions extremely well, and offers the advantage of reproducible driving conditions for the various loads and RPM ranges in an ideal way.

Specially manufactured measurement adapters which are resistant to rotation and are fixed on to the respective end of the crank and gear shaft, leading out of the crank housing, form the measurement objects that can be acquired by the Rotational Laser Vibrometer (Fig. 2). For this purpose, the vibrometer is set up at an appropriate distance (the operating range of the RLV-5500 is approx. 200 mm) and is aligned so that both of the laser beams emitted hit the measuring shaft at right angles and are set to be in line with the

direction of rotation (Fig. 3 and 4). Applying a diffusely reflecting self-adhesive film improves the measurement signal-to-noise and thus reduces any fluctuations in the signal. The measurement principle of laser vibrometry is based on the Doppler effect. This measurement methodology is very effective and works without making contact and is thus non-reactive (zero mass loading), allowing it to be used independently of the material properties and temperature. With the recently released RLV-5500 Rotation Laser Vibrometer, it is easy to make high resolution rotational measurements on high-revving motorcycle engines with a maximum RPM of well over 10,000/min.

Results

Measurements made on initial prototypes generally showed excellent correlation with simulation results. However, within the framework of comprehensive analyses and test drives, there were special driving conditions which under certain circumstances were perceived by drivers as uncomfortable vibrations in the vehicle. Such effects are often missed during construction and simulation and can only be detected and classified by selective examination of the rotational vibration in the driveshaft (Fig. 5 to 7). Using carefully calibrated variations of the spring package for the clutch tor-



Fig. 2: RLV-5500 Rotational Vibrometer.

sional vibration damper, optimizing the rubber packages of the rear wheel jerk damper and taking measures to limit the play in the driveshaft, it was possible to selectively influence and remedy these resonance vibrations.

Conclusions and Outlook

The comfort requirements made of modern motorcycles and their power drives are continuing to increase. This leads to additional technical challenges to make sure that the driveshaft of future motorcycles is sporty and dynamic, yet comfortable. For this purpose, the described measurement methods to acquire rotational vibrations are very important and form a comprehensive process for gaining a better understanding of complex vibration systems and to reach the design goals.



Fig. 8: Spring package for the clutch torsional vibration damper.

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Fig 3: Measurement of torsional vibrations on the crank shaft using the RLV-5500.



Fig. 4: Measurement points at the crank shaft and at the gear shaft.

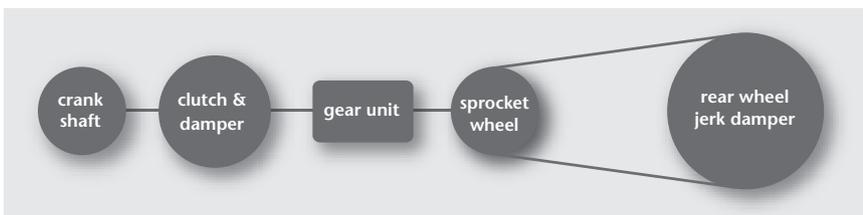


Fig. 1: Schematic of a motorbike's driveshaft.

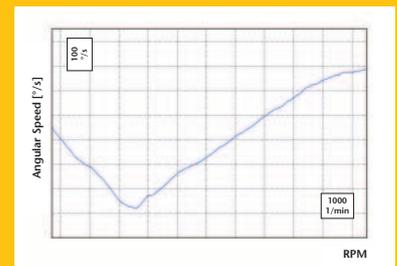


Fig. 5: First irregular rotational speed pattern vs. RPM.

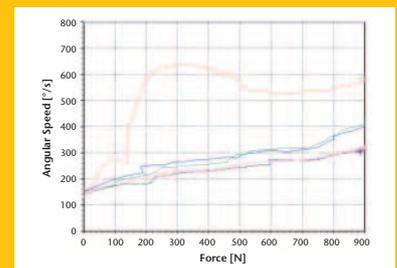


Fig. 6: First irregular rotational speed pattern vs. load.

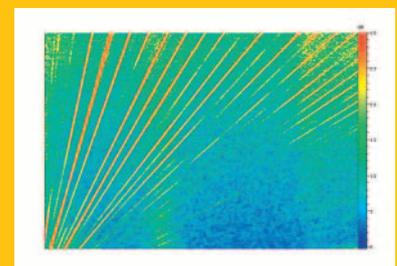


Fig. 7: Campbell diagram of a run-up measurement.

See Through Concrete

Laser-Based Ultrasonic Evaluation of Cement Hydration

Laser Ultrasonics is a scanning, acoustic method for non-contact, non-destructive evaluation (NDE) of materials. This article describes its application to cement-based materials during setting and hardening. The ultrasonic excitation is created by a small amount of ablation produced by a short-pulsed Nd:YAG-laser, and the detection on the reverse side of the sample is carried out interferometrically by a laser vibrometer. By matching the appropriate pulsed laser beam parameters to the material under study, a reproducible sound excitation was achieved. This allows the interferometric measurement of the ultrasonic pulse velocity, v_p , as well as the velocity amplitudes of the compressive wave.

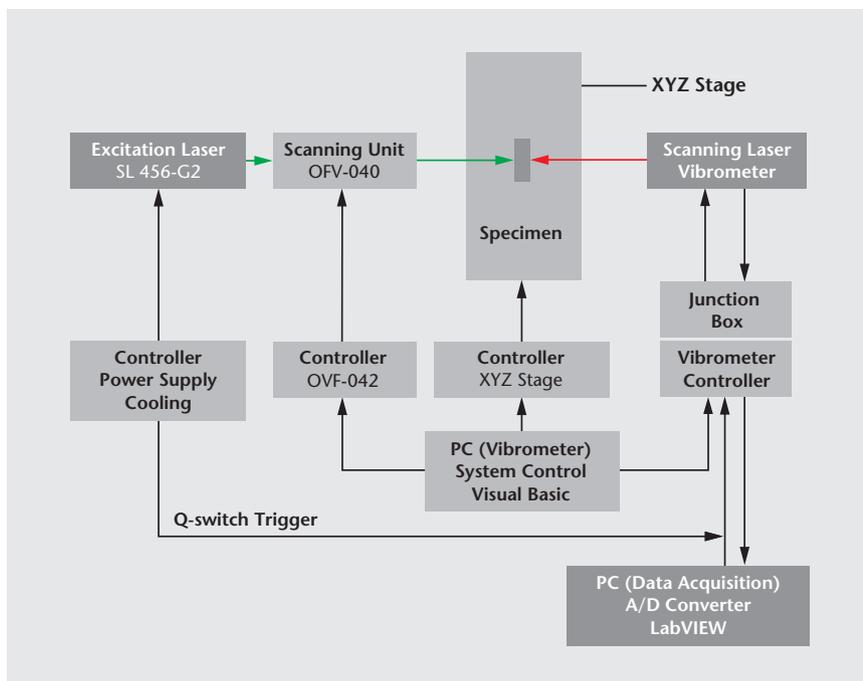


Fig. 1: Laser ultrasonic inspection setup and configuration.

Characterization of Cement-Based Materials with Laser-Ultrasonics

An understanding of the curing process for fresh cement-based materials is essential for material research, quality control, and the practical planning and implementation of construction projects. In order to describe the material properties, the ultrasonic pulse velocity (v_p), the first amplitude of the longitudinal wave and the transmitted frequency content can be used.

Immediately after mixing, cement-based materials show a significant damping effect on ultrasonic waves together with low pulse velocity. During the course of the curing process, the ultrasonic pulse velocities and signal amplitudes increase continuously. The ultrasonic pulse velocity depends on the used cements, admixtures and additives but also on the water/cement (w/c) ratio, grain distribution and air pore content. Since objects can be non-destructive



Photo: Bernd Sterzl/www.pixelio.de

faces. The resulting velocity amplitudes are measured without contact by means of a laser vibrometer using the Doppler effect and heterodyne detection. In the following paragraphs, the principles of laser-induced excitation and interferometric detection of ultrasonic waves are described with respect to the specific experimental setup that permits the investigation of cement pastes and mortars.

Experimental Setup

The principle hardware configuration is shown in Fig. 1. For laser ultrasonic generation, a Q-switched, solid-state Nd:YAG-laser with a fundamental wavelength of 1064 nm is used (Fig. 2). To characterize the excited ultrasonic waves, a scanning laser vibrometer is deployed which uses a heterodyne interferometer to detect the acoustic displacements. A sample mold with transparent walls was specifically developed for this application to allow laser-induced excitation and detection of through-transmission ultrasonic waves in setting and hardening mixtures (Fig. 3). Two measuring grids consisting of 27 measuring points for excitation and detection were created and aligned opposite to each other. The data acquisition and evaluation was managed by an algorithm implemented in LabVIEW. This algorithm allows the automatic detection of the compressive wave onset and further signal parameters such as the first amplitude of the longitudinal wave and the signal-to-noise ratio.

tively investigated without contact and at a standoff distance of several meters, laser-ultrasonic inspection is a preferred technique for a number of specific applications. Pulsed lasers permit a contactless excitation of longitudinal, shear and surface waves directly on the exposed sur-

Experimental Investigations and Results

Continuous investigations on cement-based materials during the hydration process have been carried out. Furthermore, the local distribution of the ultrasonic pulse velocity, v_p , have been determined at definite times after mixing. Various cement pastes and mortars were investigated. Regarding the cement pastes, two different w/c ratios were applied. The mortar samples had various grain size distributions and various PCE-based superplasticizer content.

In Fig. 4 the development of the ultrasonic pulse velocity is shown for two cement pastes under variation of the w/c ratio. A measuring point in the center of the specimens was chosen. The laser ultrasonic measuring sensitivity is sufficient for a through-transmission of these strongly absorbing systems. In the course of the curing, both experimental mixtures show an increase in the ultrasonic pulse velocity.



Fig. 2: Laboratory setup: Excitation laser with scanner (right, background); positioning stage with sample (center); Scanning Laser Vibrometer (left, foreground).

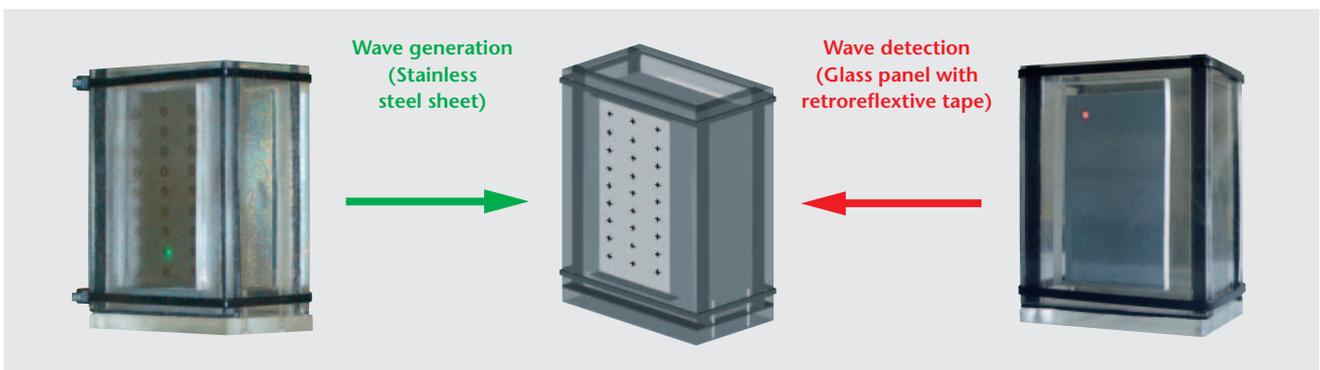


Fig. 3: Testing mold for laser-based ultrasonic evaluation: front view with excitation laser spot (left); schematic view (center); back view with vibrometer laser (right).

Continued from Page 13

See Through Concrete

Laser-Based Ultrasonic Evaluation of Cement Hydration

The cement paste with a lower w/c ratio shows a significantly stronger increase in velocity. In contrast, increasing the amount of water will lead to a delayed and much smaller increase.

In Fig. 5, the development of the first amplitude of the longitudinal wave is shown as the surface displacement on the detection side. The cement paste with a lower w/c ratio shows an earlier and steeper increase when compared to the one with the higher w/c ratio. This parameter allows a continuous evaluation of hydration kinetics. As the microstructure continues to develop, the influence of shrinkage processes on the coupling conditions becomes clear.

Local Distribution of Elastic Parameters

In Fig. 6, the distribution of the ultrasonic pulse velocity of a cement paste with a w/c ratio of 0.31 at varying points in time after

the beginning of the hydration is shown. At every point in time, similar sound velocities were determined over the whole specimen. Therefore, it can be assumed that there are no differences in the hydration progress or in the mixture composition and that the specimen is homogeneous. The comparison of the ultrasonic pulse velocities with time allows an evaluation of the hydration kinetics.

The distribution of the ultrasonic pulse velocity of a mortar sample at 5 h and 24 h after mixing is shown in Fig. 7. Over the test piece's height there are significant differences in the ultrasonic pulse velocities. In the bottom part of the specimen higher sound velocities are reached which can be explained by a higher aggregate content. This is due to insufficient mortar sedimentation stability. Before stiffening, a settling of the coarse components of the aggregate takes place and an enrichment of fine

mortar in the upper part. This is confirmed by the visual examination (Fig. 7, left). Thus, by means of the laser-based ultrasonic transmission method, a non-destructive evaluation of local structure differences vertical to the through-transmission direction can be achieved.

Summary and Outlook

The experimental results using laser ultrasonic inspection on cement pastes and mortars show that ultrasonic through-transmission can be used for a non-destructive, contactless investigation of setting and hardening of building materials. In order to describe the evolution of the material properties, the time-dependent and local changes of the ultrasound parameters can be used. The ultrasonic pulse velocity and the velocity amplitude of the longitudinal wave allow a continuous evaluation of the hydration kinetics. Using the ultrasonic pulse velocity, it is possible to show local variations of the mixture composition of the investigated cement pastes and mortars vertical to the transmission direction. This can be used to evaluate the sedimentation stability of such mixtures.

The experimental setup described here enables detection of vibration velocity only in the out-of-plane direction. Further investigations using a 3-D Scanning Vibrometer which measures the complete displacement vector (out-of-plane as well as in-plane) have revealed that the velocity of propagation of transverse vibration components (shear waves) can be simultaneously acquired during the hydration. This is an interesting approach that allows for a more comprehensive assessment of the evolution of the material's elastic parameters including Young's modulus and Poisson's ratio.

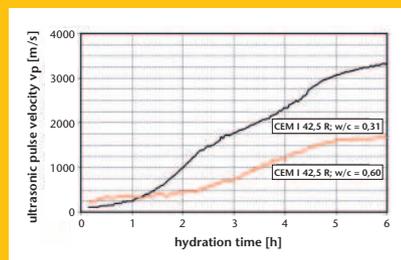


Fig. 4: Ultrasonic pulse velocity vs. hydration time for cement pastes with different w/c ratios.

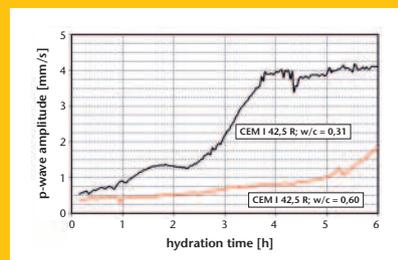


Fig. 5: Evolution of longitudinal wave first amplitude for cement pastes with different w/c ratios.

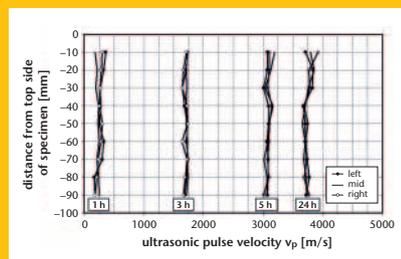


Fig. 6: Distribution of ultrasonic pulse velocity over a cement paste sample. The narrow distribution in velocity across the sample at any given point in time indicates that the sample is homogenous.

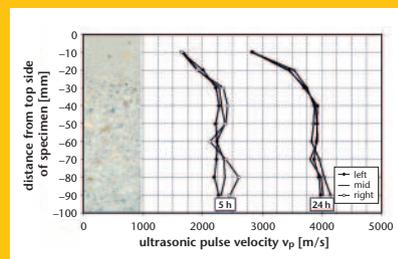


Fig. 7: Spatial distribution of ultrasonic pulse velocity in a mortar sample. The trend from lower velocities at the top of the sample to higher velocities at the bottom indicates an inhomogeneous sample. The cross sectional image at the left confirms the inhomogeneity showing larger aggregate in the bottom of the sample.

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Long Live Solar Technology

Measuring the Dynamic Response of Solar Panels with Scanning Vibrometers Supports Service Time Simulations

Computer modeling and simulation can help to determine load/strain scenarios and processes for materials and parts prior to actual deployment. In this way, they can be further developed and improved based on the results and customized to their future applications and environments. Combining simulated results with real experimental data allows a highly precise calculation of mechanical properties and can be used to predict service times for newly designed materials.



Fig. 1: Vibration measurement test setup for solar panel characterization using the Scanning Vibrometer.

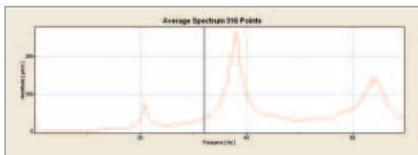


Fig. 2: Frequency spectrum averaged over all 316 measurement points.

For instance, researchers at the Fraunhofer Center for Silicon Photovoltaics CSP in Halle, Germany, investigate the mechanical vibrations on solar panels. Using this data, they are able to engineer appropriate design improvements to achieve the best possible stability and service time.

Unlike traditional contact transducer measurement techniques, the Scanning Vibrometer measurement of solar panel dynamic properties is a non-destructive, non-contact, remote method (See Fig. 1 and notice the distance from the measurement head at the top of the tower to the panel at the bottom) that enables the determination of resonance frequencies, operational deflection shapes as well as material parameters like stiffness and damping without mass loading. In Fig. 2, three of the panel's measured resonance frequencies are shown. The operational

deflection shapes (ODS) for two of the resonance frequencies are compared to the respective simulation results (See Fig. 3 and 4). The frequencies and shapes confirm the basic simulation model that has been used. To optimize mechanical strength, thus increasing the service time, variable parameters such as panel dimensions or mounting/installation techniques can now be confidently simulated, measured, and adjusted to match the expected application.

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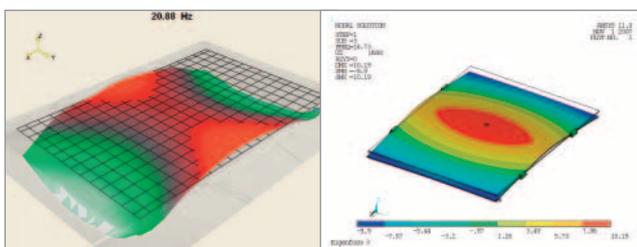


Fig. 3: First ODS measured at 20.9 Hz (left) corresponding to the simulated mode at 18.7 Hz (right).

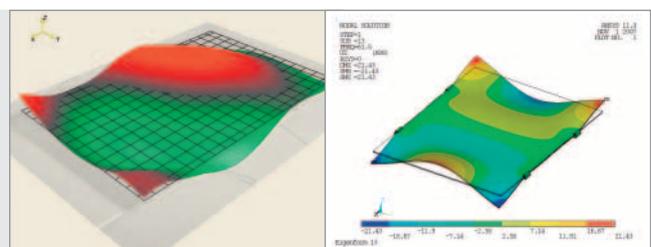


Fig. 4: Third ODS measured at 63.8 Hz (left) corresponding to the simulated mode at 61.5 Hz (right).

Harvesting Energy

In-Plane Motion Characterization of Energy Harvesting MEMS Devices

Micro-electro-mechanical (MEMS) transducers can be used to harvest energy from ambient vibrations. These electrostatic devices convert the mechanical energy contained in the vibrations of a seismic mass to an electric current by means of variable capacitors arranged in comb structures. In this article, we discuss the in-plane resonator dynamics measured with nanometer resolution using Polytec's Micro System Analyzer. By driving the transducer with increasing excitation from small to large, both linear and non-linear mechanical responses were produced and measured. Most importantly, the effect on the harvested electric power was determined for different excitations and load resistors.

Why Harvest Energy?

Miniaturized systems for energy harvesting are a key component in self-sustaining sensor and actuator systems. They produce electrical current from environmental energy sources such as temperature gradients, mechanical vibrations, or air flow. The MEMS device discussed in this article uses ambient vibrations to drive the motion of a spring-suspended seismic mass that varies the capacitance of a electrostatic comb microstructure to generate a

current. Ambient vibrations cover a wide range of amplitudes and frequencies. Examples of living body and machinery motion are presented in Fig. 1. Typically, frequencies for machinery are higher and amplitudes lower in comparison with those of living body motions.

Device Layout

The energy conversion from the mechanical domain into the electrical domain is performed by charged variable capacitors

designed as interdigitated comb structures. In Fig. 2, the functional layout of the MEMS transducer is shown next to a magnified image of an actual device. The transducer comprises a seismic mass suspended by four 1-mm-long straight springs of different widths, w_s , between 1.4 and 7.4 μm . Depending on w_s , the analytically calculated resonance frequencies vary between 96 and 1160 Hz for a seismic mass of 0.1 mg. The seismic mass with comb fingers on two opposite sides acts as

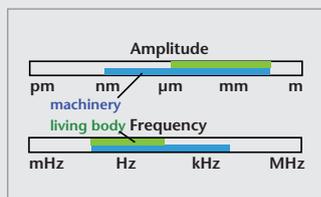


Fig. 1: Typical frequency and amplitude ranges for machinery and living body motions.

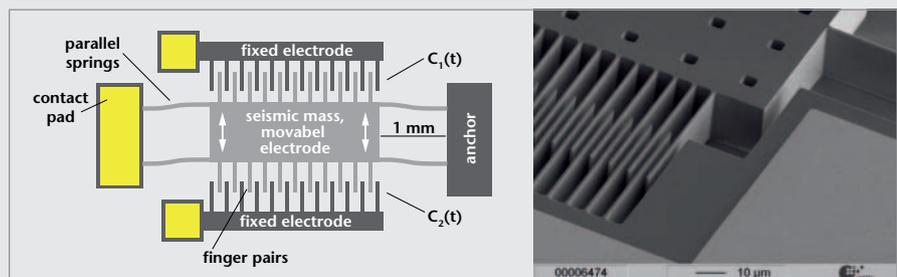


Fig. 2: Functional layout of the electromechanical transducer and SEM image of the comb structures.

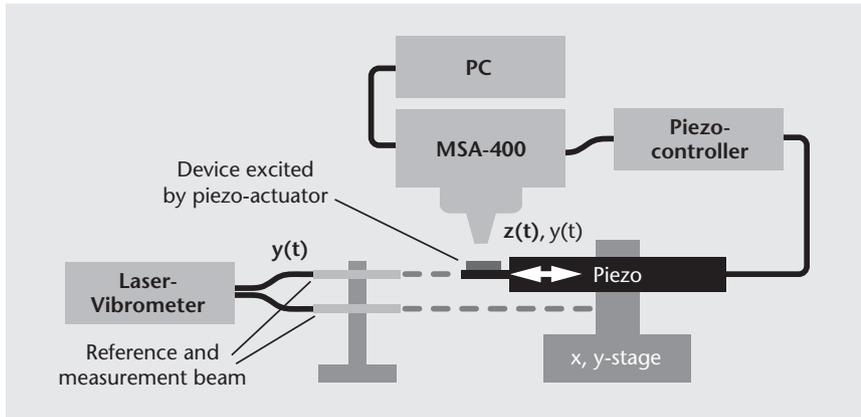


Fig. 3: Setup for the excitation and motion measurement of the seismic mass.

a movable electrode. Together with the outer comb electrodes fixed on the substrate, two variable capacitors are thus obtained. The overall in-plane dimensions of the transducer, which was fabricated using a Silicon-on-Insulator (SOI) process, are $3 \times 6 \text{ mm}^2$.

Characterization of In-Plane Motion

To gain a deeper understanding of the mechanical dynamics of the energy transducers, it is useful to characterize the frequency behavior of the resonators. For this purpose, devices were excited using a piezo-actuator as a vibration source. The in-plane seismic mass motion, $z(t)$, [amplitude and phase] and the excitation vibration, $y(t)$, are measured with nanometer resolution using stroboscopic video microscopy and optical image processing. The measurement system, a MSA-400 Micro System Analyzer from Polytec, incorporates a synchronized stroboscopic LED light source with a progressive video camera to extract in-plane motion from images “frozen” at different phases of the periodic motion. In addition, the excitation is controlled by a single-point laser-Doppler vibrometer using a measurement beam and a reference beam. The experimental setup is schematically shown in Fig. 3.

To characterize the dynamic behavior of the devices, the resonance of the seismic mass peak-to-peak displacement z_{pp} resulting from a 2.4 nm input vibration is recorded. The results are plotted in Fig. 4. The measurement data indicates a Lorentzian behavior in amplitude and phase. The phase of the motion $z(t)$ relative to the excitation vibration $y(t)$ has a shift of 90°

at resonance which is also observable in Fig. 4. When operated at atmospheric pressure, the resulting Q-factor is 190. The resonance frequency calculated from the model is 1160 Hz , which is lower than the actual measured value of 1522 Hz . The resonance frequency of the devices will further decrease with weaker driving excitation. At higher excitation amplitudes, the devices show a non-linear behavior as illustrated in Fig. 5 for three increasing drive amplitudes of 8 , 19 and 37 nm . The resonance peaks are shifted to higher frequencies with stronger input vibration. This effect is referred to as spring hardening.

What Determines the Power Output

Further experiments confirmed the correlation between the seismic mass motion and the capacitance variation and, thus, the harvested power. In Fig. 6, the measured harvested power, P , is plotted against the frequency, f , with an excitation amplitude of $0.2 \mu\text{m}$ and 70 V charge voltage for different load resistors R_{load} . It can be shown that the load value applied to an energy harvesting device is an important parameter for the power output and therefore has to be optimized in a specific application.

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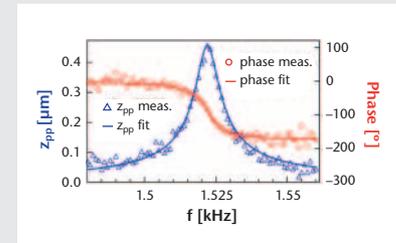


Fig. 4: Amplitude and phase of transducer oscillation vs. frequency.

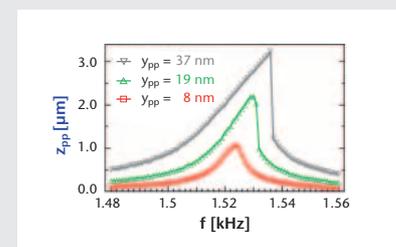


Fig. 5: Nonlinear behavior of the peak-to-peak value, z_{pp} , at higher input vibration amplitudes, y_{pp} .

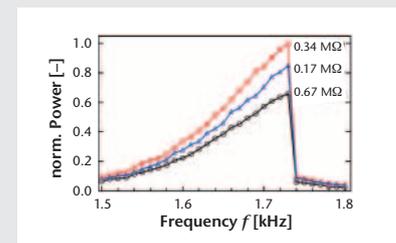


Fig. 6: Measured harvested power vs. frequency for different load resistors.

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Shock sensors that measure high accelerations from about 3000 m/s² upwards are used in crash tests and in the aerospace and aviation industries. To calibrate these sensors properly, impulse accelerations are necessary that cannot be generated with conventional electro-dynamic shock exciters. Alternative shock exciters such as the Hopkinson bar are used with laser vibrometer monitoring for accuracy.

Certified Crash Sensor Calibration

Precise, Laser Vibrometer-enabled Primary Calibration of Shock Sensors up to 750,000 m/s²



Shooting for a Good Cause

With the classic Hopkinson bar (Fig. 1), a projectile hits a long, movably bedded slim metal rod and generates a high short power surge, which the bar converts into a sinusoidal like acceleration impulse at the other end (Fig. 2). This acceleration

impulse is used to calibrate the attached sensor (Unit Under Test or UUT). For calibration purposes, a reference signal is required which can be measured in the following ways:

- A reference sensor attached to the end of the rod, on which the test sample

is mounted back-to-back, supplies the reference signal. This version is the least expensive but reliable; however, the additional mass of the reference sensor can lead to mechanical problems, meaning that higher tolerances must be accepted.



Fig. 1: Measurement setup with Hopkinson bar.



Fig. 4: OFV-5000 Vibrometer Controller and OFV-505 Sensor Head.



Combination of Proven and New Technologies

To produce the highest accelerations from 10,000 m/s² to 750,000 m/s², a projectile driven by compressed air is used. The strength of the impulse is controlled by the length of the acceleration path which can be set using an electric motor. For medium accelerations of 20 m/s² up to 50,000 m/s², a completely new kind of electromechanical impulse generator is used. This new method allows, for the first time, accurate, independent setting of shape, amplitude and duration of the impulse over a wide range. By controlling the shape and duration of the input impulse, the spectrum of the shock can be selectively influenced. This process can prevent excitation of the test sample close to its resonant frequency, avoiding excessive values of sensor sensitivity during calibration or even a destruction of the sensor.

The new electromechanical shaker has the great advantage that it can easily be linked into automated shock calibration and measurement systems, and that the shock parameters are precisely reproducible as a result of the precise mechanics and the high-precision reference measurement. Automation is of great interest when determining the linearity of the sensor's response by subjecting the sensor to a series of shocks with increasing shock amplitude. Using the SPEKTRA CS18's software, the number of shocks, the shock

width and the required amplitudes can be set. After the start of the measurement, the results of the measurement series are available within a few seconds without any further intervention by the operator.

Primary Calibration through Laser-accurate Measurement

As a reference, the primary shock calibration systems used by SPEKTRA incorporate an OFV-5000 laser vibrometer from Polytec. The vibrometer is capable of measuring speeds in a range from 1 mm/s up to 10 m/s with great precision and covers the required acceleration range. The direct traceability of the measurement to a standard physical quantity, in this case the wavelength of the laser light, allows a primary calibration according to ISO 16063-13. For this purpose, the vibrometer provides a continuous measurement signal in both analog and digital form to the SPEKTRA CS18 measurement system. A close and productive relationship between SPEKTRA and Polytec has made it possible to find an optimal solution for this measurement task.

- Strain gauges, which are attached along the rod, measure the transitory shock wave and supply the reference signal. Due to the properties of the strain gauges also higher tolerances must be accepted.
- A laser beam is aligned towards the contact surface between the end of the rod and the UUT and measures the acceleration there during the impulse (Fig. 3). Although this process is the most complex, it offers the highest accuracy, since there is no corruption of the impulse by a contact measurement.

The new family of shock exciters for the calibration at high acceleration amplitudes, which has been developed at SPEKTRA Schwingungstechnik und Akustik GmbH in Dresden, is based on the Hopkinson bar principle and additionally allows programmable calibration tasks to be processed efficiently.

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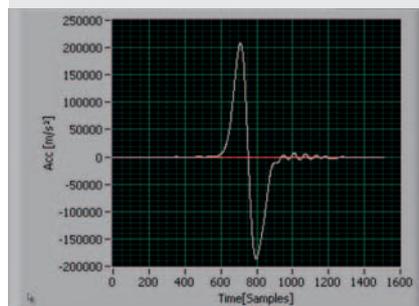


Fig. 2: Acceleration impulse from a Hopkinson bar, calculated from the velocity measured using a laser vibrometer.

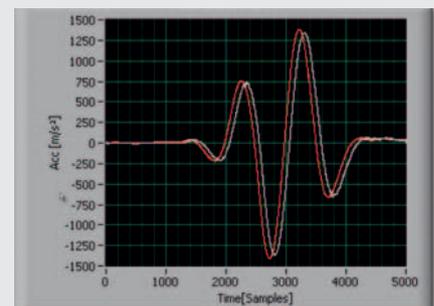


Fig. 3: Shape of the acceleration produced with electromechanical shock exciter (white = laser vibrometer, red = conventional acceleration sensor).

Smooth as a Mirror

Meeting Critical Flatness Specifications Using Polytec's TopMap Topography Measurement System

Critically precise mirror holders are used in the Geometry Scan Unit of Polytec's Scanning Vibrometer. These holders are manufactured in an automated machining center installed in Polytec's production machine shop. Stresses induced in the part from the machining can impair the flatness of the mirror mounting surface. Deviations from acceptable flatness tolerances were identified using a TopMap Topography Measurement System and were corrected appropriately in the manufacturing process.

Precision is Key

To perform correctly, the Geometry Scan Unit of the scanning vibrometer sensor head must direct the probe laser to the required measurement points using software control. The mirror holders must be manufactured with great precision to hold the optic accurately. Starting with an aluminum rod, the outer surfaces, windows and holes are turned and milled in a single run using a CNC machining

center. The mirror holder is a complex structure (Fig. 1) with narrow portions that can twist and distort during and after manufacturing. The effect of these distortions is to move the mounting surfaces and misalign the mirror. If the flatness of the mounting surface falls below a critical value, the mirror will be out of alignment and will not work properly.



Fig. 1: Mirror holder for the PSV geometry scan unit (small figure).

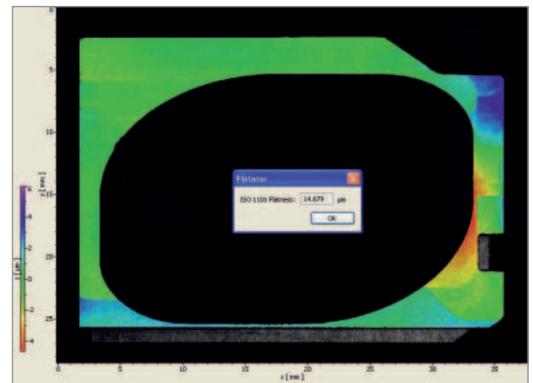


Fig. 3: A good mirror holder shows a flatness measurement ($< 15 \mu\text{m}$) that is within dimensional tolerances (ISO 1101).

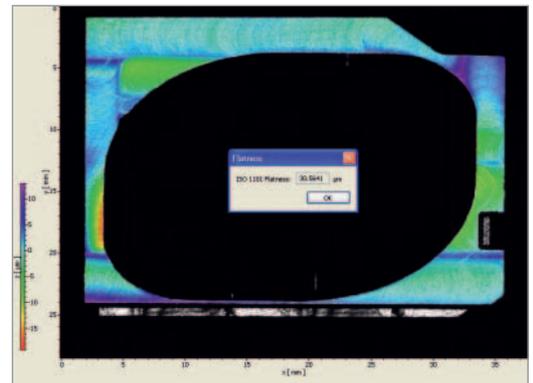


Fig. 4: A defective mirror holder shows a flatness measurement ($> 30 \mu\text{m}$) that fails dimensional tolerances (ISO 1101).

Flatness Measurements – Tactile or Optical

The mounting surface is very intricate and is made up of relatively narrow, partially recessed ligaments. It was not possible to determine the flatness with a conventional tactile sensor system because only a small portion of the surface was accessible to the scanner tip.

This situation was easily solved with the TopMap Topography Measurement System. The non-contact optical measurement procedure allows the characterization of almost any surface, independently of its specific geometry constraints. The simple-to-use TMS-100 TopMap Metro.Lab was chosen to determine the flatness of the mirror holder quickly and with high precision (Fig. 2).

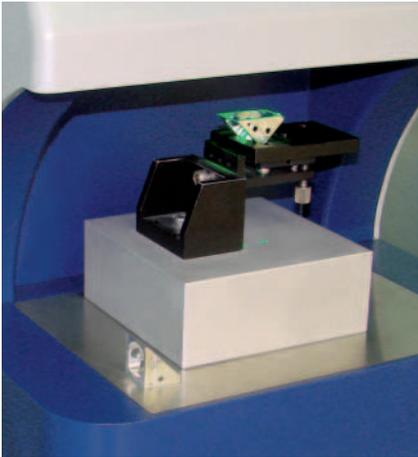


Fig. 2: Measurement setup with TopMap Metro.Lab White-Light Interferometer.

Results and Conclusions

Following ISO 1101, a comparison was made of the flatness of a good mirror holder (Fig. 3) and a defective mirror holder (Fig. 4). The measurements show that deviations of up to 100% can occur. The good part shows a flatness of about 15 μm , whereas the flatness of the defective part is more than 30 μm . With the aid of these measurements, it was possible to adapt the manufacturing process to minimize the stress causing the deformations. The manufactured parts now have the required flatness without any further efforts being taken. Thus, when setting up the machining center, an early examination of the workpieces using the TopMap

Metro.Lab can ensure better quality control while simultaneously saving both time and money. For production runs, the TopMap Metro.Lab is perfect comparison standard for statistical process control, taking random samples at set intervals in batch processes and verifying the consistency of a manufacturing process. This allows much longer manufacturing intervals with sustained quality. Serial measurement of workpieces on pallets is also possible. Because of the TopMap's good price-performance ratio, an investment in the Metro.Lab generally pays for itself very quickly.

More Info: www.topmap.info

“Quality Essentially Depends on Our Employees”

Interview with Thomas Kunz, Mechanical Manufacturing Expert at Polytec



Mr Kunz, how many different parts does Polytec manufacture in house and why?

Just on our modern INDEX G160 machining center alone, we produce over 250 different parts over the year. The manufacturing lot size varies from just a few critical parts to several hundred depending on the application. Then, of course, there are many other products, such as housings for sensor heads, that are produced on other

machines. The mirror holder for the Geometry Scanner is turned and milled from aluminum, as are 95% of all our parts. The tolerances must be absolutely accurate to assure proper fit and function in their optical assemblies. These precision parts are critical to Polytec's success and, to maintain this success, we have developed a great deal of proprietary in-house know-how. External production of these parts would not be a good solution for us.

How is the data entered in the machine?

We work very closely with the Engineering Department that supplies us with drawings and dimensions, often in the shape of a 3-D model. We examine the task in great detail and then define the individual processing steps for the CNC control. For the INDEX G160, we use a so-called “virtual machine” to simulate each program in 3-D prior to making real cuts. Once everything is OK, it entered into the G160. Following this process reduces our setup times considerably.

How do you ensure the quality of the components?

We verify all fits defined in the drawing, the shape and position tolerances, the external dimensions and the position of drill holes and threads. All test equipment is regularly calibrated. For complex and critical surfaces, we use the Metro.Lab manufactured right here in our own production group. Excellent metrology equipment isn't the complete answer. It is just as important to make sure our employees are trained and given access to professional development. Of what use is a calibrated piece of test equipment with a test certificate if it is not used properly? Our employees make a real difference in our quality and deserve a big thanks for the success of our products.

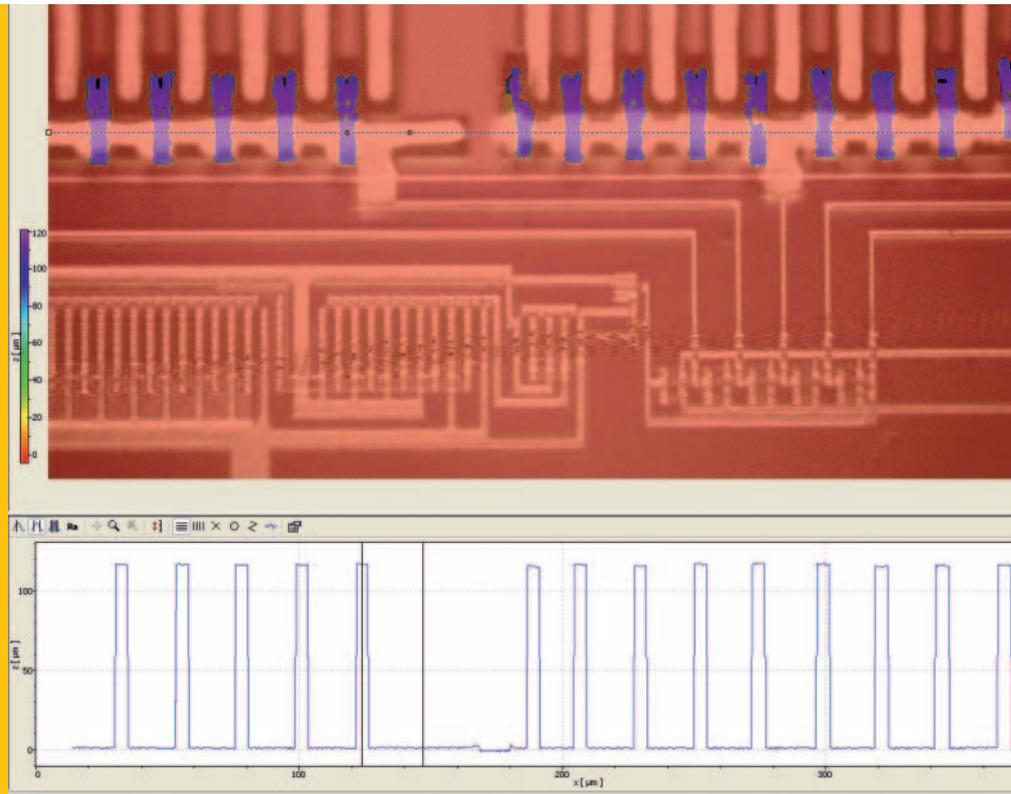


Thomas Kunz at the virtual machine.

The Ups and Downs of Microsensors

Out-of-plane Topography of 3-D Surface Micromachined Microsensors

In this article, Polytec's MSA-500 Micro System Analyzer enables characterization of the topography of two microsystems that use large out-of-plane deflections as sensor elements. The scanning white light interferometer incorporated in the MSA-500 was first used to measure an integrated magnetometer (magMEMS) whose detection principle is based on deflecting a current half-loop with a magnetic field (Lorentz force) and then to measure a flow micro-sensor that uses cantilever deflection induced by incident air flows.



Introduction

Starting with a Silicon-on-Insulator (SOI) wafer and standard CMOS technologies, an out-of-plane (3-D) movable part was created through surface micromachining by adding several CMOS-compatible steps such as a chemical release and a low temperature annealing to achieve structures that are sensitive to air flow or magnetic

field. Such mechanical structures are interfaced with electronics on the same chip and target applications where requirements include a low power consumption, a high and tunable sensitivity, and a small footprint.

Successful assembly of 3-D CMOS-compatible MEMS sensors relies on the chemical release of the microstructures and on the

control of the residual stresses built up in multilayered structures undergoing a complete thermal process. The deflection of multilayered structures made of both elastic and plastic thin films results from the thermal expansion coefficient mismatches between the layers and from the plastic flow of a metallic layer. Meeting the deflection specification for multilayered micro-cantilevers is attained a posteriori by monitoring the process thermal budget and the stack thickness.

Experimental Setup

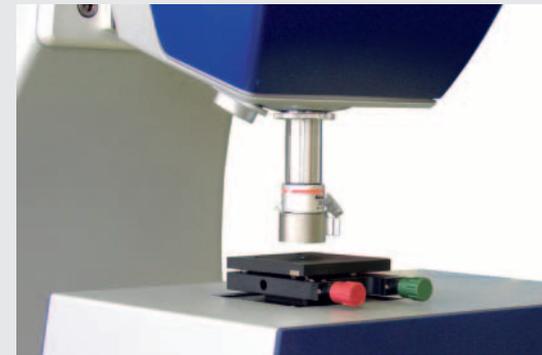
To test these MEMS sensors, Polytec's Micro System Analyzer was mounted to a probe station sitting on a vibration isolation table (Fig. 1). Two additional items are part of the system – a pressure unit with nozzle and a goniometer.



Fig. 1: Measurement and test system including the Micro System Analyzer and pressure unit (to the right, close views of the pressure nozzle).

MSA-500

Micro System Analyzer



The MSA-500 is the premier measurement technology for the analysis and visualization of structural vibrations and surface topography in micro structures such as MEMS (Micro-Electro-Mechanical Systems) devices. By fully integrating a microscope with Scanning Laser-Doppler Vibrometry, Stroboscopic Video Microscopy and White Light Interferometry, the MSA-500 is designed with an all-in-one combination of technologies that clarifies real microstructural response and topography.

Incorporated in the MEMS design and test cycle, the MSA-500 provides precise 3-D dynamic and static response data that simplifies troubleshooting, enhances and shortens design cycles, improves yield and performance, and reduces product cost. For the vibration measurement, the MSA-500 features also direct geometry scan data acquisition.

More Info:

www.polytec.com/microsystems

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Results: 3-D half-loop magMEMS (Integrated Magnetometer)

An SEM image of this CMOS-compatible magnetic field sensor is shown in Fig. 2. Within the device, an out-of-plane magnetic flux is converted into a mechanical force on the M-shaped cantilever via the Lorentz force. A Wheatstone bridge composed of four piezoresistors is integrated at the anchors of the magMEMS. The colored visualizations show the resulting deflection for the off and the on state of the device.

Results: CMOS/MEMS Co-integrated Flow Microsensor

A magnified SEM view of the flow microsensor is shown in Fig. 3. Under air flow the cantilevers bend downwards which leads to an increase of their capacitance and a lowering of the oscillating frequency of the integrated ring oscillator. Such elec-

trical measurements, combined with real-time monitoring of the cantilever topography enabled by the pressure module, are under investigation. A topographic scan at rest position is shown in Fig. 3.

Conclusion/Outlook

New CMOS-compatible microsystems are taking advantage of Silicon-on-Insulator (SOI) technology for building three-dimensional surface micromachined sensors and actuators. Topographic analysis using Polytec's MSA-500 Micro System Analyzer is critical to their development. By using accessories that inject static pressure or constant air flow in association with a compensated objective lens, flow sensors can be topographically scanned and measured. The MSA-500 also features dynamic out-of-plane and in-plane vibration measurements that could be applied in future studies.

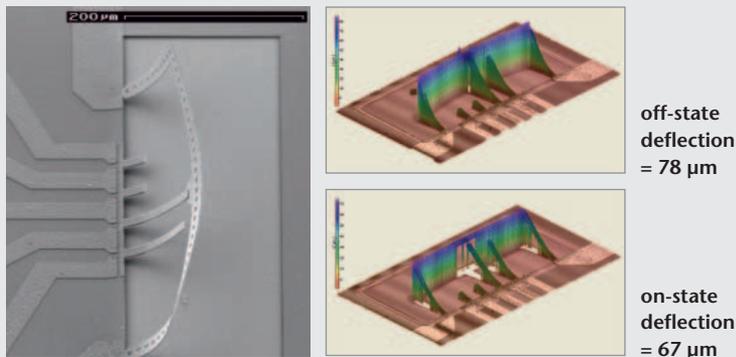


Fig. 2: SEM view of a magMEMS (on the left); resulting deflections for off and on states (on the right).

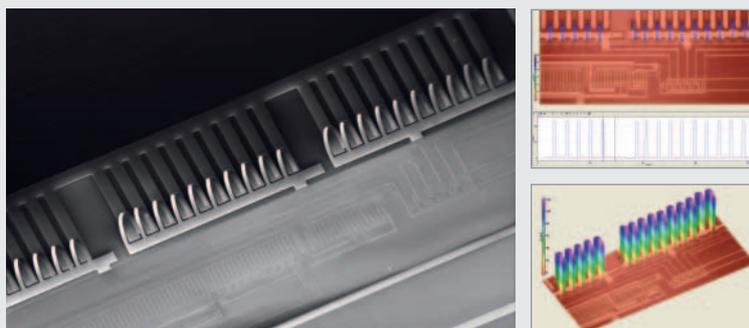


Fig. 3: MEMS flow microsensors co-integrated with SOI CMOS circuits: SEM view (on the left), 2-D and 3-D topography profiles (on the right).

Scanning for Nano Defects

Measuring Nano-Defects on Hard Disk Drive Platters Using Laser-Doppler Vibrometry



Nano-defects on the surface of today's hard disk drive (HDD) platters are both difficult to find and difficult to accurately measure using conventional optical techniques. Laser-Doppler vibrometry offers a unique capability for measuring nano-defects that might otherwise escape detection and cause drive failure. Polytec LLC (formerly THôT Technologies) has been using Polytec vibrometer systems in turn-key data storage measurement solutions for 16 years.

Introduction

With today's disk drives pushing performance limitations, measurements of defects on the surface of the disk has become critically important. Disk drives consist of a read/write head flying over the surface of a spinning disk. The head is flying over the surface at a distance of several nanometers from the surface, following the topography of the surface (i.e. curvature and waviness). As it encounters "bumps" in the surface, the flying height becomes modulated. In the case of significant flying height modulation, undesirable head-disk interaction can occur resulting in the loss of data, wearing of the disk or failure.

Therefore, surface topography measurement of the disk becomes critically important. Several techniques to perform disk topography measurements are available. These include white light interferometry, scatterometry, atomic force microscopy and laser-Doppler vibrometry. Each method has its advantages and disadvantages; users

tend to use familiar techniques at their disposal to "see" aspects suitable for each tool. For instance, imaging techniques such as white-light interferometry are capable of mapping the whole disk, but lack lateral resolution. Scatterometry can be used for looking at the roughness of disks. Atomic force microscopy has high lateral resolution for looking at nano-defects, but would be tediously slow for mapping a disk.

Using Laser Vibrometry

Laser vibrometry has the desired advantages of high resolution (both vertical and lateral), as well as speed for scanning the whole surface of the disk (see the article Higher Density, Higher Performance in issue 2004/2 on www.polytec.com/infocus). Here we explore the capabilities of this technique for finding and accurately measuring nano-defects. Nano-defects are categorized as defects that are at or below the wavelengths of visible light (0.4 to 0.7 microns). This characteristic makes them particularly difficult to measure using optical techniques. From the Rayleigh Criteria, the resolution limit for an optical imaging system is approximately equivalent to the wavelength of light used. For example, a confocal microscope using high aperture, oil immersion lens can achieve resolution of 0.2 microns under ideal conditions. As shown in Fig. 1, laser vibrometry is implemented for scanning disks by focusing the beam using a micro spot lens and directing it with a 90 degree

prism down on the surface of the disk. A spot size of 2 microns is achieved using a micro spot lens. As the disk spins (at right angles to the laser beam), any disk tilt, warping, waviness, and roughness are measured as "up and down" motion in the measurement direction. These "up and down" motions are interpreted as vibration by the laser system and each vibration frequency can be isolated (filtered) as needed. Frequency is converted to wavelength by simple knowledge of the rotation speed and measurement radius. For instance, for small defects, using a high pass filter eliminates the longer wavelengths and allows analysis of roughness and micro/nano defects.

Scanning for Defects

If a particular feature has a return signal response higher than the background level of roughness, then this is marked as a defect. In Fig. 2, the velocity response is shown from a defect where the velocity response is significantly higher than the background level for roughness. Another important feature of the laser vibrometry technique is that the polarity of the velocity for the measurement (positive velocity for "up" and negative velocity for "down") determines the shape of the defect. Because of its spatial size, a defect typically has fast rising and falling edges. The advantage of using a velocity signal is that these fast edges have higher velocities and are measured as distinct impulses on the vibration signal. A bump defect has a

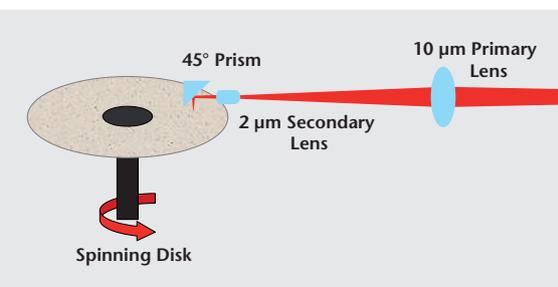


Fig. 1: Set-up for scanning a disk with a laser vibrometer.

distinct “positive followed by a negative” impulse response and a pit has the opposite “negative followed by positive” response. This logic is used to categorize bumps and pits.

Nano Defects

The example above shows what happens for a large defect. What happens to the response when a nano-scale defect is measured? Because of the defect’s spatial size to imaging beam diameter disparity, the measured velocity signature is distorted or “convolved” by the imaging (measurement) beam. When imaged with a laser beam larger in spatial size, the result of the defect measurement is a “convolution” or reduction in measured height and associated broadening. Fig. 3 shows the effects of convolution on defects of the same height, but reduced size. The first example on the left shows the response (bottom) from a defect with 2 micron width (middle, blue) with corresponding laser beam intensity profile (top, red). As the defect spatial size is reduced, the velocity response becomes smaller. In the last case to the right, a defect of 0.2 micron size is measured (corresponding to 0.2 micron section of the measurement beam). Note that the response is only slightly larger than the background roughness, establishing a threshold for detectable defect size. Only velocity signals that are 10% above than the background roughness are determined to be defects. Hence, the smallest height detectable is dictated not by the spatial size of the defect or by the beam diameter but rather by the background roughness of the measured surface.

Deconvolution

Here deconvolution techniques can be used to determine accurate height/depth values from defects with sizes smaller than the beam diameter. In optics and imaging, the term “deconvolution” is specifically used to refer to the process of reversing the optical distortion that takes place in an optical microscope, telescope or other imaging instrument, thereby creating clearer images. A well known example is the Hubble Space Telescope. The early space telescope pictures were distorted by a flawed mirror. Knowledge of the mirror distortion allowed a fixed deconvolution algorithm to be applied to sharpen the images.

The deconvolution technique used is mathematically given by:

$$(f * g) + \epsilon = h$$

where:

h is the recorded signal,
 f is the signal we wish to recover,
 g is the convolving function, and
 ϵ is any noise that has entered the recorded signal.

As the laser is scanned across the disk to create a continuous surface map, the spatial size of the defect is determined “on the fly” using the velocity response from the defect edges. Using this spatial size information, the raw velocity is deconvolved to determine the true velocity signal and this “corrected” velocity is integrated to determine height (or depth).

Results

Once the defects are identified, they are classified by shape (bump or pit) and size (nano-asperity, micro-asperity, asperity, contamination, and particle). A disk map is produced showing the precise location of the defect on the disk. Separate plots are made for both asperities and pits. In Fig. 4, a disk is shown with nano-asperities that would pass normal glide and certification tests, but fail at the drive level. This nano-asperity pattern is fairly typical of a

polishing process not quite “in control” because the manufacturer currently has no way to detect these nano-defects and therefore take corrective action. Similarly, the nano-pit mapping is shown in Fig. 5 where a “nano-scratch” is seen in the lower right quadrant.

Conclusion

We have described a measurement technique using Laser Vibrometry that can quickly scan and map out defects on HDD disks that are below the optical limit for light, so called nano-defects. The laser vibrometer technique has many advantages over conventional techniques such as high vertical resolution ($\ll 1\text{\AA}$) and rapid measurement of the whole surface of the disk. Using deconvolution, we can extend lateral resolution to the sub-micron level and measure nano-defects. Laser Vibrometry allows accurate and reproducible measurements to be made that correlate well with Atomic Force Microscope (AFM) results. Given the current development trends, laser vibrometry will become a critical tool for finding the nano-defects that affect the performance of tomorrow’s disk drives.

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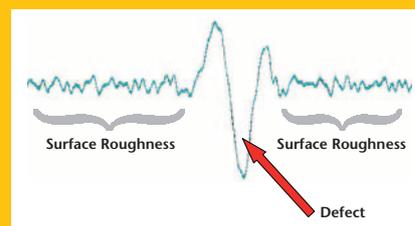


Fig. 2: Velocity signal for a defect measured against background roughness.

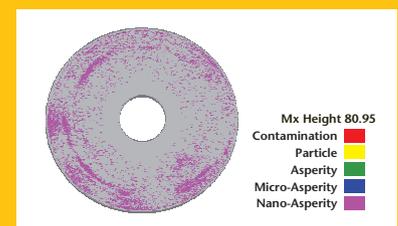


Fig. 4: Plot of nano asperities on a disk.

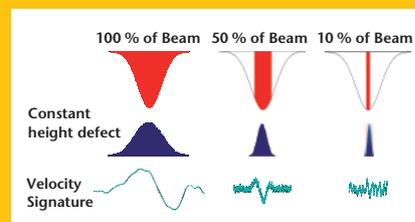


Fig. 3: Velocity signal (bottom), defect (middle) and corresponding laser beam profile (top) for defects with size decreasing to 0.2 microns (or 10% of laser beam diameter).

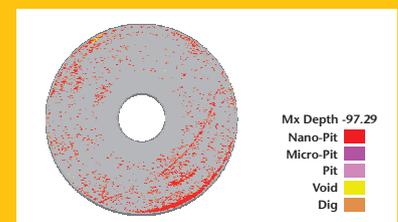
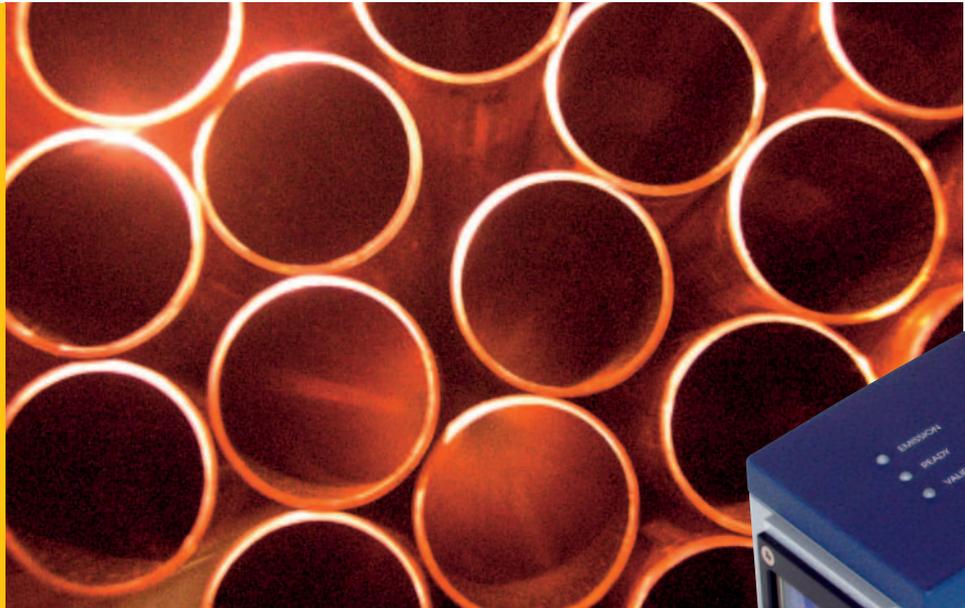


Fig. 5: Plot of nano pits on a disk.

A Clean-cut Case

Laser Surface Velocimeters for Cut-to-Length Control at Tube Factories

Online, high-precision, laser-based velocity and length measurement by Polytec's Laser Surface Velocimeters reduces the manufacturing costs, improves quality and increases yield in tube mills around the world.



Mueller Copper Tube is the UK's biggest copper tube manufacturer and operates the most modern and environmentally efficient plant of its type in Europe. In 2007, Mueller purchased and installed three

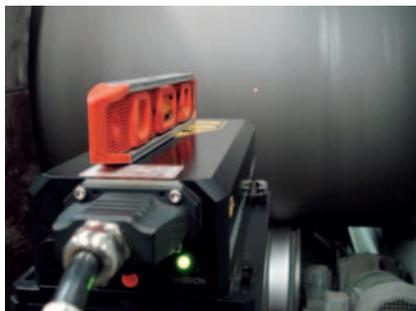
LSV-300 laser surface velocimeters to control cut-to-length of copper tubes. Before discovering the advantages laser velocimetry, Mueller used encoder wheels that would slip and wear introducing substan-

tial errors into the cut-to length process. After making the transition to non-contact laser velocimetry, there have been demonstrable improvements in yield. With a 0.05% cut-to-length accuracy, laser velocimeters are becoming increasingly more important due to rising costs of copper. Additional savings are secured by using the LSV, a measurement system with no moving parts, virtually eliminating maintenance and associated labor costs.

The Borusan Mannesmann tube factory, located near Bursa in Turkey, has used a Polytec LSV-300 system since 2006. New meetings took place with their management to furnish all their production lines with LSVs. Erdemir is another leading Turkish tube and metal producer who uses a Laser Surface Velocimeter. Initial tests for cut-to-length control were run at Borusan Izmit factory, where they produce large diameter tubes.



Two of the installed LSV-300 Surface Velocimeters for cut-to-length control at Mueller Copper Tube in Bilston, Great Britain.



LSV installations at Borusan Mannesmann and Borusan Izmit tube factories in Turkey.

Now All-in-One!

Robust Velocity Measurement Improves On-line Feed Control and Operational Efficiency: New, Ethernet-ready Industrial Velocimeter

The LSV-1000 Laser Surface Velocimeter (LSV) represents a new generation of compact industrial velocimeters offering cost-effective, non-contact length and surface velocity measurements. On-line feed control and cut-to-length applications benefit from eliminating error-prone contact wheels and installing velocimeters for fast, reliable, and precise speed and length data. Measuring steel, high-gloss aluminum, oiled metal sheets, wire, cable or non-metallic surfaces – it doesn't matter. Polytec's new LSV can measure on virtually any material and enable process control that delivers tighter specifications, lower maintenance costs and faster ROI.



There are many key features incorporated into the LSV-1000 including:

- Safe operation in harsh industrial environments with available IP 66 and IP 67 housings
- Rugged sensor design with optional cooling and air purge systems
- Efficient and simple integration, direct replacement for contact wheels
- Many stand-off distances: 300 mm, 500 mm, 700 mm, 1000 mm (more in preparation)
- 24 V power supply
- Ethernet, serial, and encoder interfaces
- Convenient accessories such as a cooled protection housing and a 90° deflection unit

More Info: www.polytec.com/lsv



For Specific Tasks:

The Small Scanning Solution

The new ODS scanning extension is capable of sequentially positioning a single-point vibrometer to give a comprehensive test station for acquiring 1-D and 3-D operational deflection shapes (ODS) on small structures such as data storage drives and actuators. The platform can be combined with the ODV-534 Compact Sensor Head with built-in camera for 1-D measurements or with the CLV-3D Sensor Head for 3-D deflection shapes. The platform is based on precision x-y-z motorized linear stages with 200 mm x 200 mm x 50 mm ranges in the respective directions. Together with a simple, interactive definition of the measurement points, a quick measurement of the operational deflection shapes (ODS) of the sample is possible. The Scanner Control Software works jointly with the VibSoft Data Acquisition Software. Together, these software packages provide a dataset of the measurement including geometry data in the Universal File Format (UFF). Thus, the operational deflection shapes can be imported into ME'scope software for modal analysis.

www.polytec.com/vibrometer

For Ultrasonic Time-Domain Measurements in 3-D:

New High Frequency PSV-400-3D-M Scanning Vibrometer



Designed for full-field vibration measurements at high frequencies, Polytec has extended 3-D Scanning Vibrometry to include ultrasonic applications by installing new digital decoders featuring 1 MHz bandwidth. This enables time-domain measure-

ments at much higher temporal resolution, for example when determining the propagation of Lamb waves for non-destructive material testing. To properly characterize ultrasonic drives, actuators or sensors, a new, high-resolution camera system including a zoom objective provides a very precise definition of the measurement points. The geometry measurement is supported by a special image processor. When working with geometry import (e.g. from FE models), the basic alignment of the system is simplified by using a high-precision reference object available from Polytec.

www.polytec.com/psv3d

PSV-400-3D-M Specifications	Data Acquisition	Signal Generator
Bandwidth	1 MHz	500 kHz
Channels	3 Vibrometer channels 1 Reference channel	1 Output channel



Trade Shows and Conferences

Oct 22 – 24, 2008	Automotive Testing Expo	Detroit, MI, USA
Nov 18 – 20, 2008	AeroTest America 2008	Fort Worth, TX, USA
Dec 03 – 05, 2008	Semicon Japan 2008	Chiba, Japan
Jan 21 – 23, 2009	SIAT 2009	Pune, India
Jan 25 – 29, 2009	MEMS 2009	Sorento, Italy
Mar 10 – 11, 2009	Smart Systems Integration 2009	Brussels, Belgium
Apr 20 – 24, 2009	Hannover Messe 2009	Hannover, Germany
May 04 – 05, 2009	AISTech 2009	St. Louis, MO, USA
May 05 – 08, 2009	Control 2009	Stuttgart, Germany

Reference our web site www.polytec.com for the most up-to-date information and links on trade fairs, events and seminars!



Register for one or many seminars at the Polytec Web Academy at <http://polytec.webex.com>

Oct 23, 2008	Introduction to Optical Vibration Measurement with Laser-Doppler-Vibrometry	11.00 CEST (Europe)
Oct 23, 2008	Introduction to Vibrometry for Non-contact Vibrational Measurements	11.00 PT (USA)
Oct 28, 2008	Introduction to Optical Surface Metrology	11.00 CEST (Europe)
Nov 4, 2008	Dynamic measurements of Microstructures	11.00 PT (USA)
Nov 12, 2008	Non-contact Vibration Measurements at Ultrasonic Frequencies	11.00 PT (USA)
Nov 20, 2008	Measuring Hearing Dynamics and Other Bio-Medical Applications	11.00 PT (USA)

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