Issue 01 | 2008

Polytec

InFocus

Optical Measurement Solutions

Fully Automated

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Innovative Solutions in 3-D Vibration Measurement

Dr. Helmut Selbach

Eric Winkler

Dear Reader,

We are proud to present the RoboVib Structural Test Station, the next step in automated 3-D vibration measurement technology. We married our market-leading 3-D Scanning Vibrometer technology to a multi-axis industrial robot, giving the engineer a stable, auto-configurable 3-D vibration measurement station for whole body measurements.

Computer aided engineering (CAE) plays a critical role in developing today's products but the results are only as good as the mathematical model. Consider the improvement in the CAE process from quickly and easily taking data on real prototypes at the exact nodal points of the underlying finite element model. The RoboVib Station not only provides seamless integration of the vibration measurement data into the CAE workflow, but also boosts productivity in test and FE model updating. With this automated solution, modal testing could even be integrated into the production line for quality monitoring!

Traditional methods, such as contact accelerometers, require direct attachment and complex cabling of sensors. Vibrometry, on the other hand, does not influence the dynamics of the measurement object and enables rapid data acquisition at high spatial resolution with freely defined and positioned measurement points.

As you make your way through this issue of InFocus, don't miss the many interesting contributions from our users, and the latest innovations from our Optical Measurement Systems business unit.

Your comments and feedback are encouraged as we work together to develop the best solutions for today and tomorrow's measurement applications.

Dr. Helmut Selbach
Managing Director
Polytec GmbH

Eric Winkler
Head of Business Unit
Optical Measurement Systems

News from the Worldwide Polytec Network

Polytec is continually enhancing its capabilities to provide our worldwide customers with the best support. In addition to our sales, service and application engineering staff in the USA, Germany, England, Japan and France, we support a network of local representatives in Europe and Asia.

We welcome new agents supporting our Vibrometers and Surface Velocimeters (LSV) in South Africa, Switzerland, India, Russia, Belarus, and the Ukraine. In addition, we now have LSV-specific representatives for Poland, the Czech and the Slovak Republics as well as the People's Republic of China. In Korea, we have added a new sales partner for topography measurement systems. You will find detailed contact information about our representatives on our homepage at **www.polytec.com/contact**

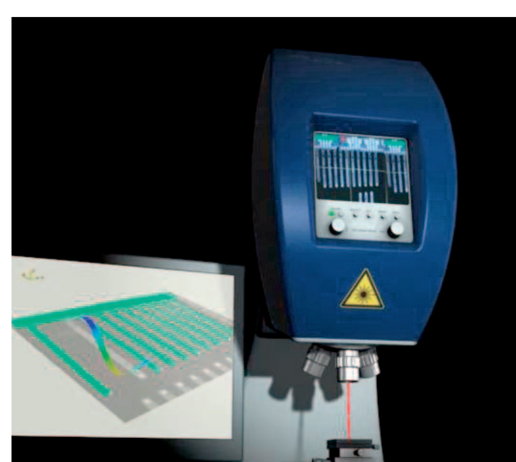
Polytec Wins Back-to-Back Awards at the MessTec Masters

Polytec's RoboVib Structural Test Station won second place for the most innovative product at the 2008 MessTec & Sensor Masters Trade Show in Stuttgart, Germany. Selected by a jury of experts and confirmed by online voting, RoboVib's extraordinary capability to improve efficiency in automated modal testing has been validated. This makes two awards in two years. Polytec also won in 2007 for the RLV-5500 Rotational Vibrometer.

Learn About Dynamic and Static Characterization of Microstructures At Your Desk – Order the Video

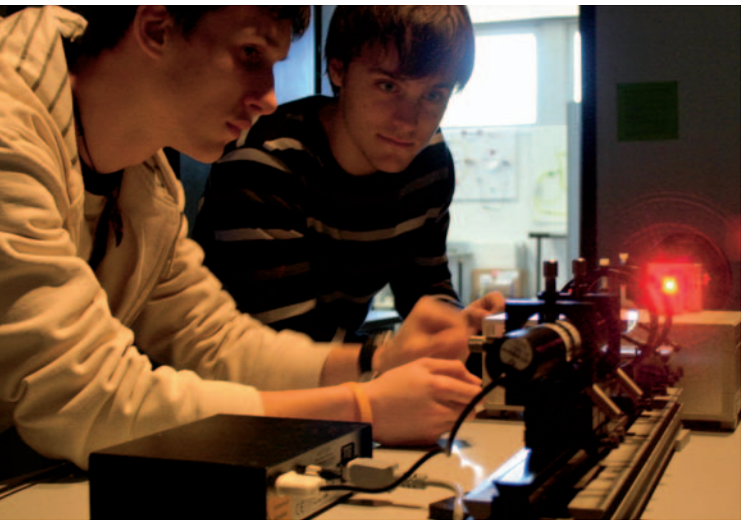
Micro-electromechanical systems (MEMS) that are reliable, precise, manufacturable and cost-effective are an enormous research, design and production challenge. Microstructure development critically depends on the right engineering tools to take a design from concept to reality. Polytec's Micro System Analyzer, or MSA, is one of the most important measurement tools, providing data on resonant frequencies, deflection shapes and static topography in a matter of minutes.

By quickly clarifying key structural responses, the development of complex MEMS devices is accelerated. To be sure that the impact of this revolutionary technology on MEMS development is well understood, we have developed a video where we show how the Micro System Analyzer works and how it is operated. View the video trailer on our web page and order your individual DVD at: **www.polytec.com/mems**



Fascinating Light

Innovation Needs People – Polytec Sponsors Students' Optics Projects



The "Innovation League" is a project of Germany's Federal Ministry of Education and Research (BMBF) and is expected to initiate 1,000 partnerships between schools and interested companies in the next two years. Polytec is actively involved in encouraging students in the sciences.

Polytec wants to motivate these young students to study optics at the university. To accomplish this purpose, Polytec sponsors a joint project with Langensteinbach High School not far from Polytec's headquarters. In cooperation with the Optics Development Department at Polytec, a group of students has configured a liquid crystal display, like those used in video projectors, to write computer generated holograms. These holograms allow them to simulate lenses, diffractive optics and other optical structures. Due to their excellent work,these students were invited by the BMBF, as one of 10 groups across Germany, to attend the Congress of Optical Technologies in Berlin to present their project in February.

http://www.bmbf.de/en/3608.php

New Vehicle-in-the-loop Test Bench

Includes a PSV-400-3D Scanning Vibrometer

A newly formed NVH/Driveability research group at the IPEK – Institute of Product Development at the University of Karlsruhe is researching methods and processes for integrating NVH (Noise, Vibration, Harshness) relevant information into early phases of the product development process. Linking objective measurement data to subjective driveability assessments is an important part of the research program. In addition to using experimental methods, simulation methods are being developed, refined and implemented.

The test lab has been completed and includes a new roller dynamometer test bench for acoustic measurements on cars. The roller dynamometer has two rollers that are driven independently of each other, with an outer diameter of about two meters and a total 440 kW drive capacity. This test bench provides a valuable research tool to study new methods in the field of NVH. Integrated into the test bench is a new Polytec 3-D Scanning Vibrometer for non-contact and nonreactive acquisition of three dimensional vibration data from complex automotive structures. Consequently, from the single element to the whole system, these research facilities provide a comprehensive test and measurement solution.

www.ipek.uni-karlsruhe.de

i, RoboVib

Structure-borne Noise Measurement with a Robot-controlled 3-D Scanning Laser Vibrometer

With the new RoboVib Structural Test Station, measurement of the vibrations produced in a vehicle can be completely automated using laser-Doppler vibrometers. In addition, the preparation of the measurement can be supported with robot simulation software, thus saving valuable time for test rig operation and prototyping. In the following application example, the acquisition of the transmission functions for an entire vehicle chassis using the RoboVib Station is described in detail. The transmission functions measured are used to characterize the natural vibration behavior shown by the chassis with the aid of experimental modal analysis (EMA).

Flexibility Through Robots

To measure a complete vehicle or car body using a 3-D Scanning Vibrometer, the scanning heads must be repositioned several times to cover all views. Each of the partial measurements or views is then stitched together to make a complete picture of the car body.

The RoboVib Structural Test Station uses an industrial robot to automate the repositioning of the heads. Using six rotation axes, all degrees of freedom in space can be used by the robot. A seventh linear axis which can be used to move the entire robot arm increases the reach. A fixed arrangement of the scanning heads has been selected for mounting on the industrial robot. By means of this mounting fixture the scanning heads take a well defined position relative to the robot's arm. In order to obtain the positions and orientations of the scanning heads, a 3-D alignment procedure is not needed anymore. The software calculates the position and orientation automatically from the robot's coordinates.

Measurements: Preparation and Operating Sequence

First, the scan points are defined. For this purpose, they can either be imported from calculation programs or set interactively. During interactive scan point definition, the 3-D coordinates are ascertained by the integrated geometry scanner. The result of the geometry measurement is shown in Fig. 1.

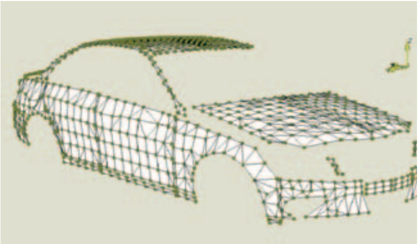


Fig. 1: Interactively defined and measured 3-D geometry, 1094 measurement points.

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i, RoboVib

Structure-borne Noise Measurement with a Robot-controlled 3-D Scanning Laser Vibrometer

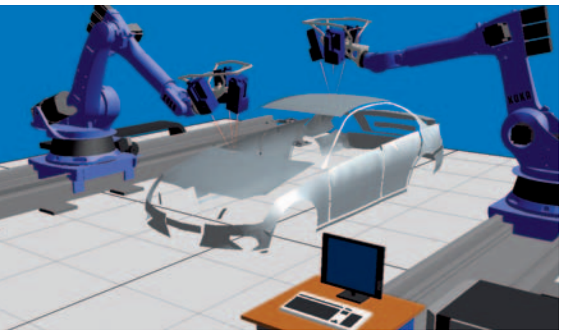


Fig. 2: Preparation of the measurement in the robot simulation software.

Before starting the measurement, the robot positions are defined, from which the measurement is made. This can either be done directly on the robot using the "Teaching" mode or through robot simulation software. Once all measurement points have been defined, a calculation is carried out to ascertain which measurement point can be reached optimally from which position. The software takes into consideration the angle of incidence of the laser beams on the surface as well as possible shadowing. Fig. 2 shows an installation with two robots and two measurement systems. An installation of this kind can be used to measure all the external surfaces of a vehicle.

For the test, the vehicle is excited by an electromagnetic shaker at one point. The force applied via the shaker is measured using a power cell and is used as the reference signal for all measurements. The total installation is shown in Fig. 3. The measurement process is fully automatic (Fig. 4). Thus the robot controller triggers the next measurement respectively as soon as a measurement position is reached. The measurement software in turn triggers the robot control to move on as soon as a measurement has been completed. This measurement includes approx. 1100 scan points with a required time of 5 seconds each. For this test, 43 robot positions were used. The total measurement time was approx. 1.5 hours, of which a total of only less than 5 minutes was needed to position the scanning heads.

Precise Results and Seamless Evaluation

Once the measurements from all positions have been completed, the individual results are stitched together to form a result that can be analyzed as a single deflection shape. In Fig. 5, one of the deflection shapes measured is shown. In the picture both the undeformed object (black lines) and also the deformed object (white lines with surfaces) are shown. More clearly illustrated than through an individual image, the deflection shapes measured can be shown as animation in the software. An important criteria for evaluating the quality of the data is the coherence between excitation and answer signals. Fig. 6 shows an example of a scan point and a measurement direction of the frequency response function and the corresponding coherence function. The coherence function for almost all frequencies is virtually 1. This supports the interference that there is excellent correlation between the excitation signal and the answer signal. Through robot supported positioning of the scanning heads, every scan point can be measured from an optimal distance and at an optimal angle.

Improved FE-Test Correlation

An important application of the measurement results is the comparison of FE simulation models with the measurement data derived from the experimental modal model. For this purpose, the measurement data is imported into the commercially available software packages for experimental modal analysis (EMA). The EMA extracts the modal parameters from the measured transmission functions – the natural vibration shapes (modes) with the corresponding eigenfrequencies and modal dampings. These results can be compared to the natural deflection shapes and the eigenfrequencies calculated from the simulation. Furthermore, you get the values for modal damping. The simulation models can now be adapted in such a way that they generate the same natural vibration shapes and eigenfrequencies as the measurement. The comparison with the simulation models is often still carried out today through interactive evaluation and visual comparisons. Measurement grids and FEM grids are usually generated separately from each other. By using the robot-supported 3-D Scanning Vibrometer, it is

Fig. 3: Measurement setup showing the scanning heads mounted on the robot, a vehicle ready to be measured, and the data acquisition and control instrumentation.

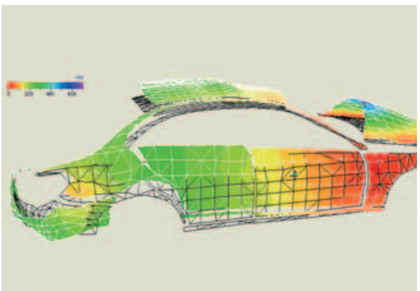


Fig. 5: Measured deflection shape at 41 Hz.

now possible to apply automated FEM grids for the preparation of the measurement. The measurement results are then at the same coordinates as the simulation results. This means the test can be seamlessly integrated into the CAE process. Updating of the simulation models becomes more accurate and safer. The boundary conditions are clearly defined and known to both the CAD engineer and the NHV test engineer.

Need more Information?

The RoboVib Video shows the operation of the RoboVib Structural Test Station step by step. It demonstrates how complex geometries can be measured quickly and easily, and how the results can be integrated in the engineering workflow. View or download the RoboVib Video from **www.polytec.com/robovib** on our homepage.

There you will find more detailed information about the RoboVib Structural Test Station. Contact a Polytec product specialist to give you expert advice: **info@polytec.com**

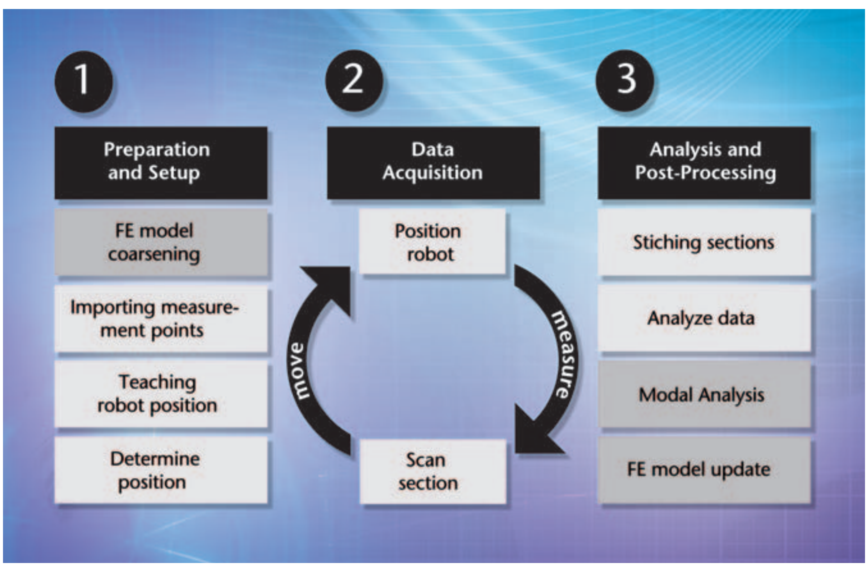


Fig. 4: Operating sequence of the robot supported vibration measurement. (Light grey boxes: RoboVib software; dark grey boxes: external software)

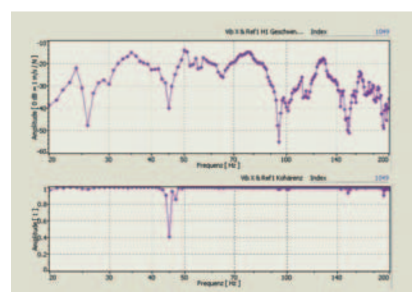


Fig. 6: Frequency response function (H1) between excitation and response (above) and coherence function at a scan point (below).

Summary

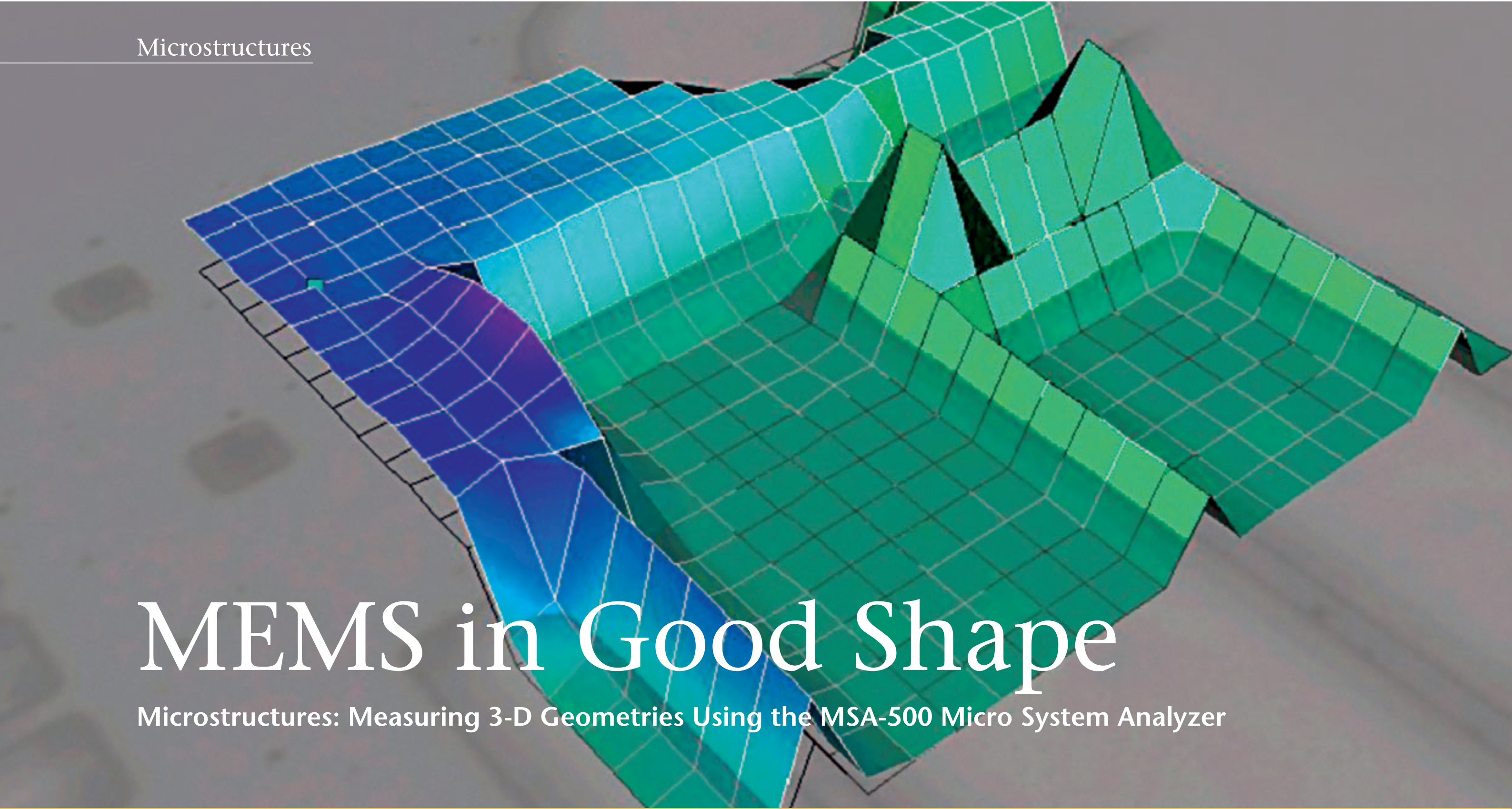
Paradigm Change in NVH Test

Structure-borne noise measurements made using Laser-Doppler Vibrometry are the perfect way to optimize the noise and vibration characteristics in vehicle development. Earlier studies confirm the significant potential of this technology to increase the density of measurement points without influencing the structure in its vibration characteristics, while at the same time saving on measurement time. The increased measurement point density greatly improves the results of experimental modal analysis and the higher frequencies captured in the data make acoustic simulation more accurate, leading to better sound radiation calculations. Using scanning vibrometry means that for the first time, the self-limitation through the number of available sensors and channels is overcome. The number and density of measurement points can now be oriented towards the physical necessities.

Two Established Processes Combined to Increase Efficiency

By combining laser vibrometers with an industrial robot, further significant efficiency increases are possible including systematic preparation of the simulation, more efficient positioning of the scanning heads and improvement in the signals through more favorable angles of incedence. The measurement time is decreased – depending on the application – from weeks to days or even hours. This increases the throughput and efficiency of a modal analysis laboratory.

The prototypes are only required for a short time, necessary measurements can be defined and carried out more quickly. Once developed, programed measurement routines can be used time and time again as required. This means that every optimization step can be documented and analyzed at a level of resolution unattainable until now.



MEMS in Good Shape

Microstructures: Measuring 3-D Geometries Using the MSA-500 Micro System Analyzer

The MSA-500 Micro System Analyzer is the newest version of Polytec's gold standard for measuring microstructure dynamics and now provides auto-focus capability with height measurement capability. The auto-focus uses a piezoelectric z-positioning stage to move the objective lens and a feedback signal from the measurement laser beam to optimize the focus. The feedback signal, besides focusing the lens, enables height measurements with a 10 nm resolution, providing precise 3-D geometries when scanned across the surface.

Fig. 1: MSA-500 Micro System Analyzer.

Introduction

To provide an experimental basis for dynamic-model refinement and modal-analysis verification, measurements of 3-D structural vibrations must be correlated to the structural 3-D geometry with a complete frequency spectrum. Three separate measurement techniques are included in the Micro System Analyzer: out-of-plane vibration measurement with a laser-Doppler technique, in-plane vibration measurement using stroboscopic video microscopy, and static topography measurement using scanning white-light interferometry. Each technique is unique and has a different lateral resolution.

Consequently, the vibrometer's laser beam is not automatically matched to the pixel positions necessary to match the lateral positions of the geometry and vibration measurement data. Also, when switching between scanning white light interferometry and vibrometry, the interference objective is exchanged with a bright-field lens, causing a shift in the image magnification and image position due to variations in the objectives and the turret. To resolve this difficulty, the new MSA-500 Micro System Analyzer (Fig. 1) includes a new measurement technique that determines the specimen's height using an auto-focus measurement at the point where the laser beam will measure the vibration. Intensity measurements of the laser carrier signal are used to precisely position the standoff distance of the microscope objective with the piezoelectric z-positioning stage until the signal strength reaches its maximum.

The difference between the two focus positions of the objective lens corresponds to the height information. This enables height measurements with resolutions of a few tens of nanometers. These geometry data automatically match to the grid points of the vibration measurements. The system can measure up to 1.5 points/sec if the full z-range of 250 µm is examined.

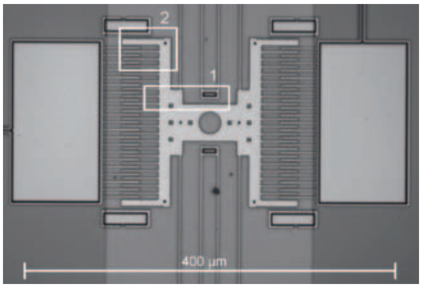


Fig. 3: MEMS comb drive showing regions 1 and 2.

Measurement Routine

The complete measurement routine of a combined geometry and out-of-plane vibration measurement has four steps (Fig. 2):

1) The user first sets the measurement parameters in the PSV Software including the definition of the measurement grid, the specimen excitation, and the analysis frequency band.
2) The second step is a linearization procedure to increase the accuracy of the z-position measurement. This is done after the user has started the overall measurement.
3) The third step is to acquire, evaluate and save the z-positions for each spot on the measurement grid as the laser beam is scanned from measurement point to measurement point.
4) The vibrometer beam is scanned again over the measurement grid and the laser beam is focused at all measurement points using the stage positions obtained in step 3. Now, the full fast-Fourier-transform (FFT)-spectrum of the vibration is measured with the laser-Doppler technique.

An Example: Determining Geometry and Vibration Data

Both geometry and vibration measurements can be made on the electrostatic comb drive shown in Fig. 3. Region 1 has been chosen for a geometry measurement while region 2 has been chosen for a combined geometry and vibration measurement. The result of the geometry measurement in region 1 is shown in Fig. 4. The measured height of the actuator with respect to the wafer surface is 5.7 µm.

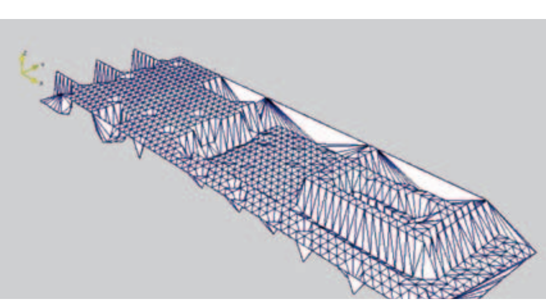


Fig. 4: Comb drive geometry measurement of region 1.

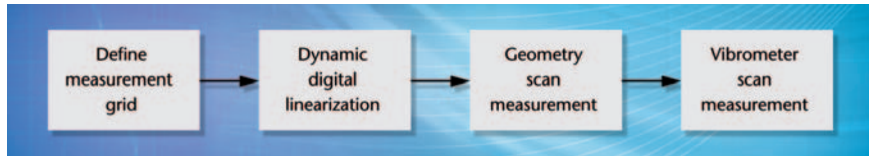


Fig. 2: Steps in the measurement routine to obtain the 3-D-geometry information and out-of-plane vibration data on overlapping measurement grids.

$$\vec{p}_i(t) = \begin{pmatrix} x_i(t) \\ y_i(t) \\ z_i(t) \end{pmatrix} = \begin{pmatrix} \hat{x}_i \\ \hat{y}_i \\ \hat{z}_i \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \\ A_i \cos(2\pi f t + \varphi_i) \end{pmatrix} = \begin{pmatrix} \hat{x}_i \\ \hat{y}_i \\ \hat{z}_i + A_i \cos(2\pi f t + \varphi_i) \end{pmatrix}$$

⇑ *Combined data data set* ⇑ *Geometry data* ⇑ *Vibration data*

Eqn. 1

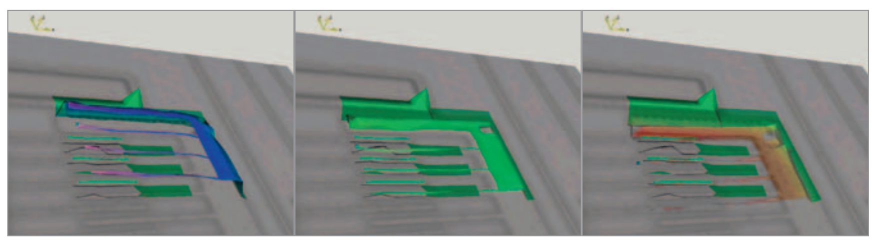


Fig. 5: Operational deflection shapes at three phase angles: 0, 90, and 180-degrees.

An aligned geometry and vibration measurement provides a combined data set. Regarding vibration data, a single line at a vibration frequency *f* at a measurement point with index i is determined by its amplitude A_i and its phase φ_i. Regarding both geometry and vibration data, the coordinates can be written as shown in Eqn. 1. In Fig. 5 the result of the animation is shown at 0, 90, and 180 degree phase angles of the operational deflection shape at 6.7 kHz superimposed with the 3-D geometry of the measurement grid.

Conclusions

An autofocus procedure has been integrated into the MSA-500 Micro System Analyzer that outputs microstructural topography data that matches the vibration measurement grid. The 3-D coordinates of the vibration measurement grid are obtained with nanometer resolution dependent on the choice of microscope objectives. Using the Micro System Analyzer software, the vibration measurements in the form of operational deflection shapes can be superimposed on the experimentally determined geometry model.

More Information

This article is based on the publication "Measuring 3-D Geometries of Microstructures with the Laser Scanning Confocal Vibrometer Microscope" by C. Rembe, S. Bödecker, B. Armbruster, M. Bauer (all of Polytec GmbH), Proceedings of SPIE 6616, 661623 (2007). **http://link.aip.org/link/?PSISDG/6616/661623/1**

For more detailed information about the MSA-500 Micro System Analyzer visit **www.polytec.com/microsystems**.

Quiet Motion

An Investigation of Rolling Tire Vibration Caused by Road Roughness

To reduce tire/road noise, it is important to understand the noise generation mechanism. Noise generated by a rolling tire is mainly emitted from the tread block. However, it has recently been reported that smooth tires also generate noise. The vibration of a rolling, smooth tire is excited from the road surface. Scanning laser-Doppler vibrometers were employed to measure the vibration of the tire tread at the leading and trailing edges since the input from the road cannot be measured directly on the contact surface. To perpendicularly interrogate the tire tread, despite the curvature of tire, the laser beam was reflected from a high-precision, flat mirror.

Introduction

External noise radiated by vehicles is a serious environmental problem that is related to traffic, and ranks with air pollution in terms of it's negative impact on the quality of life. As the population has grown, environmental awareness has also increased and traffic noise regulations have been strengthened year by year. With the reduction in noise from today's body structures and power trains, tire/road noise has become the dominant vehicular noise source. Consequently, the reduction of tire/road noise emission is critical to meeting future noise regulations and preserving a quality lifestyle. To reduce noise, each of the noise sources has to be classified and effective methods for noise reduction need to be established. The first source is tread block vibration, the second is tread air groove resonance, and the third is tire vibration excited by road roughness. These are caused by tread pattern and vibration noise, mainly radiated from the sidewall. This means there is a limit to reducing the rolling tire noise by modifying tread patterns.

Furthermore, it has been proven that the tire/road noise is also generated in tires without a tread pattern. This study aims to understand rolling tire vibration excited by road surface roughness. Smooth tires are used to exclude the influences of tread pattern.

Operational Analysis

The rolling tire operational deflection shapes (ODS) were identified by measuring the cross spectrum between the response point vibration and the reference point vibration to maintain fixed phase relations using

$$G_{xy}(\omega) = X_x(\omega) \cdot X_y^*(\omega)$$

where x is the response point, y is the reference point, and G_{xy} is the cross spectrum of the reference point and response point. The scaled rolling tire mode can be obtained by dividing the cross spectrum by the RMS value of the auto power spectrum of the reference point

$$X_x(\omega) = \frac{G_{xy}(\omega)}{\sqrt{G_{yy}(\omega)}}$$

where G_{yy} is the auto power spectrum of the reference point. The rolling tire vibrations were measured and the rolling tire ODS were obtained using the equations just listed.

Experimental Setup

To exclude tread block influence, a smooth radial tire (215/70R16) inflated to 200 kPa was selected. It is difficult to measure the vibration of the whole tire.

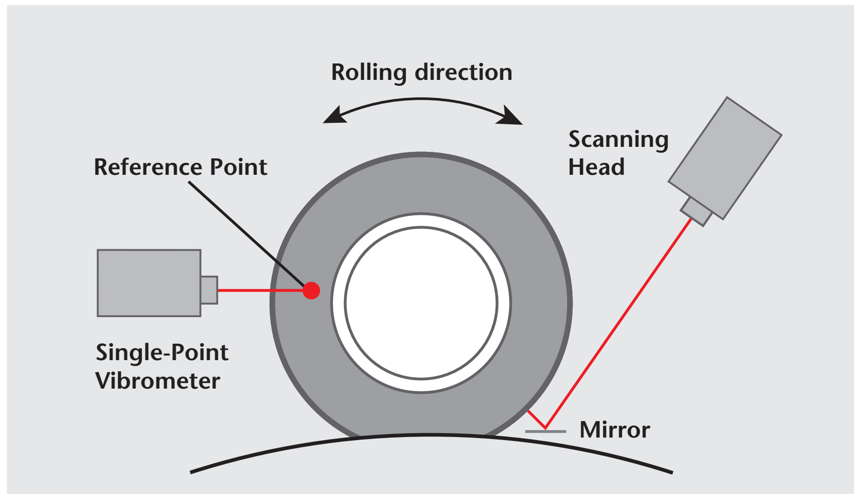


Fig. 2: Experimental setup to measure tread vibration.

Therefore, the vibration of the sidewall and the tread were separately measured. To measure the vibrations, the tire was mounted on a single drum tester and loaded at 4,500 N at the tire axis. The test speed was 50 km/h. The rolling tire vibrations were measured and the rolling tire ODS were obtained by measuring the cross spectrum between the response point vibration and the reference point vibration to maintain fixed phase relations.

Measuring Sidewall Vibration

Laser-Doppler Vibrometers (LDV) were chosen for the measurement. A single-point LDV was used to measure the reference point vibration, while a Scanning Vibrometer was used to measure the vibration of response points. The experimental setup for the sidewall vibration measurement test is shown in Fig. 1.

Measuring Tread Vibration

The experimental setup for the tread vibration measurement test is shown in Fig. 2. The single-point LDV was used to measure the reference point vibration at the sidewall, while the scanning LDV was used to measure the vibration of response points at the tread (both leading and trailing edges).

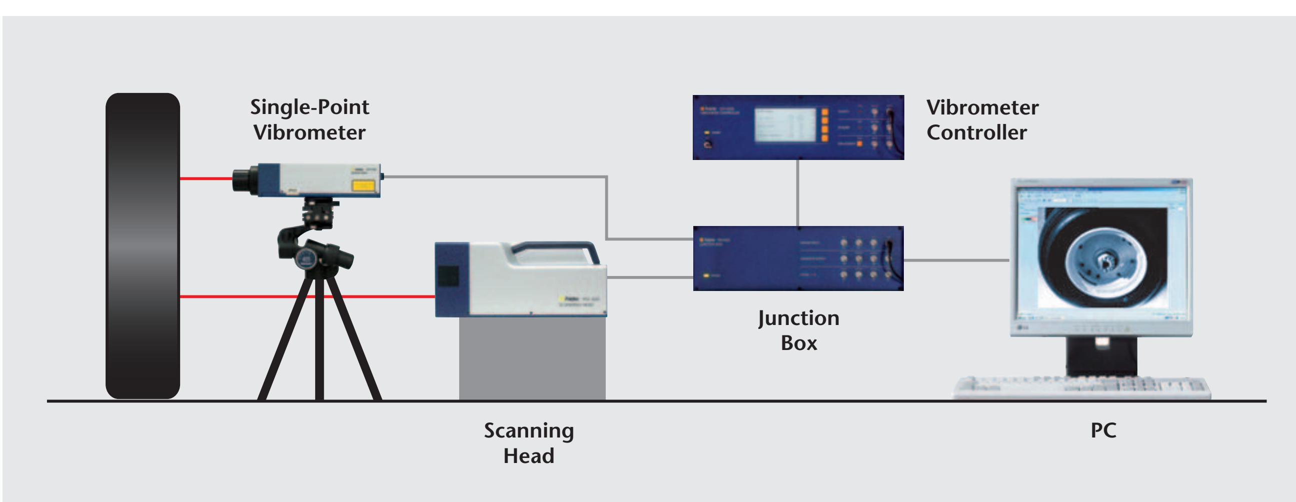


Fig. 1: Experimental setup to measure sidewall vibration.

Continued from Page 11

Quiet Motion

An Investigation of Rolling Tire Vibration Caused by Road Roughness

Comparison of Leading Edge and Trailing Edge

In Fig. 3, the average velocity spectra of the leading edge, the trailing edge, and the sidewall vibrations are plotted. A simple comparison finds that the dominant peaks match between 70 Hz and 150 Hz for each of the spectra.

Furthermore, the vibrational velocity level of the leading edge is greater than that of the trailing edge, a result that exists at all measurement positions. The difference ranges from 6.8 dB to 9.0 dB. The range of forced excitation, which the tire receives from the road surface, seems to be very narrow as the vibration peaks of the leading edge, trailing edge, and the sidewall are in agreement.

The leading edge peak at 83.75 Hz was further analyzed. An animated half-cycle ODS was made using the commercial software SYSNOISE (LMS). An examination of the ODS data (not shown) indicates that a standing wave that is established at the leading edge extends to the trailing edge but only at one side. This asymmetry is due to the belt inside of the tread which is arranged at an angle of approximately 20° with regard to the rolling direction. The belt angle affects the timing of the release of tire deformation after being pressed onto the road surface.

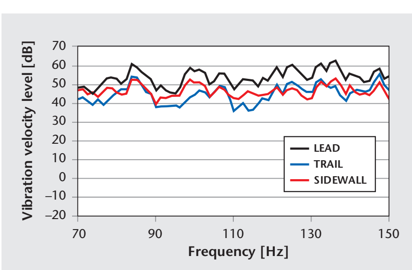


Fig. 3: Comparison of average vibrational spectra for the leading edge, the trailing edge, and the sidewall vibrations.

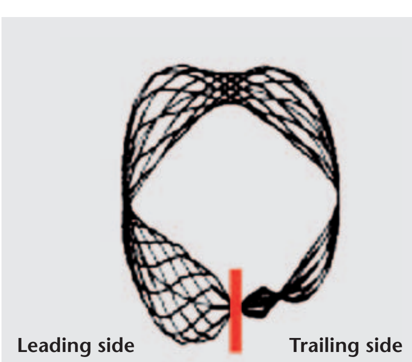


Fig. 4: Vibration amplitude fluctuation of the sidewall at 83.75 Hz.

Peak frequency (Roll) [Hz]	Calculated Acceleration [dB]	Measured Acceleration [dB]	Difference [dB]
83.75	27.50	24.49	3.01
113.75	33.78	17.33	16.45
136.25	32.43	29.76	2.67
147.50	32.11	26.08	6.03
166.25	28.62	16.18	12.44
170.00	22.53	13.88	8.64

Table 1: Leading edge vibration level comparison between analysis and experiment.

Vibration Behavior at the Sidewall

In Fig. 4, the measured amplitude fluctuation of the sidewall's maximum width at 83.75 Hz is plotted. The vibration of the rolling tire shows the standing wave at the leading edge and at the trailing edge. This vibration behavior agrees with the vibration behavior in the tread.

Calculation and Verification of the Input Force

In order to simulate the vibration behavior, it is necessary to know the input from the road surface to the tire. To calculate the input force from the tire's deformation volume, both its profile and the road surface are modeled. The calculated tread vibration level is compared with the measured tread vibration level. Further, an excitation experiment of the non-rolling tire is carried out to examine tread vibration characteristics in the non-rolling condition.

Through this method it becomes possible to compare the calculated tread vibration level with the measured tread vibration level by frequency response function (FRF) in the non-rolling condition used as FRF in the rolling condition. The experimental results are in good agreement with the analytical results (see Table 1).

Conclusions

The vibration of a rolling smooth tire, which is mainly excited from the road surface, has been investigated in detail using a scanning vibrometer. The experiments have shown that the vibration level of the rolling tire's leading edge is greater by 6.8 to 9.0 dB compared to the trailing edge. Also, the vibration behavior of the trailing edge of the rolling tire is affected by the belt. The input force of the leading edge must be determined analytically and, by using FRF in the non-rolling condition, it is possible to predict tire vibration at the leading edge.

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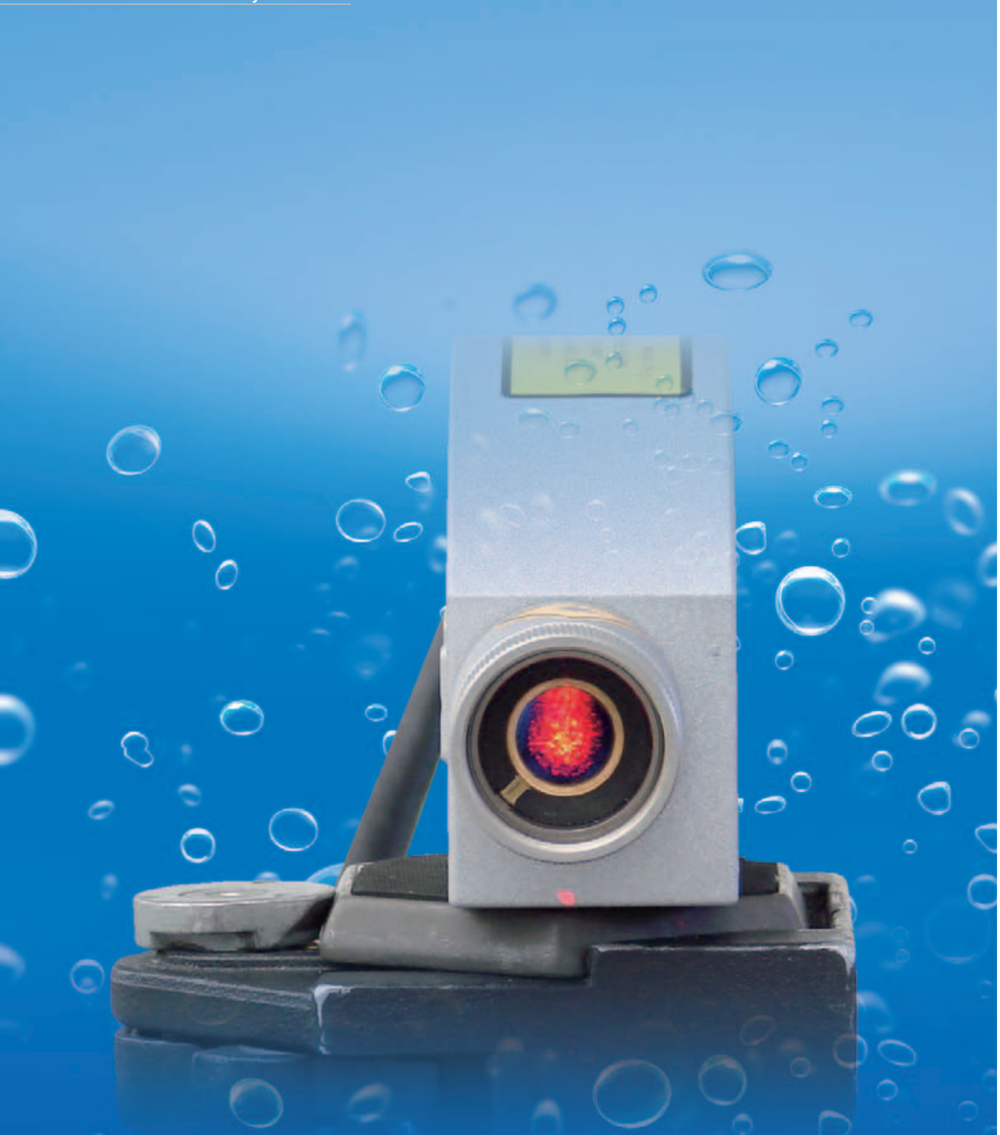

Bubble Dynamics

Determining a Bubble's Resonance Frequency Using Laser-Doppler Vibrometry

The dynamic behavior of small bubbles has important ramifications in many applications, including underwater sound and sonar, industrial processes, sonochemistry and cavitation, and medical acoustics. Non-contact laser-Doppler vibrometry is a viable method for observing bubble resonance and is capable of precision equal to that of traditional acoustic techniques.

Introduction to Bubble Dynamics

Despite being small, a millimeter-sized gas bubble suspended in a liquid can have a significant effect on the acoustics of that medium. One primary effect is acoustical scattering since bubbles scatter sound much more effectively than a rigid object of the same size. This scattering efficiency is because a bubble exhibits a strong resonance, based on the exchange of kinetic energy in the liquid shell that surrounds it with the potential energy of the compressed gas inside it, as shown in Fig. 1.

A liquid shell surrounding a bubble of radius a is an effective mass m_{eff} dependent on the bubble radius and the liquid density ρ_l. The gas inside a bubble is effectively a spring, with spring constant k_{eff}, dependent on the bubble size, the polytropic exponent of the gas ν, and the local hydrostatic pressure P_0. The system can be modeled as a simple harmonic oscillator, with perturbation x of the bubble radius about its static radius a. The governing ordinary differential equation is

$$\ddot{x} + \omega_0^2 x = 0$$

With $k_{eff} = 12\pi a \nu P_0$ und $m_{eff} = 4\pi a^3 \rho_l$ the resonance frequency is given by

$$\omega_0 = 2\pi f_0 = \sqrt{\frac{k_{eff}}{m_{eff}}} = \frac{1}{a}\sqrt{\frac{3\nu P_0}{\rho_l}}$$

This means that the resonance frequency f_0 for air bubbles in water can be calculated according to

$$f_0 = \frac{3.23}{a}$$ (a = bubble radius in m)

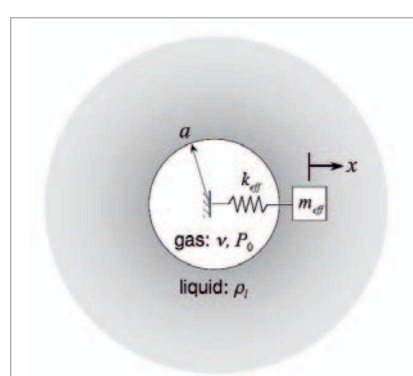

Fig. 1: The resonance of a gas bubble immersed in liquid can be modeled as a simple harmonic oscillator.

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Bubble Dynamics

Determining a Bubble's Resonance Frequency Using Laser-Doppler Vibrometry

Measurement Challenges

Recently, the behavior of bubbles confined in tubes or channels and near surfaces has become important for medical and industrial applications. In confined spaces, such as in a narrow tube with a diameter on the order of the bubble diameter, traditional means of experimentally observing bubble dynamics – either acoustically with hydrophones or optically with Mie scattering or stroboscopy – are often impossible or else would significantly perturb the system. The Mie scattering technique would also require the light source and receiver axes to be separated by an angle of about 80°.

A laser-Doppler vibrometer (LDV) only requires a narrow (less than 1 mm diameter) line-of-sight access for the beam, and illumination of the bubble does not perturb its dynamics. To illustrate the utility of this measurement technique, bubble resonance frequencies, obtained from LDV measurements of the acoustically-excited response of a bubble suspended in a small tank, are presented and compared to theory. No absolute standard exists to assess the accuracy of bubble resonance frequency measurements, therefore the precision of the technique was considered and found to be similar to the precision of a traditional acoustic technique that inferred the bubble resonance from a pair of acoustic pressure measurements.

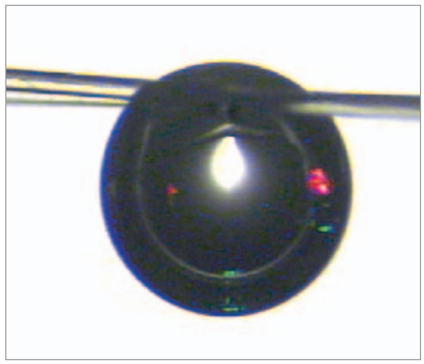

Fig. 2: Air bubble captured on a pair of nylon monofilament lines.

Apparatus and Measurement Procedure

A small acrylic-walled tank with a tight fitting lid was filled with degassed distilled water. A single air bubble (radius between 0.8 – 1.5 mm) generated by a syringe and a needle was captured under a pair of parallel nylon monofilament lines and positioned in the tank, as shown in Fig. 2. The tank was completely filled and closed so that no air remained in the tank. Acoustic excitation was provided by an electromagnetic shaker and a circular piston through a rubber membrane covering a hole in the tank wall. The source signal (band-limited, pseudorandom noise between 1 – 5 kHz) was generated by the data acquisition computer and directed to a power amp and the shaker. Standing waves were set up inside the tank and the bubble was forced into oscillation. The normal velocity of the bubble wall was observed using a Polytec OFV-534 Laser-Doppler Vibrometer (Fig. 3).

Vibration Measurement and Data Analysis

A number of challenges are associated with using an LDV to measure bubble motion. The measurements must be conducted through a volume of water and the tank wall, which causes additional attenuation of the laser beam as compared to a beam path of the same length in air. If an absolute measurement of velocity is required, the optical index of refraction of the water

Fig. 3: Experimental setup with OFV-534 Sensor Head.

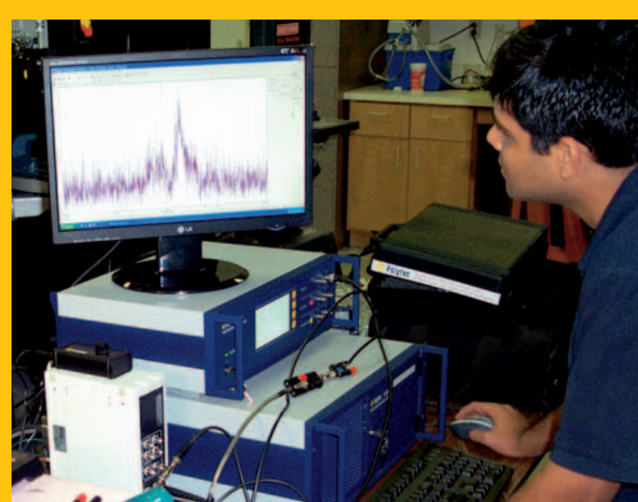

Fig. 4: OFV-5000 Vibrometer Controller and Data Management System.

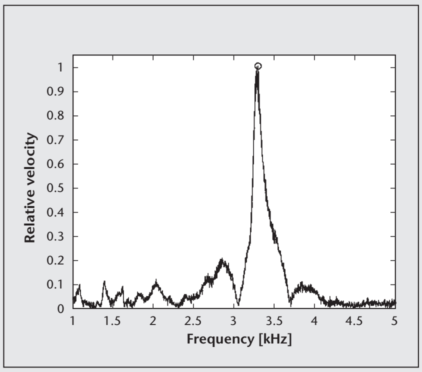

Fig. 5: A typical, normalized spectrum of bubble wall velocity measured with the LDV.

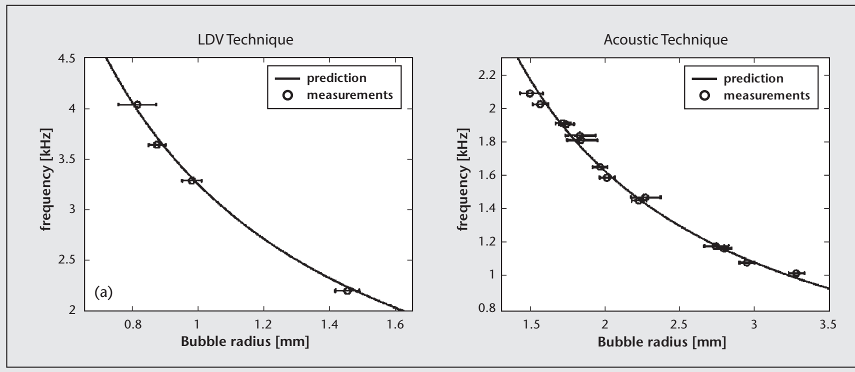

Fig. 6: Measured bubble resonance frequencies for the LDV measurement technique (left) and for an acoustic technique (right).

and the tank wall must be accounted for. The spherical shape of the bubble's surface further reduces the intensity of light scattered back to the interferometer, compared to that scattered from a flat surface. Finally, scattering from the tank walls must not interfere with the light scattered from the bubble.

To overcome these difficulties, a Polytec OFV-534 Vibrometer Sensor Head that sends and receives the laser beam through a microscope objective was used.

A coaxial video image of the bubble was also acquired through the objective lens and displayed in real time on the data-acquisition PC, which afforded precise alignment of the laser beam with the normal point on the bubble surface. The beam was focused to a diameter of approximately 2 µm, illuminating a relatively small portion of the bubble surface.

A 10X objective lens was used to ensure that sufficient light was reflected back to the photodetector. The working distance provided by the objective allowed for unfocused light to pass through the tank wall, which in turn reduced spurious reflections to a negligible level. A time-domain voltage signal that was a direct analog of the normal surface velocity of the illuminated patch on the bubble was output from a Polytec OFV-5000 Controller/Demodulator (Fig. 4). For a given bubble size, the time-domain signal was windowed and an FFT was performed. A typical spectrum, averaged from 50 measurements, is shown in Fig. 5. The resonance frequency of the bubble (marked with a circle) was taken to be the frequency that corresponded with the maximum amplitude of the spectrum. Finally, the bubble size was measured using a diffuse white backlight and a stereo microscope equipped with a CCD camera oriented on an axis normal to the LDV axis.

Results

The resonance frequencies extracted from the LDV velocity spectra at different bubble sizes are shown in Fig. 6 (left). The error bars represent uncertainty in the measured bubble radii due to the resolution limitations (pixelization) of the digital images, which were obtained with various degrees of magnification.

The solid line is the prediction given by the equation shown above in Fig. 1. For comparison, bubble resonances obtained with the acoustic technique are shown in Fig. 6 (right).

Discussion

The RMS error between the measurements and the predicted values are 1.5 % for the LDV technique and 2.1 % for the acoustic technique. We therefore conclude that a laser-Doppler vibrometer is a viable alternative for observing bubble resonance and is capable of precision equal to that of a traditional acoustic technique. The non-invasive nature of the LDV technique permits use in confined spaces, where acoustic techniques would be difficult due to the size requirement imposed on the measurement hydrophone, and where the Mie scattering technique would be impossible due to geometrical requirements.

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The Balanced Mode Radiator is a new approach to loudspeaker design with unique visual and acoustic features. Tight control of the membrane properties is essential to providing proper acoustic fidelity from the device. Polytec's Scanning Vibrometer enabled in-situ measurements on operating devices with no contact or loading of the panel membrane, successfully accelerating the development and manufacturability of the new loudspeaker.

Sounds Good

Vibration Analysis is a Valuable Tool for Loudspeaker Development

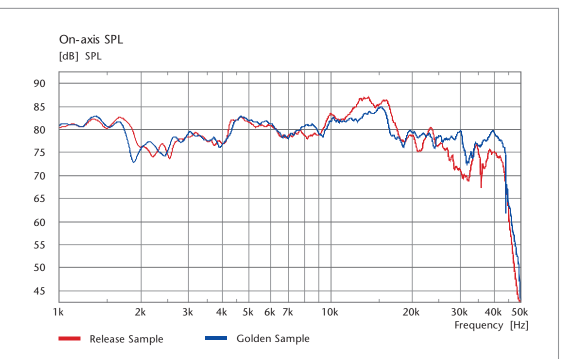

Fig. 1: On-axis Sound Pressure Level (SPL) spectra from tested BMR's.

Introduction

The "Balanced Mode Radiator" (BMR) represents a new class of loudspeaker with distinct design features and acoustical properties that distinguish it from the traditional, well-known electrodynamic loudspeaker design based on conical membranes. The most obvious difference between traditional conical speakers and the BMR is the use of a suspended flat circular disc as the radiating membrane panel (see title image). The drive unit features a clean appearance and a plane front that allows for innovative industrial designs with unique sound properties. Acoustically, the BMR is designed as full-range driver which supports almost the entire audible spectrum. For frequencies above the panel's first eigenmode, the BMR operates as a bending-wave device where its acoustic behavior is predominantly determined by the panel's mass density, bending stiffness, damping, and shear. These parameters are of paramount importance for the acoustic performance of the BMR.

From Prototype to Mass Production

The design of the BMR was done in Germany. But, due to cost constraints in the consumer market, most drive units had to be manufactured in China.

During the product development phase, all required parts were tooled and made in China then assembled and tested in Germany. Each part's geometry and material was changed until satisfactory performance was achieved. A construction manual was written and sent to China together with the final drive unit. This Gold Standard called "Golden Sample" serves as a reference when setting up the production line.

An initial set of prototype drive units known as "Release Samples" were sent back to Germany for approval. In the case study presented here, unexpected changes in the panel's material composition degraded the acoustic performance. A Release Sample was found to produce a less bright sound than the Gold Standard, although both units were built according to the same nominal specifications. Thus, the task was to identify the source of this difference.

On-axis Frequency Response

To begin the drive unit assessment, the acoustic on-axis frequency response was measured (Fig. 1). Above 18 kHz the Release Sample is slightly louder than the Gold Standard, indicating a somewhat brighter sound. This measured result was the opposite of what was subjectively noted when auditioning both units.

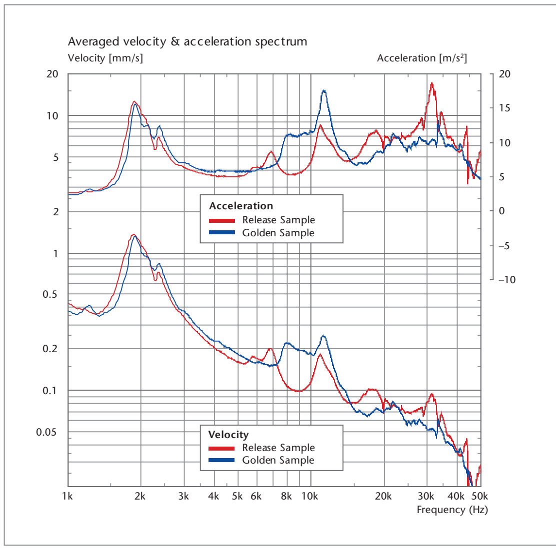

Fig. 2: Average velocity and acceleration spectra from tested BMR panels.

Consequently, the next step was to try to resolve this apparent contradiction by spatially measuring the dynamic response of the BMR panels of both units using the Scanning Vibrometer.

Vibration Analysis of Drive Units

Vibration analysis was performed using a Polytec PSV-300 Scanning Vibrometer. For sample excitation, the vibrometer generated a swept sine wave signal ranging from 150 Hz to 50 kHz, and acquired the velocity frequency response data from 1781 measurement points that were evenly distributed in a circular symmetric mesh across the panel.

The average spectrum calculated using the Scanning Vibrometer software allowed quick access to mean velocity and mean acceleration data. In Fig. 2, the acceleration spectra of both units are plotted in the upper half of the diagram with the associated ordinate axis positioned to the right, while the velocity spectra are located in the lower half with the associated ordinate axis to the left. The most obvious deviations occur in the 7–12 kHz range as opposed to the 12–18 kHz range identified by the on-axis Sound Pressure Level (SPL) measurements. Differences in this frequency range (7–12 kHz) are more likely to be judged as “bright” or “dull”. The brighter sounding Gold Standard shows higher activity in both average spectra than the Release Sample, supporting the results of the informal subjective evaluation.

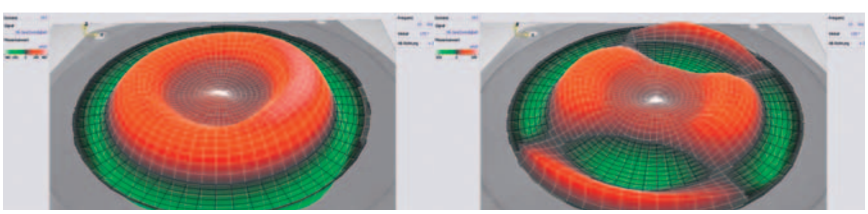

Fig. 3: Out-of-plane deflection shapes for BMR panels at 10 kHz, Release Sample (left), Gold Standard (right).

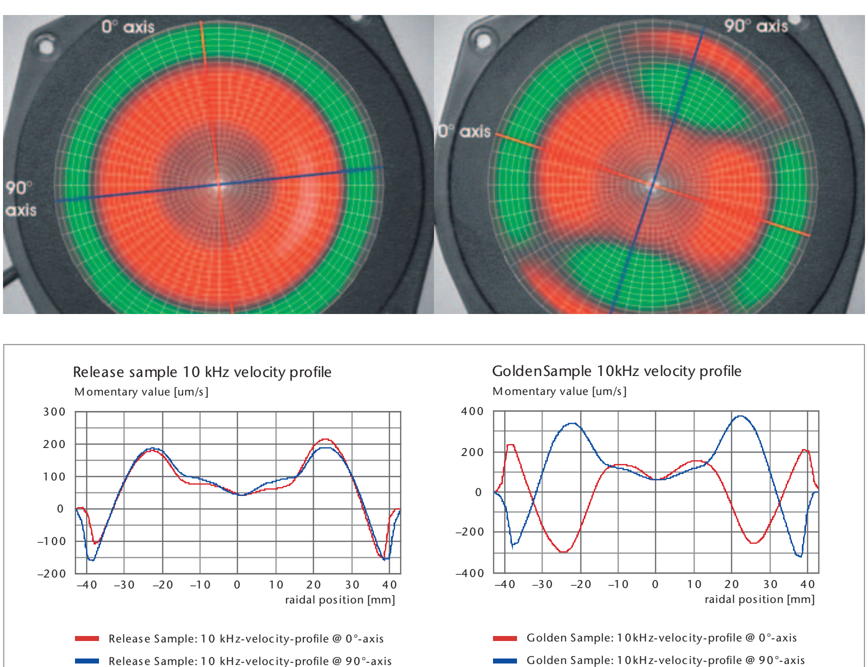

Fig. 4: Plots of orthogonal cuts through Fig. 3 deflection shapes, Release Sample (left), Gold Standard (right).

Modal Analysis

The results shown in Fig. 2 suggest that the two drive units have different panel materials. In Fig. 3, the operational deflection shapes (ODS) at 10 kHz are compared. It is obvious that the Release Sample shows a bending mode with circular symmetry on its panel (left) while the Gold Standard features rotationally symmetric structures that break circular symmetry (right).

The results confirm the previous findings. The Gold Standard BMR panel shows a much less isotropic bending stiffness than the Release Sample panel. Obviously, the panel manufacturer had actually tried to improve the panel quality by making it more isotropic.

Conclusions

Structural response data taken with Polytec’s Scanning Vibrometer allowed in-situ identification and characterization of dynamic material properties in loudspeakers and clarified inconsistent preliminary SPL measurements and auditory tests. The net result of the vibration analysis was an improved understanding of the BMR and reduced development time by eliminating trial-and-error approaches.

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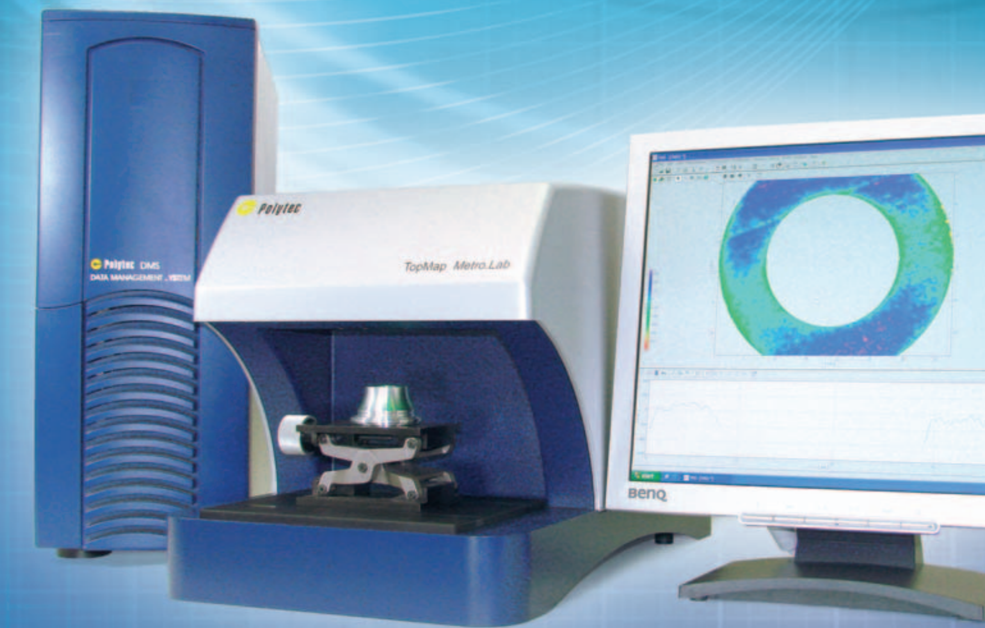


Interferometric techniques are well suited to quality control measurements in production environments given the technology's non contact, long standoff, highly accurate and short measurement times. The measurement principle and several applications of scanning white-light interferometry are described.

Sub Nanometer Resolved

Advanced Production Control Uses White-Light Interferometry to Characterize Surface Topography with Nanometer Accuracy

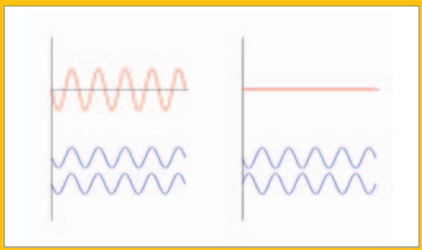


Fig. 1: Constructive (left) and destructive (right) interference.

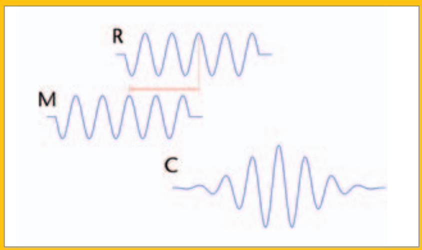


Fig.3: Superposition of white light. R = reference beam; M = measurement beam; C = correlogram.

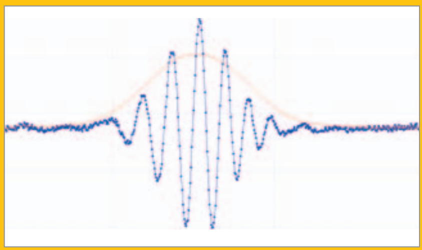


Fig. 4: Intensity correlogram for one pixel of the camera. Oscillations depend on the distance from the reference surface.

Introduction

Today's manufacturing lines are producing precision parts with remarkable accuracy. By necessity, specifications on functional surfaces have kept pace and are more refined and difficult. If for example, you want to produce car engines with low fuel consumption and emissions, long service life and great performance, tight tolerances must be met. The precision of the measuring instrument must be at least one order of magnitude better. Thus, for a required tolerance of 1 µm, it must be possible to reproducibly attain accuracies in the 100 nanometer range.

This implies that optical metrology must be able to precisely measure the topography of very large surface areas of a workpiece. For production line applications, 100 % inspection is often desired and very short measurement times are essential with data taken directly on the line. Of course, this situation is not ideal for data acquisition; however, with the aid of white-light interferometers, it is possible to check all critical surfaces for compliance.

The Principles of Scanning White-Light Interferometers

If two monochromatic, coherent light sources are superimposed, then, depending on the phase of the two waves relative to each other, you get either constructive or destructive interference (Fig. 1).

The superposition of two lightwaves and the interference produced can be verified experimentally by using a Michelson interferometer where the light is split into two beams using a beam splitter (Fig. 2). Part of the light is directed onto a reference surface, for example a coplanar mirror, and the other part onto the surface of the object under investigation. The light is reflected from both the reference and from the test surface and is superimposed again at the beam splitter. If the surface of the object is flat and at an angle, then the camera will see vertical light and dark fringes depending on whether the reflected light is in phase or out of phase. The angle thereby produces light-dark fringe pattern.

Such coherent interferometric measurements are difficult to analyze when the surface is not joined or has large steps. In both of these cases, the number of cycles of the interference fringe pattern is lost, meaning it is no longer possible to determine the

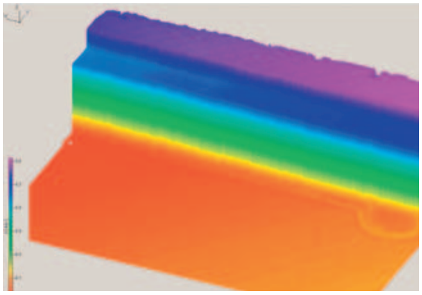


Fig. 5: Curvatures/radii measured on an optical part.

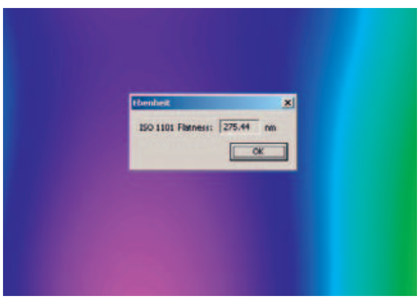


Fig. 6: Flatness of a glass surface.

height of the two surfaces to relative to each other. An innovative solution gives up the coherent light in favor of "incoherent" white light (i.e. light made up of several wavelengths). A "replacement model" for white light is a short wave train with an average wave length (Fig. 3). If the distance to the reference surface and to the measurement surface is exactly the same, then the output has the maximum con-

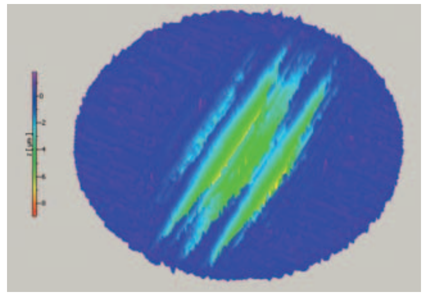


Fig. 7: Tribological pattern (ball on disc method).

trast. If the distance is slightly shifted, but still within the range of the wavetrain, then only one part of the two wave trains is contributing to the interference and the contrast is less strongly pronounced. This effect gives you information on the precise distance of the points on the surface in comparison to the distance of the reference surface. If you now move the reference mirror, then for every point on the surface you will get an intensity correlogram, as can be seen in Fig. 3 (below) or respectively Fig. 4 (real measurement data). At the maximum of the envelope of this correlogram, the distance of the reference and the surface are exactly the same, so by determining the position of the reference you get absolute scaling. Typical accuracy for determining surface height can be in the subnanometer range, depending on the ambient conditions, the scan speed and the evaluation procedure.

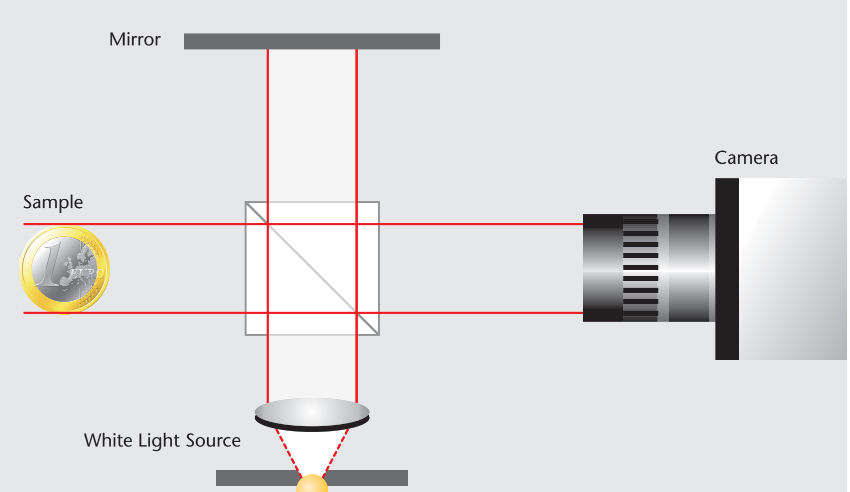


Fig. 2: Michelson interferometer.

Good/bad Analysis

In industrial manufacturing, compliance with given tolerances needs to be checked as often as possible so that faulty parts are eliminated and manufacturing equipment is restored to acceptable precision before any further processing steps are taken. With white-light interferometers, many surfaces can be examined quickly and over a large surface area to check for defects, incorrect curves or radii (Fig. 5), ejecta, and missing connections or dropouts.

Parameters

Specific parameters, such as roughness, flatness (Fig. 6) and ripple, are stipulated for manufactured parts. In particular, for surface area parameters, white-light interferometers can get excellent results in seconds. Tactile or contact methods require a much longer measurement time and can damage or change the surface during the measurement.

Important figures-of-merit, such as percentage contact area or spatial frequency distribution, can be quickly determined. Roughness can be optically determined; but, the values are different from the tactile measurements to which the dimensions of the drawing and standards generally refer. New guidelines for calibrating white-light interferometers give the user the security that the measured values can be traced back to calibration standards.

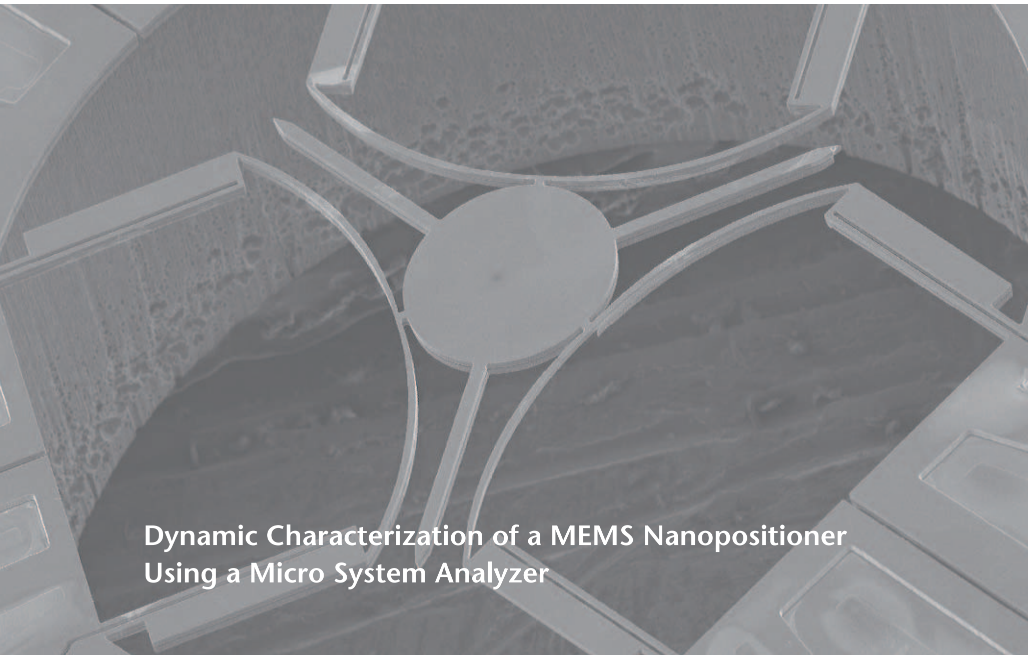
Ejection Volumes

Tribology measurements to study the effect of wear on a surface (Fig. 7) are helped substantially by measurements of the ejection volume. The surfaces are often very jagged and the light reflected back shows great intensity differences. TopMap's Smart Surface Scanning Technology guarantees optimal results in such cases as well.

Need More Info?

Please find detailed information about topography measurement in our new brochure "TopMap Interferometer – Basics, Applications, Products". This brochure can be downloaded from our website at **www.topmap.info**

Small Device, Large Motion



Dynamic Characterization of a MEMS Nanopositioner Using a Micro System Analyzer

The Micro System Analyzer (MSA) was used to determine the natural dynamic characteristics of a micro-scale, six-axis nanopositioner, and to demonstrate the enhanced dynamic performance that can be achieved through input shaping the drive signal to minimize unwanted dynamic positioning errors.

Challenges in the Application of Micro-Scale Positioners

Over the past 10 years, an increasing number of applications require high-precision micro-scale multi-axis positioning stages. Endoscopic scanners for medical applications and integrated positioning of microoptic devices for optical telecommunications are just two of many possible examples. Positioning requirements range from tens to hundreds of microns and operate at speeds of a few hundred Hertz. There are several challenges associated with obtaining this level of performance.

Due to some unique damping issues associated with microstructures, these devices often have problems with dynamic positioning errors, such as overshoot and ringing. The result is large settling times and reduced operational bandwidth.

To take advantage of the high natural frequencies of micro-scale devices, input shaping control techniques can be applied. Input Shaping® is the trade name for a deterministic and robust feed-forward technique for preventing motion-driven errors and achieving motion execution times at or near the theoretical minimum.

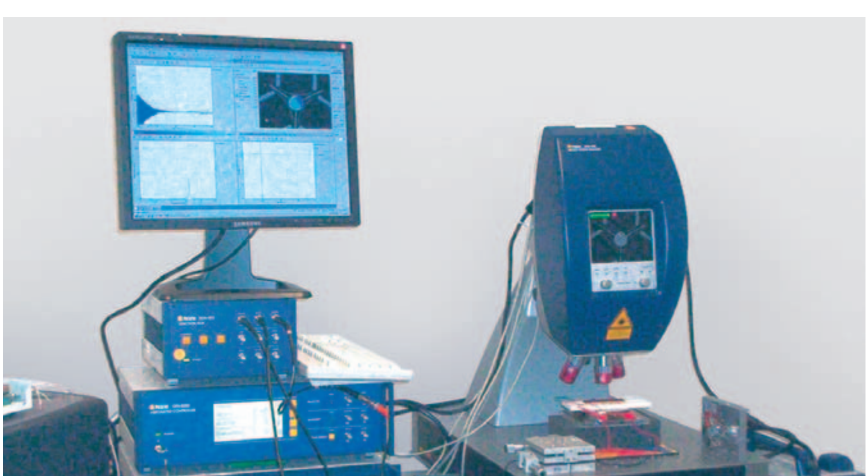


Fig. 1: Measurement setup including the Micro System Analyzer.

The system quantifies the frequency of the vibrations in advance, for instance by using a laser vibrometer. The Input Shaping Controller is then programmed and provides a preconditioned complex drive signal preventing unwanted vibrations.

The µHexFlex Nanopositioner

The µHexFlex, shown in the image above, consists of a central stage attached to an amplification flexure and micro-actuators. The µHexFlex is capable of moving independently in one of six axes or simultaneously in all axes. Thermomechanical actuators are used to drive the µHexFlex. The actuators are capable of exerting in-plane and out-of-plane forces on the central stage and flexure bearings. Controlled commands cause the micro-actuators to exert the appropriate forces on the stage-flexure bearings to achieve the desired displacement.

Experimental Setup

A Polytec MSA-400 Micro System Analyzer using a scanning laser-Doppler vibrometer measured the transient out-of-plane motions (see Fig. 1). At first, the resonant behavior of the µHexFlex was characterized by applying periodic chirp broadband excitation with constant energy over the desired frequency range. A function generator provided this repeated excitation

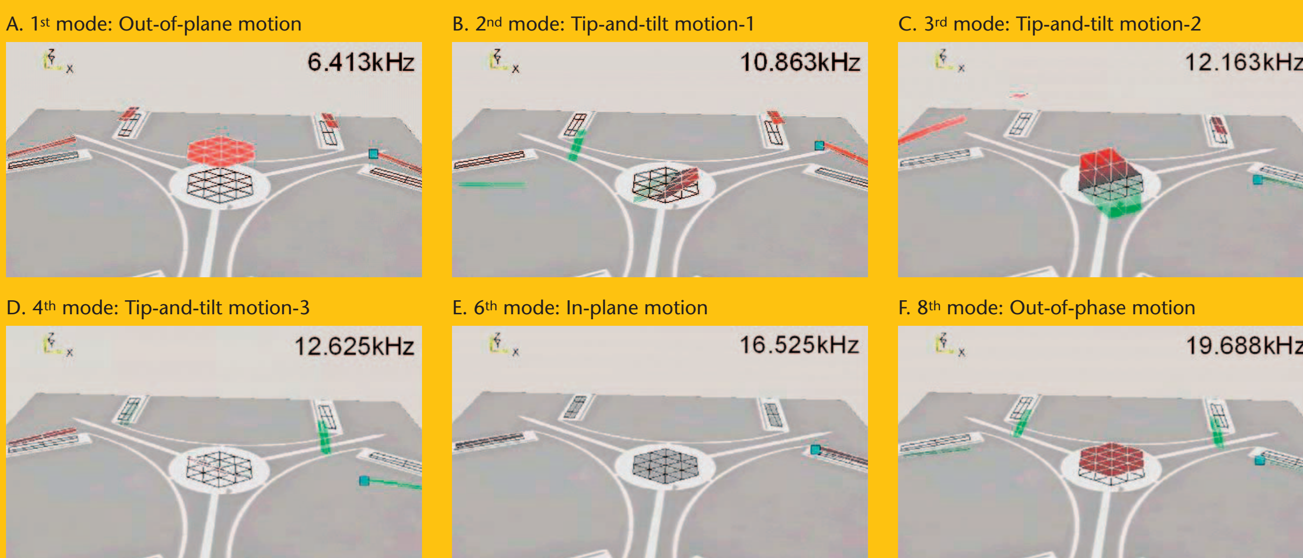


Fig 2: Deflection shapes of the µHexFlex at different resonant peaks provided by the Micro System Analyzer.

while the scanning vibrometer measured the structural response at multiple points on the µHexFlex.

Dynamic Characterization of the µHexFlex

In Fig. 2, selected examples of prominent in-plane and out-of-plane deflection shapes are presented. In Fig. 3, the 0 – 20 kHz frequency spectrum for the µHexFlex is shown. The measurements yielded a natural frequency of ~ 6.4 kHz and damping of $\zeta \sim 0.005$. Three peaks in Fig. 3 between 10 kHz to 13 kHz correspond to the tip and tilt motion based on the images in Fig. 2B, 2C, and 2D. Three peaks located closely between 15 kHz to 18 kHz do not represent out-of-plane motion and are presumed to correspond to deflection shapes for in-plane motion, one of which is shown in Fig. 2E. Fig. 2F presents the out-of phase oscillation at 20 kHz.

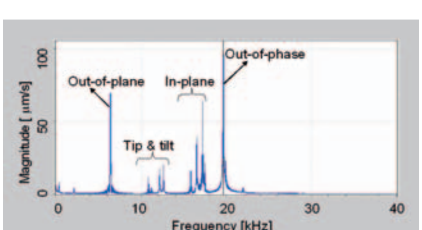


Fig. 3: Frequency spectrum of the µHexFlex.

Effect of Input Shaping on the Out-of-plane Behavior

After identifying the natural frequency response spectrum for the µHexFlex, a square wave excitation signal was applied and the effect of Input Shaping was explored. In Fig. 4, the displacement responses are presented for a µHexFlex driven out-of-plane by a 100 Hz square wave signal with no input shaping (left plot) and with input shaping control (right plot). When the µHexFlex is driven without Input Shaping control, a high-frequency ripple of 100 nm amplitude is observed at the first resonant frequency, "riding" on the stage motion profile. After applying Input Shaping control, a clean time-displacement profile is observed with errors less than 5 nm at 100 Hz. The drift/slope up and to the right is due to the integration of the measured velocity to obtain position, it is not reflected in the actual movements of the nanopositioner.

Conclusions

The dynamic characterization of the µHexFlex nanopositioner has been studied including the natural frequencies and their corresponding deflection shapes. The effect of Input Shaping on the nanopositioner's resolution and settling time has been demonstrated. Using Input Shaping, it is possible to obtain millisecond settling times with sub-nanometer resolution. The practical implications of this work are that future small-scale precision devices will be able to use these techniques to provide low-cost, multi-axis positioning at high speed and with fine resolution.

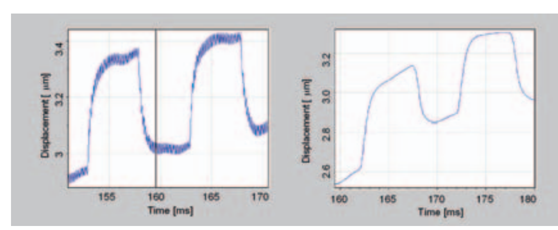


Fig 4: Displacement responses without (left) and with (right) Input Shaping control

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This article is based on the paper "Application of Input Shaping® and Hyperbit Control™ to Improve the Dynamic Performance of a Six-axis Microscale Nanopositioner" presented at the ASPE Annual Meeting, 2006. Input Shaping® is a trademark of Convolve, Inc.

Product News

Automated, Non-contact Full-Body Vibration Mapping

RoboVib Structural Test Station

The new RoboVib Structural Test Station includes a 3-D Scanning Laser-Doppler Vibrometer, the perfect tool for measuring a deflection shape over a single structural view, and a six-axis industrial robot to replace the stationary tripods. The result is extraordinary – for the first time an experimental modal analysis (EMA) test can be fully embedded in the CAE data workflow. As the results are acquired at the actual nodal points of the FE mesh, the update and validation of the FE model by means of the experimental data is now straight forward. Flexibility is integral to the RoboVib Structural Test Station. Use RoboVib and the vibrational characteristic of a complete car body can be mapped in only a few hours – including set-up time!

www.polytec.com/robovib

Characterize High Frequency Structures With All-digital Decoding

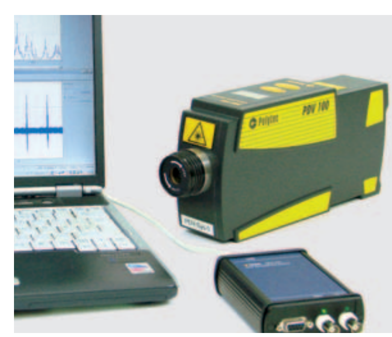
PSV-400-M Scanning Vibrometer

Characterizing high frequent systems like piezo actuators or micro-membranes requires some special consideration. The new M-series scanning Vibrometers are the perfect choice. Polytec provides versions with either a 2-channel or 4-channel data acquisition system up to 1 MHz and a special 2-channel version for data acquisition up to 24 MHz. All of the PSV-400-M systems benefit from the new digital VD-09 Velocity Decoder with a bandwidth of 2.5 MHz at 10 m/s maximum velocity. This performance guarantees a low noise floor with high frequency measurements such as investigations of piezo drives, ultrasonic sensors, or material testing. The standard M-system features an additional high precision digital VD-07 Velocity Decoder, adding additional optical sensitivity with a bandwidth up to 350 kHz. The optional PSV-S-Bw2M bandwidth extension enables data acquisition up to 2 MHz making use of the VD-09's wide bandwidth.

For complete information visit our web page at **www.polytec.com/psv400**

Small Package, USB Convenience

Compact Data Acquisition and Vibration Analysis



Polytec introduces its new VibSoft-20 compact USB data acquisition system, designed for portable and stationary laser-Doppler vibrometers. If you need accurate measurements without time-consuming sensor installation, even in the field, the laser vibrometer offers many advantages over contact sensors. Comprising a compact USB data acquisition unit featuring two channels with 20 kHz bandwidth, an IEPE source for third-party sensors and a powerful software package, VibSoft-20 is compatible with laser vibrometer frequency and time domain measurements. The VIB-E-220 data aquisition unit is powered solely by the USB port and is ideally suited for notebook operation. VibSoft-20 works with all single-point Laser Vibrometer models. Packaged with the PDV-100 Portable Digital Laser Vibrometer, sophisticated, non-contact vibration measurement is now highly mobile. Many new applications are now practical – free from external power sources!

www.polytec.com/software

Polytec

Events

"Experience Innovations in Measurement Technology"

Polytec's 2008 Roadshow

Polytec comes to visit – product road shows have proven to be an effective means of reaching both novice and expert customers interested in vibrometry. Between February 28 and March 05, Polytec visited six locations in Germany to introduce our newest products and applications of vibration and surface measurement technologies. Over 90 participants took the opportunity to learn about new instruments and upgrades of their current equipment, to see examples of measurements, and to find solutions to their specific measurement requirements with the help of Polytec's team of experienced engineers. In addition to the live demonstrations, the exchange of information between the experienced users turned out to be the highlight of the event.

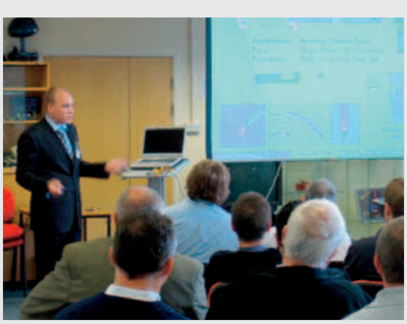
Coming Soon:

8th AIVELA Conference in Ancona, Italy

The 8th International Conference on Vibration Measurements by Laser Techniques will be held on June 17–20, 2008. Since the first conference in 1984, the international research community has enthusiastically attended and made this a pre-eminent conference. The conference aims to create an active and stimulating forum for sharing current research results, technical advances and for promoting the development of new systems for laboratory use, field testing and industrial application. Academic and commercial experts in vibration and acoustics are expected to come from all over the world to present their research and innovative approaches to vibration measurements.

http://www.aivela.org

Fifth UK Laser Vibrometry Users Meeting



www.lambdaphoto.co.uk

The 5th UK Polytec Vibrometer Users Conference (September, 2007) was held once again at Loughborough University and supported by speakers from the UK and Germany. The subject matter was wide and varied with talks ranging from MEMS to NASCAR engines, from inkjet printer design and soccer ball vibrations to teeth descalers, and from 3-D scanning vibrometry to underwater sonar and dolphin teeth! A Technology session was given by speakers from Polytec Headquarters discussing vibrometry basics and demonstrating equipment, including live measurements of customer supplied parts.

Polytec Web Academy – Learn about Optical Metrology Online

Meet Us – Your Place or Ours

The Polytec Web Academy provides scientists, engineers and managers with easily accessible, technical explanations, measurement solutions and market applications of optical metrology, with no obligation and free of charge.

Optical metrology is applied to vital measurements in automotive, aerospace, ultrasonic, MEMS and micro structure technologies as well as biology, medicine and R&D.

Technical know-how, application examples and current product innovations are explained including live question and answer time to address specific issues – all of this is presented in the convenience of your office through your computer. Polytec technology and application seminars can be scheduled right now on the Internet.

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

Please see the back page for a list of upcoming seminars in English and Spanish!

Polytec Web Academy

Polytec

Trade Shows and Conferences

May 05 – 07, 2008	AISTech 2008	Pittsburgh, PA, USA
May 06 – 08, 2008	Automotive Testing Expo Europe	Stuttgart, Germany
May 06 – 08, 2008	Sensor & Test	Nuremberg, Germany
May 18 – 22, 2008	Euspen - 10th International Conference	Zurich, Switzerland
Jun 12, 2008	Journée Française de la Vibroacoustique	Lyon, France
Jun 17 – 20, 2008	8th A.I.V.E.L.A. Conference on Vibration Measurement	Ancona, Italy
Jun 29 – Jul 04, 2008	Acoustics 08	Paris, France
Jul 30 – Aug 01, 2008	Micromachine/MEMS 2008	Tokyo, Japan
Aug 31 – Sept 04, 2008	COMS 2008	Puerto Vallarta, Mexico
Sept 17 – 19, 2008	Automotive Testing Expo China	Shanghai, P.R. China

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

Polytec Web Academy

Apr 30, 2008	Optical Measurement Solutions in Automotive Applications: NVH and Experimental Modal Analysis	11:00 CEST (Europe)
May 01, 2008	Introduction to Scanning Laser Vibrometry for Non-contact Vibrational Measurements	11:00 PDT (USA)
May 21, 2008	Non-contact Rotational Vibration Measurements	11:00 PDT (USA)
Jun 05, 2008	Measuring Hearing Dynamics and other Bio-medical Applications	11:00 PDT (USA)
Jun 11, 2008	Ultrasonic Applications of Non-contact Optical Vibration Measurement	11:00 CEST (Europe)
Jun 12, 2008	Scanning for Nano-Defects using Laser Vibrometry	11:00 PDT (USA)
Jul 02, 2008	Full-Field & Complete Object Vibration Measurement with Scanning Vibrometry	11:00 CEST (Europe)
Aug 11, 2008	Medidas Dinámicas Automotrices Usando Técnicas Láser Doppler (Spanish)	11:00 PDT (USA)
Aug 28, 2008	Non-contact Vibration Measurement at Ultrasonic Frequencies	11:00 PDT (USA)
Sept 11, 2008	Non-contact Topography Measurements	11:00 PDT (USA)

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