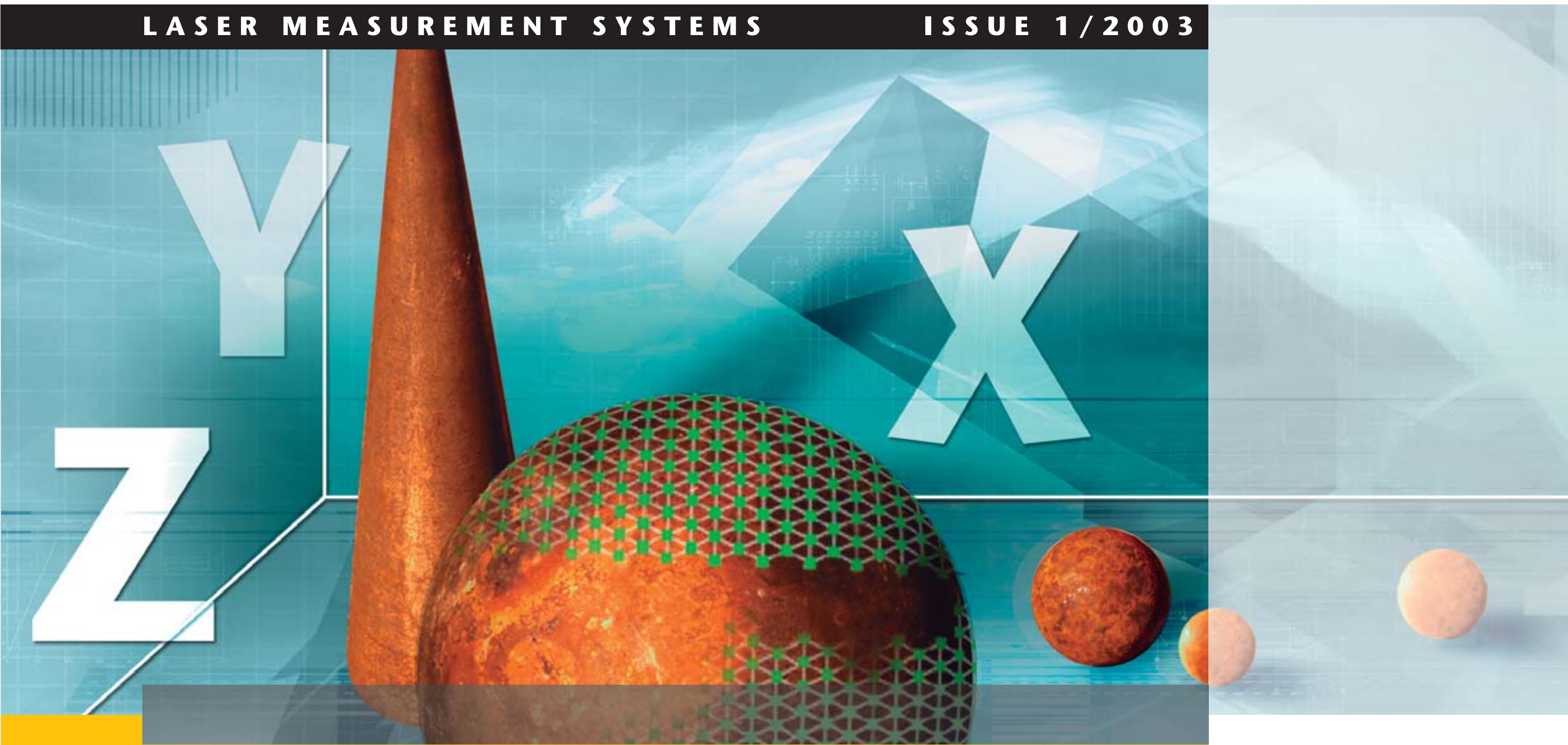
Polytec

LM INFO Special

LASER MEASUREMENT SYSTEMS ISSUE 1/2003



ALL GOOD THINGS COME IN 3'S

Make three-dimensional measurements. From very small ones to very large ones.

Everything vibrates! And many things vibrate in a very complex manner in all 3 dimensions at once! Although out-of-plane measurements – whether at a single point or scanned over a whole surface – give important information on the vibration characteristics of structures, they do not provide the whole picture of what is happening. This has only become possible with advanced methods for precise structural vibration measurements in all 3 dimensions.

With its pioneering new products, Polytec now makes it possible for you to conquer the 3rd dimension using non-contact measurement techniques to measure structural vibration on not only microstructures but also macrostructures.

On page 6 you will see how the Micro Motion Analyzer MMA-300 makes it possible to quickly and completely characterize the vibration of microstructures in all three dimensions.

On page 4 we are pleased to present the Polytec Scanning Vibrometer PSV-300-3D for non-contact, non-invasive measurement of 3D vibrations on macroscopic objects.

CONTENTS

Dear Reader,

Welcome to the world of laser measurement systems!

Browsing this issue of Polytec INFO Special, you will encounter a variety of systems and applications developed for non-contact measurement of surface vibration and velocity. Just take a little time to learn about the principles of vibrometry, or to get to know the sophisticated ways our customers investigate the motions of their specific parts and objects. Whether you want to analyze minute electro-mechanical structures or whole car bodies, Polytec vibrometers will help you to accomplish your goals, better and faster. We invite you to benefit from our experience following our basic idea: Advancing Measurements by Light.

With Best Regards,

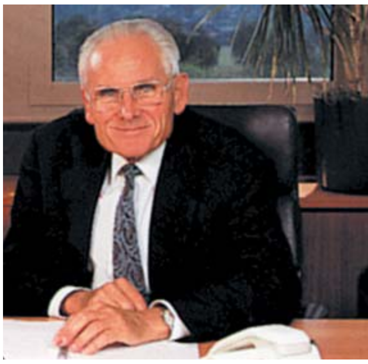
Dr. Helmut Selbach
Managing Director
Polytec GmbH

Michael Frech
Head of Business Unit Laser Measurement Systems

P.S.: Please let us know if you like to receive future issues of this INFO Special!

Just send an e-mail to Lm@polytec.de or use the reply fax sheet inside this magazine.

80th Birthday *of Polytec Founder Heinz Lossau*



Heinz Lossau, the founder of Polytec GmbH and co-founder of PI Physikinstrumente GmbH, celebrated his 80th birthday at the beginning of 2003.

Heinz Lossau established his company with his wife Liselotte in 1967, laying the foundation for successful introduction of laser technology in Germany. Polytec started as the first sales company in Germany importing lasers for research & development. Great demand for this technology quickly confirmed Heinz Lossau's business idea. But after a very short period of time, selling lasers alone was not enough.

By manufacturing its own products for laser measurement technology, Polytec initiated the extremely successful laser vibrometry product division, which has led to Polytec becoming the world market leader in this area.

Today, over 35 years after being set up, Polytec and PI Physikinstrumente GmbH together have nearly 600 employees throughout the world.

Polytec is divided into the following 4 business units:

- **Photonics**
- **Spectral Technologies**
- **Laser Measurement Systems**
- **Polymer Technologies, Epoxies and Silicones**

Continuing along the path to success with a strong team!

Making excellent products available and working closely with our customers is the standard that we at Polytec set for ourselves every day.

To achieve continued future improvements accompanied by increased demand for our products and services, we have strengthened our team in the business unit laser measurement systems.

Since the fall of 2002, 8 employees were added supporting national and international sales, product management as well as the application team and office management.

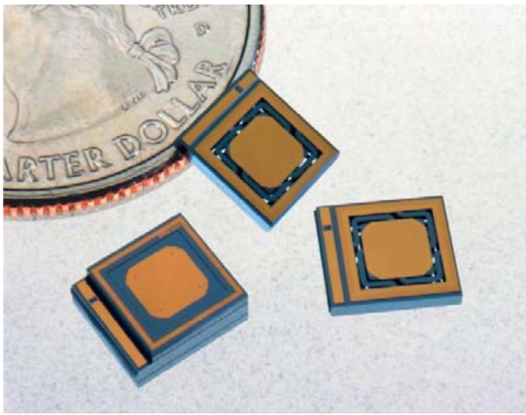
MEMS – *a Success Story*

The continued miniaturization of electronics since the 1960's led to a development in Micro-Electro-Mechanical Systems, or MEMS. Attention to research and development of MEMS intensified once it was realized that they have great commercial potential.

The necessary measurement technology for characterizing the behavior and assuring the quality of components is a constituent part of every development project, as it is validating the models used to predict mechanical behavior. High-performance measurement technology from Polytec, more familiar to some for testing large-scale structures, is also available for characterizing microstructures.

Microsystems Technology and MEMS

As exotic as microsystems technology appeared to be a few years ago, it has now rapidly become indispensable in many products. Today it supplements or replaces numerous traditional sensor and actuator technology systems.



MEMS acceleration sensor (Courtesy Applied MEMS)

Examples of established applications of MEMS technology are:

- Automobile technology (rotation rate sensors for ESP and GPS, acceleration sensors for airbags)
- Entertainment electronics (Digital Light Processing (DLP) for computer projectors and high definition television)
- Telecommunication (optical switches)

Polytec Measurement Technology for MEMS

On the basis of its well-trusted knowledge in the area of non-contact vibration measurement technology, Polytec offers a series of products for characterizing the structural dynamics of MEMS components.

MSV-300 Microscope Scanning Vibrometer

The MSV-300 uses Laser Doppler Vibrometry principle for non-contact measurement of the out-of-plane vibration characteristics of microstructures. The instrument can easily be connected up to any microscope with a C-mount adapter and allows you to make measurements on surfaces up to 320 x 240 μm^2 with a resolution of 1 µm.

PMA-300 Planar Motion Analyzer

The in-plane movement characteristics of silicon MEMS are not accessible with the laser Doppler methods used by our In-plane Vibrometer due to the virtually mirror-like reflection from flat, mirror-like surfaces. This is why Polytec uses the technique of stroboscopic video microscopy in the PMA-300 Planar Motion Analyzer. This can be used to examine the mechanical vibration characteristics of microstructures parallel to their surface.

MMA-300 Micro Motion Analyzer

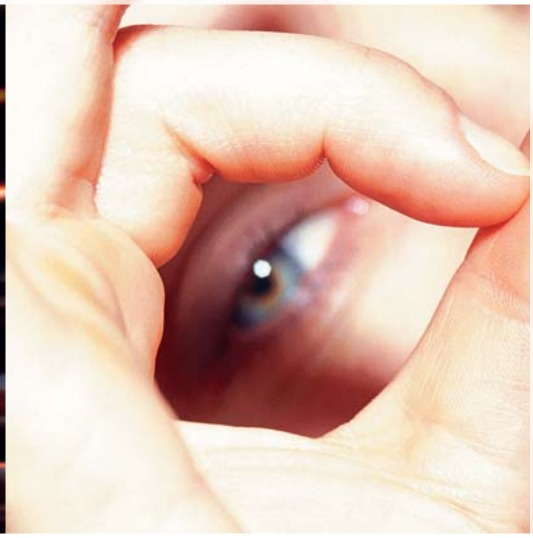
The MMA-300 Micro Motion Analyzer combines our award-winning MSV-300 Microscope Scanning Vibrometer with the PMA-300 Planar Motion Analyzer for in-plane analysis. By covering all 3 dimensions, MMA-300 can characterize the dynamic behavior of MEMS completely.

MMA-300 has received immediate acclaim among users. The first systems are already in use and further orders have already been received from Asia, Great Britain and Germany.

Read on about the advantages, operating principles and areas of application of the MMA-300 on page 6 of this edition.

For more information please send an e-mail to Lm@polytec.de

All 3 Dimensions *in Sight*

Vibration Measurement using the Polytec Scanning Vibrometer PSV-300-3D

The new Polytec Scanning Vibrometer PSV-300-3D is the first system to allow complete 3-dimensional measurement of a structure vibrating in space.

Mathematical modeling used to predict the vibration characteristics of components and machines has become an established part of product development that makes a decisive contribution towards the operational safety and quality assurance. The basis for the reliability of mathematical simulations is a comparison of the model with data gained experimentally to deternine unknown material properties such as the stiffness and damping of a real object.

For some years now, laser vibrometers have prevailed in the area of vibration measurements among a wide variety of other techniques.
In comparison to the mechanical acceleration sensors, they provide significant advantages such as a considerably higher bandwidth (up to 30 MHz), better resolution (~1pm) as well as zero mass loading on the object under investigation. Moreover, Polytec's newly developed PSV-300-3D offers for the first time the option of scanned measurement of an object to determine the vibration in three dimensions.

Principle of the PSV-300-3D

Polytec's PSV-300-3D is based on the technology of the well-established PSV (Polytec Scanning Vibrometer). By using three independent scanning vibrometer sensor heads and controllers, vibration velocity measurements are made simultaneously from three different directions for each respective sample point. The three sensors are controlled centrally by the PSV measurement and control software.

Making a typical measurement involves these simple steps:

- Train the space coordinate system
- Define the sample points on the object
- Set the parameters for analog and digital acquisition of measurement values
- Start scan
- Evaluate and/or export the data

The following example measurement describes this procedure:

Making a measurement

Training the coordinate system

To ensure that the 3D coordinates of the measured data points match those on the object with regards to orientation and absolute values, the first step is to align the space coordinate system with that of the PSV-300-3D. This is done by co-aligning the three laser beams of the PSV-300-3D on at least four (known) points on the target object or suitable reference object and entering the corresponding coordinate values.

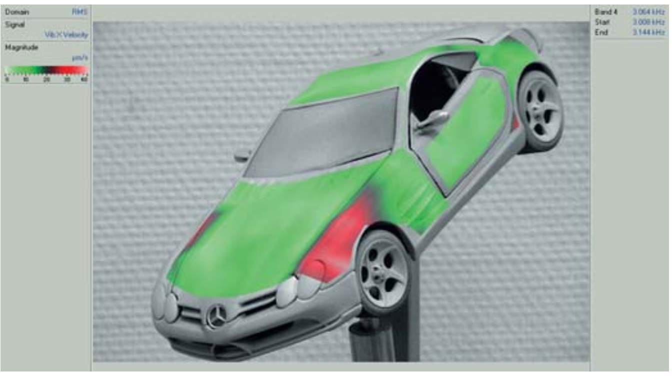
Defining the sample points

To define the sample points, the APS (Advanced Point Selection) mode is used, as is done with the (1D) PSV-300. In contrast to previous PSV versions, the software will now allow you via the menu item “File Import“ to import an externally created geometry model which has been saved in Universal File Format. The measuring grid created with the PSV software for the measurements shown here is shown in the illustration in the background of this page.

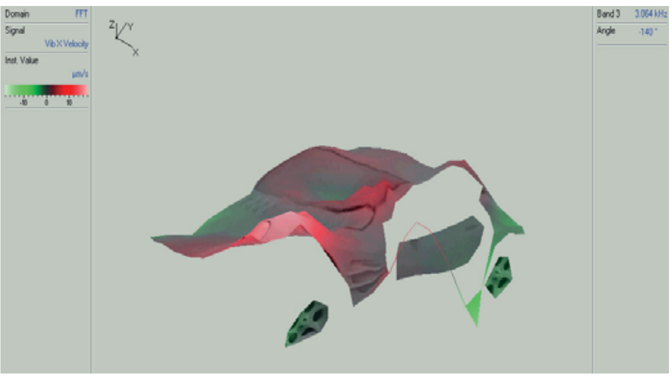
The software also makes it possible to define the individual sample points directly using the live video image. This method makes it possible to make a measurement on a structure there is no geometry model available for.

Evaluation of the data

Once the measurement has been made, the data can be evaluated in Presentation Mode or can be exported to external software packages for further analysis (such as for example ME Scope, LMS, IDEAS). Within the PSV software, the vibration mode is independently presented as a digital image or animation for each coordinate (x, y, z) (spatial representation is available now). The following illustration shows the rms value of the vibration at 3064 Hz in the x-direction of the model car.



In addition to the two-dimensional colormap shown here, you can also present the vibration as a 3D color animation or with isolines:



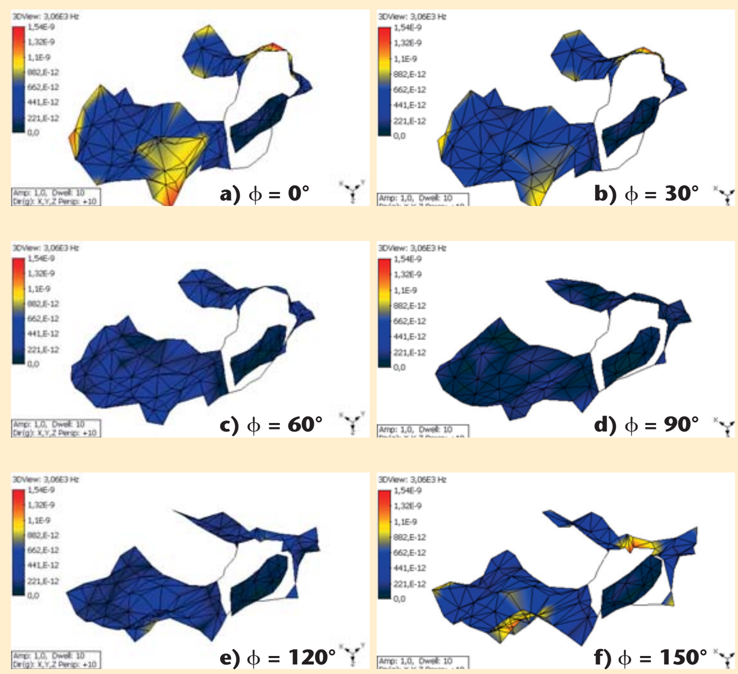
For more information please send an e-mail to Lm@polytec.de

Additional presentation and analysis options are provided by exporting the measurement data as a Universal File Format file and then analyze it with modal analysis programs such as ME Scope. Once the structures and vibrations/spectra of interest to you have been selected and saved using the menu “File - Export Universal File“, the file can be imported by any modal analysis software that supports Universal File Format.

An animation that has been created using ME Scope after importing this data and subsequently splitting it into individual images is shown in the figure at the bottom right.

SUMMARY

Polytec's PSV-300-3D opens up completely new options for modal and vibration analysis. With the ability to measure the three-dimensional vector of a vibration on an object's surface in a single scan, the effort required to make a three-dimensional vibration measurement for modal analysis is considerably reduced. The new geometry import feature simplifies the preparation for the PSV measurement. The first systems are already being used in industry. According to the operators, they are delivering remarkable results.



Colormap presentation of the amplitude of the 3064 Hz vibration in all dimensions at 6 different phases ϕ (created with ME Scope)

Insight *into the Dynamics of the Micro-World*

Micro Motion Analyzer MMA-300

Comprehensive measurement technology to characterize Micro-Electro-Mechanical Systems.

The Microscope Scanning Vibrometer MSV-300 has proved its value for years now in characterizing out-of-plane vibrations of microstructures. The new MMA-300 Micro Motion Analyzer presented here now makes it possible to acquire in-plane motion components also. It is made up of the proven MSV-300 and the new PMA-300 Planar Motion Analyzer for in-plane analysis. This modular approach allows you to upgrade an existing MSV to a Micro Motion Analyzer.

Objective

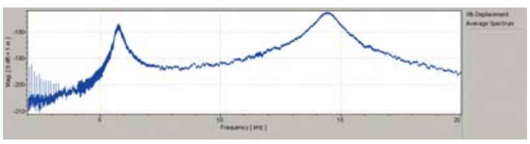
Attaining fast, quality data is the main objective for measurement systems used not only in research and development but also in production. Anyone familiar with laser Doppler vibrometers (MSV-300) is accustomed to receiving the complete frequency spectrum response to broadband excitation in a matter of seconds. Through the scanning process, high density structural measurements can be made and evaluated quickly (up to thousands of points with a speed of > 20 points/s).

However, due to the additional in-plane components found in many MEMS, this option alone is insufficient because the vibrometer only receives vibration information parallel to the direction of the laser beam.

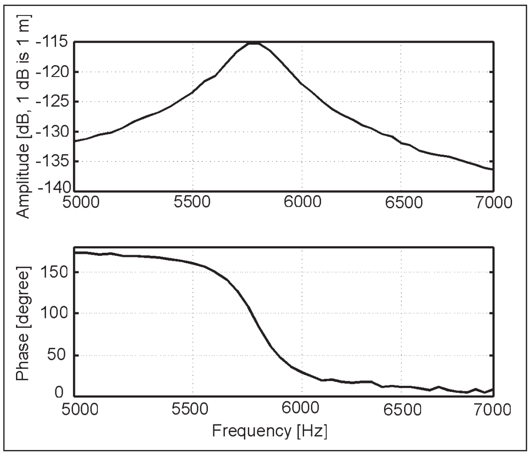
Alternative interferometric image-generating processes such as ESPI or white light interferometry can be used, as used by Polytec for optical topography acquisition in the nanometer range. These methods are undesirable, however, for broadband frequency response measurements. This is because the interferometric process requires an image to be acquired for every phase position and every frequency, making it impossible to rapidly traverse wide frequency ranges.

Measurement Principle

Combining laser Doppler vibrometry and stroboscopic video-microscopy, resonant frequencies of in-plane movement can be detected, verified and evaluated immediately (refer to box “Stroboscopic Video Microscopy” on page 7). The MSV with its picometer resolution does not miss even the tiniest in-plane resonance corresponding to out-of-plane components. Using the live mode of the PMA, you can see at a glance whether there is movement and/or whether there is obvious damage to the component. The live mode thereby shows the movement of the components up to frequencies of 1 MHz in slow motion or at a standstill at a defined phase position.



Spectrum of a broadband excitation (periodic chirp)



Bode Plot calculated using the PMA-300 to verify the in-plane resonance

An advantage of the combined procedure is that in-plane data are only acquired within the frequency ranges determined using the laser vibrometer. This significantly reduces the sample time that would be otherwise wasted acquiring a vast amount of data. In production control it would be plausible to even dispense entirely with the in-plane measurement if the characteristics of the out-of-plane movement are known.

Why are FFT and image processing combined?

The combination of FFT and image processing measurements offers unique advantages. Without the FFT measurement, the image processing measurements would be required at many frequencies. Particularly for weakly attenuated components (in a vacuum), which show steep resonance peaks, the frequency step between two image processing measurements must be very small. Small step sizes, however, considerably increase the volume of data and measurement time.

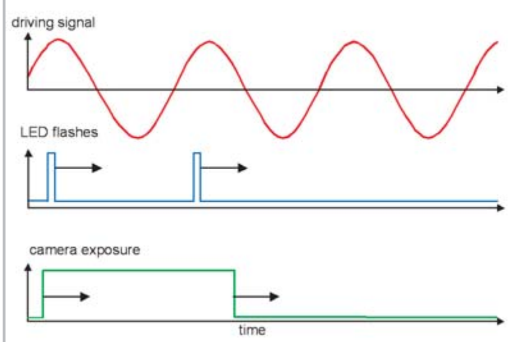
The FFT measurement can be used to identify the resonance peaks. The time needed for a high resolution FFT-measurement is in the order of milliseconds to a few seconds. With random excitation even resonance peaks, which are narrower than the FFT resolution, can be identified. Once the resonance frequencies are known, image processing measurements can be performed with sinusoidal excitation only at these frequencies.

The analysis is carried out according to the Pattern-Matching process, which acquires and tracks the defined pattern in a high-resolution video image (1030x1300 pixels). As a result, all in-plane movement data for the selected area is available for further analysis.

Stroboscopic Video Microscopy

The internal signal generator of the MMA periodically excites the component with a sine or a pulse signal. A so-called "pattern generator" uses an LED to generate ultra-short flashes of light (< 100 ns) synchronously with the phase position of the excitation signal. This means that a high degree of phase accuracy is attained, even with high-frequency excitation. The electronic camera shutter in turn is synchronized with the excitation. This remains open until enough light has been collected to save the image after several periods. The power of the LED generally allows sufficient illumination with only a few flashes.

This procedure guarantees a high degree of measurement accuracy and a visual real-time analysis in live mode.



Principle of stroboscopic video microscopy

SUMMARY

The development of the MMA-300 Micro Motion Analyzer to include PMA inplane analysis now makes it possible to fully characterize MEMS components.

The modular design allows retrospective adaptation of existing MSV-300 systems with the PMA to make it a fully functional MMA-300.

By combining the quick vibrometer process with stroboscopic video microscopy, the time required is minimized while retaining full acquisition of information. The MMA-300 reveals our micro-mechanical worlds.

For more information please send an e-mail to Lm@polytec.de

Primary Vibration Calibration
by Laser Interferometry

Requirements, Challenges and First Experiences with a New Calibration System

In recent years, the old standards for calibrating vibration and shock transducers have completely been revised. Result of these activities is a new series "Methods for the calibration of vibration and shock transducers, ISO16063-xx".

By Uwe Bühn and Holger Nicklich – SPEKTRA GmbH Dresden, Germany

This revision was sparked off by new international requirements and the possibility to use new and well-known technologies at a higher level. The method most frequently used for the calibration of vibration sensors is a secondary system in accordance with ISO 16063 Part 21. In this case, the device under test will be compared with a reference standard accelerometer. This reference standard must be calibrated at a higher level, e.g. by PTB in Germany using primary calibration.

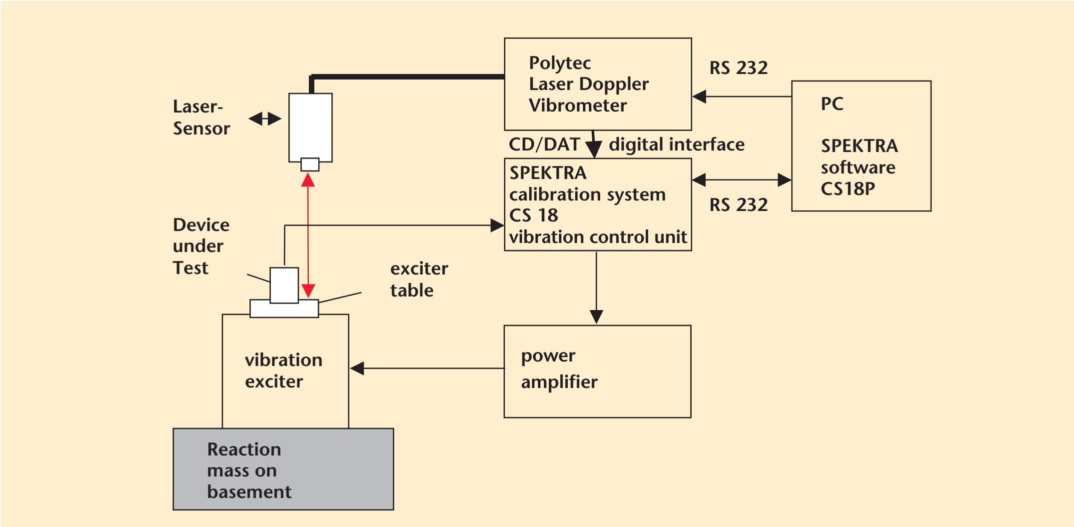
Calibration by Laser Interferometry

Part 11 of the new ISO standard describes methods of primary calibration by laser interferometry. Measurements of vibration acceleration, velocity or displacement are made with a precision that is traced back directly to the wavelength of laser light.

In the ISO standard, several methods of primary calibration are described. Because of the benefit of wide frequency and amplitude ranges, and the possibility to measure both amplitude and phase of the vibration signal, SPEKTRA integrated a Primary Option based on Method 3 "Sine-Approximation Method" into their Calibration System.

Due to the high precision of interferometers, primary calibration with very low measurement uncertainty is obviously not too difficult to achieve. As the prices of these systems are becoming more affordable, these will be installed not only in national metrology laboratories but also in highly specialized accredited industrial calibration laboratories.

To fulfill all requirements of ISO standard 16063-11, it is necessary to make use of a high quality measurement system. The vibrometer is without question an essential tool for carrying



Block diagram of the calibration system

out primary calibration. SPEKTRA successfully integrated the Polytec vibrometer with digital interface into their calibration control and measurement system.

The vibration exciter generates the mechanical excitation signal to which the device under test (DUT) is exposed. The instrumentation has to be so designed such that there are only minute transverse and rocking motions over a wide frequency and amplitude range. In practice this is definitely a major problem because it is not easy to generate the mechanical excitation signal only in the desired direction.

At first glance, it seems relatively easy to successfully make the primary calibration system by combining a good vibration exciter with a vibrometer and voltmeter. Unfortunately, this is more difficult than it seems. It is necessary to integrate these components in an optimized system that takes into consideration all requirements and influences that reduces the uncertainties of the calibration procedure to the lowest possible values.

Components and requirements

In the following list, the reader will find the important system components and parameters that have to be controlled. Also, values that are typically achievable are listed.

- Frequency stability and uncertainty: ± 0.05 %
- Acceleration stability and uncertainty: ± 0.05 %
- Total Harmonic Distortion THD: < 2 %
- Transverse, bending and rocking movements: f < 10 Hz: < 1 %, f > 10 Hz: < 10 %
- Voltage generation / measurement: < 0.1 %
- Environmental conditions: Noise, Humidity ...
- Vibration isolation between vibrometer and exciter
- Laser Interferometer: digital signal demodulation, choice of measuring points
- Combination of components: synchronized signal processing
- Dependence of the uncertainty of the sine approximation on the number of sample points

SUMMARY

Component integration for a calibration system is an optimization task. Requirements of the overall system and the individual requirements to each component have to be regarded.

This happens with consideration to the interaction between all components to reduce the calibration uncertainty to the lowest possible value.

CONTACT

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New Product *Developments*

IVS-300

Digital Industrial Vibrometer

The new Polytec Industrial Vibration Sensor (IVS-300) is an integrated single box vibrometer, specifically developed for non-contact vibration measurement in production test applications. It features a robust and compact design, sealed to IP-64 standard to cope with the challenges of harsh industrial areas.

The IVS-300 exploits the latest digital signal processing techniques to ensure accurate and repeatable measurement from un-cooperative surfaces.

The IVS-300 features:

- 0.5 Hz to 22 kHz frequency response (highly linear)
- Up to ± 500 mm/s velocity (3 ranges for best resolution)
- Advanced digital signal electronics for lowest noise/highest sensitivity

The IVS-300 is the first choice for non-contact measurement on “difficult“ surfaces with poor light scattering characteristics and for the resolution of low vibration amplitudes requiring high resolution. All range and filter settings are software configured via a serial interface, leaving no risk of accidental changes in key settings on the production line. Vibration signal output is via an analog (± 4V BNC), or digital audio interface (SP-DIF).

OFV-5000

Modular Vibrometer Controller

The new OFV-5000 Controller is the core of Polytec’s latest state-of-the-art laser vibrometer systems.

Its modular design allows the frequency, velocity and displacement capabilities to be tailored to specific or multiple applications. Both analog and digital decoders are available, giving a frequency range from near DC to 20 MHz, with velocities to ± 10 m/s and displacements from the sub-nanometer to meter range.

Full remote control, laser auto-focusing and other functions are incorporated, allowing the OFV-5000 to be incorporated as part of a small scale lab test, or expanded all the way up to a full scanning vibrometer system.

OFV-505

Vibrometer Sensor Head

Matched to the OFV-5000 controller is the new design OFV-505 Sensor Head, with improved optical sensitivity and range of short, medium and long-range optics. The latter can measure accurately from matt black surfaces at 30 m and beyond. Also incorporated is Intelligent Focusing, featuring recall of focus distances, auto-focus and remote control, allowing the OFV-505 to be used in hazardous, repetitive test and other applications.

New Software Releases

PSV-7.4 and VibSoft 3.4

Polytec’s PSV scanning and standalone VibSoft software has already gained a reputation for user-friendliness and high performance. This reputation is enhanced by the availability of the following new functions and features:

- Increased sample points in Time Acquisition mode (now up to 67 Mega-Samples)
- Optional High Frequency data acquisition (in MSV and VibSoft)
- Peak Hold function
- Zoom-in function for all surface view styles, including live video image
- Pan function in analyser windows
- Mouse control of the laser beam in Alignment mode
- Simplified vibrometer configuration

CONTACT

For more information, contact your local Polytec Technical Team, or send an e-mail to Lm@polytec.de

Polytec

Measurement Solutions
Made Possible by Laser Vibrometry

FOR BEGINNERS AND EXPERIENCED USERS

We have assembled the most popular techniques and solutions for non-contact laser vibration measurement technology. With a wide range of products, even experienced users can overlook the many options available.

The following presentations illustrate the way in which the vibrometer can be used for different applications. Laser vibrometry has all the advantages of a non-contact measurement technique. The only condition is that the laser beam has unhindered access to the object. For this reason the following explanations pay careful attention to the relationship between the object, its direction of vibration and the necessary beam path.

Laser vibrometers measure vibrational velocity without any contact and, depending on the configuration, the vibrational displacement. It is possible that this summary will provide the stimulus for new ideas. We wish you success and would be more than happy to support you with a more extensive, detailed consultation.

Continued on Page E4 >>

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Principles *of Vibrometry*

Laser Doppler Vibrometers (LDVs) are particularly well suited for measuring vibrations where alternative methods either reach their limits or simply cannot be applied. For example, LDVs can measure vibrations up to the 30 MHz range with very linear phase response and high accuracy. Measurements of the surface of liquid materials or vibrations of very small and light structures can also only be made using non-contact measurement techniques. Contacting transducers can fail when attempting to measure high amplitudes. The principle of laser Doppler interferometry is explained in the following.

The Doppler Effect

Everybody has experienced the Doppler principle behind LDVs when, for example, the acoustical tone of a moving vehicle changes as it passes you by on the highway. Because the propagation of light can be viewed in a similar way, the same physical principles can be applied here as in acoustics. The following description gives a graphical representation of this phenomenon for a moving sound source.

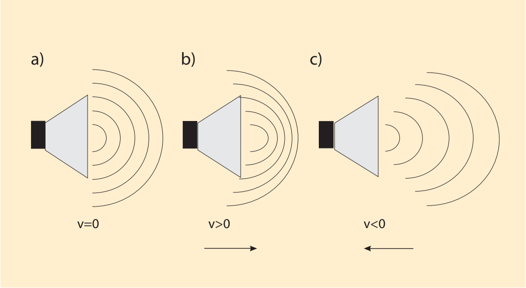


Figure 1 shows the three cases of a sound source (loudspeaker): at rest (A), moving to the right (B), and moving to the left (C). The lines originating from the loudspeaker represent vibration maxima at a specific observation time t. An observer standing to the right of the loudspeaker in case A will hear a frequency that corresponds to the frequency emitted by the loudspeaker. In case B, the loudspeaker is moving towards the observer ($v > 0$). This would make the wave front seem to be "compressed". The vibration maxima approach at shorter intervals than when the loudspeaker is resting. This results in the frequency heard being higher than the frequency emitted by the loudspeaker. Consequently, the frequency heard by an observer where the sound source is moving away (case C), is lower.

If a wave is reflected by a moving object and detected by a measurement system (as is the case with the LDV), the measured frequency shift of the wave can be described as:

$$f_D = 2 \cdot v/\lambda$$

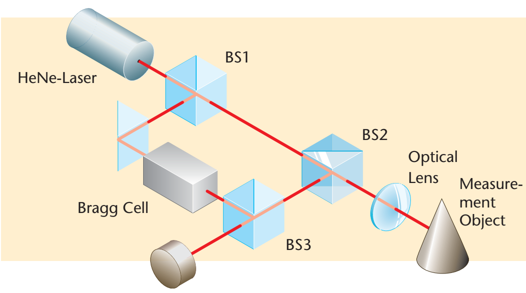
where v is the object's velocity and λ is the wavelength of the emitted wave. To be able to determine the velocity of an object, the (Doppler-) frequency shift has to be measured at a known wavelength. This is done in the LDV by using a laser interferometer.

Interferometry

The Laser-Doppler vibrometer works on the basis of optical interference, requiring two coherent light beams, with their respective light intensities I_1 and I_2, to overlap. The resulting intensity is not just the sum of the single intensities, but is modulated according to the formula

$$I_{tot} = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos\left[2\pi(r_1 - r_2)/\lambda\right]$$

with a so-called "interference" term. This interference term relates to the path length difference between both beams. If this difference is an integer multiple of the laser wavelength, the overall intensity is four times a single intensity. Correspondingly, the overall intensity is zero if the two beams have a path length difference of half of one wavelength. In case (a), the two beams interfere constructively, and in case (b) it is referred to as destructive interference. Figure 2 shows how this physical law is exploited technically in the LDV.



The beam of a helium neon laser is split by a beamsplitter (BS 1) into a reference beam and a measurement beam. After passing through a second beamsplitter (BS 2), the measurement beam is focused onto the object under investigation, which reflects it. This reflected beam is now deflected downwards by BS 2 (see figure), is then merged with the reference beam by the third beam splitter (BS 3) and is then directed onto the detector. As the path length of the reference beam is constant over time (with the exception of negligible thermal effects on the interferometer) (r_2 = const.), a movement of the object under investigation (r_1 = r(t)) generates a dark and bright (fringe) pattern typical of interferometry on the detector. One complete dark-bright cycle on the detector corresponds to an object displacement of exactly half of the wavelength of the light used. In the case of the helium neon laser used almost exclusively for vibrometers, this corresponds to a displacement of 316 nm! Changing the optical path length per unit of time manifests itself as the Doppler frequency shift of the measurement beam. This means that the modulation frequency of the interferometer pattern determined is directly proportional to the velocity of the object.

As object movement away from the interferometer generates the same interference pattern (and frequency shift) as object movement towards the interferometer, this setup cannot determine the direction the object is moving in. For this purpose, an acousto-optic modulator (Bragg cell) is placed in the reference beam, which shifts the light frequency by 40 MHz (by comparison, the frequency of the laser light is $4.74 \cdot 10^{14}$ Hz). This generates a modulation frequency of the fringe pattern of 40 MHz when the object is at rest. If the object then moves towards the interferometer, this modulation frequency is reduced and if it moves away from the vibrometer, the detector receives a frequency higher than 40 MHz. This means that it is now possible not only to detect the amplitude of movement but also to clearly define the direction of movement.

Displacement or Velocity?

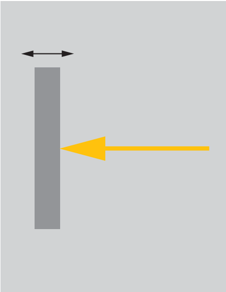
In principle the LDV can directly measure displacement as well as velocity. In this case, the Doppler frequency is not transformed into a voltage proportional to velocity; instead the LDV counts the bright-dark fringes on the detector.

Using suitable interpolation techniques, Polytec's vibrometers attain a resolution of 2 nm, and with digital demodulation techniques even down to the pm range! Displacement demodulation is better suited for low frequency measurements and velocity demodulation is better for higher frequencies, because the maximum amplitudes of harmonic vibrations can be expressed as follows:

$$v = 2\pi \cdot f \cdot s$$

As its frequency increases, a certain vibration generates higher velocities at lower displacement amplitudes.

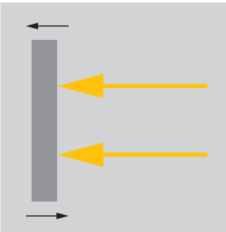
>> Continuation of Page E1



Measuring "Out-of-Plane" Single-Point Vibration

Single point vibrometers measure the vibrations of an object in the direction of the laser beam. If aligned at a right angle to the object surface, then the term "Out-of-Plane" vibrometer is also used.

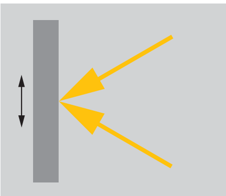
- Proven solutions for all surfaces: OFV-505 and OFV-503
- Fiber optic systems for locations that are difficult to access: OFV-511, OFV-518
- For harsh industrial applications: CLV with IP64 protection rating, IVS-200, IVS-300
- Portable and digital: PDV-100



Measuring "Out-of-Plane" Differential Vibration

Differential vibrometers allow vibration measurement between two points vibrating relative to each other. Specialized fiber optic probes allow the examination of locations that are difficult to access.

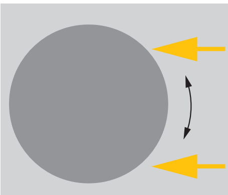
- OFV-512 fiber optic vibrometer
- Particularly for high amplitudes: HSV-2002 high-speed vibrometer



Measuring In-Plane Vibration

Measurements of vibrations in the surface plane, i.e. at right angles to the optical axis.

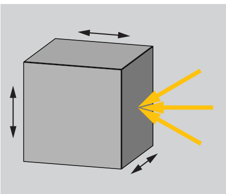
- With the combination of LSV-065 (sensor) and OFV-3310/-3320 (controller), applications such as measuring the vibrations of v-belts or pistons are possible



Measuring Rotational Vibrations

For measuring torsional vibrations of continuously rotating surfaces or angular vibrations of fixed surfaces. Output independent of the surface shape.

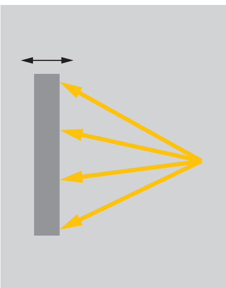
- "RotVib" OFV-400 sensor head and OFV-4000 controller



Measuring 3D Vibration

Three independent laser beams intersecting at the focus point allow you to measure the vibration characteristics in three dimensions.

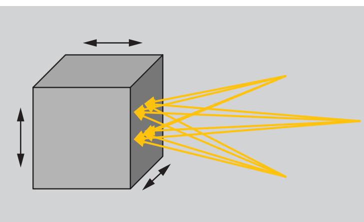
- Simultaneous measurements in all three axes with 3D-LV



Mapping Vibration over Surface

Scanning vibrometers and video microscopy systems for automated surface vibration measurement and visualization. Optimum productivity achieved with fast, comprehensive & accurate acquisition and data handling.

- PSV-300 for all large and small surface vibration measurements
- MSV-300 for microscopic examinations – for example in the MEMS area
- PMA-300 Planar Motion Analyzer for measuring in-plane vibrations of microstructures (stroboscopic video microscopy)



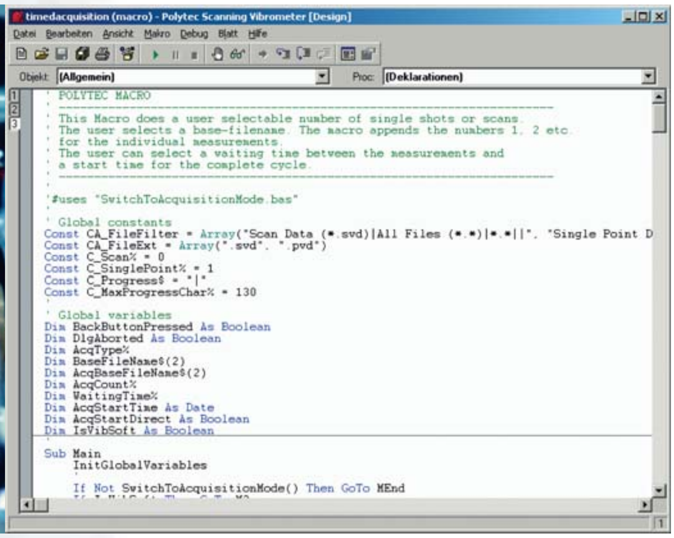
Mapping 3D Vibration over Surface

Acquisition of complete 3-dimensional structural dynamics.

- PSV-300-3D Scanning Vibrometer for automatic measurement and visualization of 3D vibration characteristics
- MMA-300 Micro Motion Analyzer system combining MSV-300 with PMA-300 for 3D vibration characterization of microstructures

Symbol explanation: ↔ = Direction of vibration ■ = Object under investigation ← = Laser beam

Higher Productivity *in the Process Lab*



Polytec Vibrometer Software Expansions allow you to automate data acquisition and analysis and access the Polytec file structures from any application.

Polytec's PSV and VibSoft software are powerful data acquisition and analysis tools for studying vibration response. They are optimally designed for interfacing with Polytec laser vibrometers and give the user access to a spectrum of high quality measurement features. Both software packages are designed for interactive implementation and analysis of measurements.

For certain defined tasks, which go beyond the standard performance specification of PSV and VibSoft, Polytec supplies software products for tailoring functions to individual requirements.

PSV Visual Basic Engine

PSV and VibSoft contain a Visual Basic Engine to implement completely automated process sequences. The Visual Basic Engine contains a development environment for generating and editing programs with a runtime environment for its implementation.

Application examples:

1. Carrying out a sequence of measurements
2. Exporting data in specific target formats
3. Customer specific applications, e.g. monitoring external instruments by programming the digital I/O port, creating customer-specific dialog boxes

Polytec File Access

Polytec File Access is a collection of software objects made available in accordance with the Microsoft Component Object Model (COM). Polytec File Access uses a class hierarchy method that allows access to almost all information, which is saved in data structures such as:

- PSV measurement data files (Scan Data *.svd and Single Point Data *.pvd)
- PSV configuration files
- VibSoft measurement data files
- VibSoft configuration files

In accordance with the COM standard, the COM objects of the Polytec File Access can be accessed from almost any programming language, e.g. Visual Basic, VBA, Visual C++, Delphi, etc.

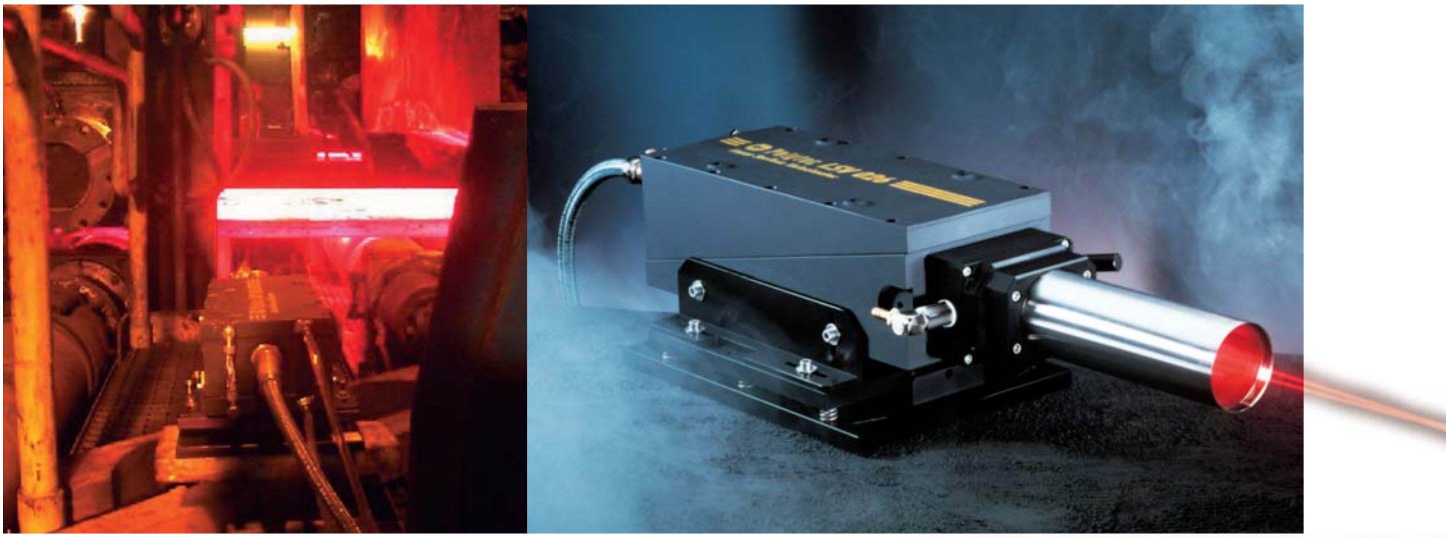
Application examples:

1. Direct access to PSV measurement data from MS EXCEL via Visual Basic for Applications requiring visualization of data in spreadsheet format.
2. Executing special evaluation algorithms in PSV or VibSoft using Basic Macros, which can be loaded in the Basic Editor from PSV or VibSoft respectively.

The specialists at Polytec in sales and applications are glad to be at your disposal to discuss your specific application.

For more information please send an e-mail to Lm@polytec.de

Measure while *the Iron is still Hot!*



Motion Measurement at a Thin Slab Steel Mill using Laser Surface Velocimetry

The title literally describes the problem addressed by the steel industry to measure precise length and velocity data from red-hot objects for regulating and controlling production processes. Non-contact measurement techniques are particularly suitable for acquiring this data.

EXPLANATION OF SPECIALIST TERMINOLOGY

Slab, metallurgical works technology:
molten metal is poured into an ingot mold in the steel works (preliminary product) with a rectangular cross-section to manufacture steel sheets and bands in the mill.

Ingot mold:
a mold made of cast iron or high temperature alloyed steels used in various molding processes (foundry).

The aim of the measurement presented here was to determine without any contact the length and transport velocity (= casting speed of the slab poured) of a hot strand, which needs to be cut. This data was then used to cross-check with the corresponding data that the steel mill itself makes available.

In the thin slab steel mill, a strand of liquid steel is continuously poured into an ingot mold, which is then passed through a system of driven and freely rotating rollers. To ensure even material transport, the ingot mold periodically makes a lifting movement with a frequency of 5.1 Hz and several cm stroke.

Measurement task

In June 2002, a trial to attain a high-precision laser measurement of the slab-length and slab-speed was carried out in the Thyssen Krupp Stahl AG thin slab mill by the engineering firm Alfred Rachner in cooperation with Polytec GmbH. Using slab cutters, the continuous strand is cut into parts of a defined length.

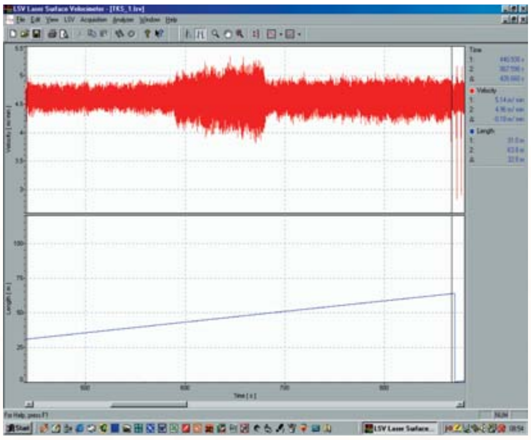
To control the cutting process, it is necessary to have precise information on the length of the slab to be processed. The mill itself measures the length of the slab using encoder wheels. However, the encoder wheels often get contaminated, which results in falsified data and makes it necessary to carry out a maintenance inspection.

The laser velocimeter measurement system was set up between two drives before the slab cutters. It was made up of a Polytec Laser Surface Velocimeter LSV-026-1506-IF with a cooling element, the Polytec Signal Processor LSV-210-01 and PC system to control and evaluate data.

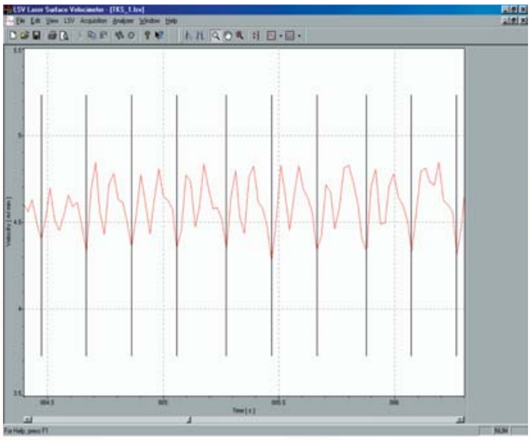
Results

Fig. 1 shows the results of a speed and length measurement on a slab. You can see the slab speed in the top section of the graphics and the length as a function of time in the bottom section.

The vibrations measurements of the velocity signal can be clearly attributed to the ingot mold lift (Fig. 2).



Speed and displacement signal from a slab Fig. 1



Ingot mold lift oscillation on the velocity signal Fig. 2

However, there was a surprising vibration increase in the middle of the slab to be cut. The cause of this increase was attributed to a mold adjuster used to correct the width of the slab. These oscillations are transmitted through the whole strand and can be identified at points much later. In measurements made on subsequent slabs with differing slab lengths, the increase in vibration was always identified in the middle part of the slab.

The slab speed was clearly determined. Here there were hardly any differences from the slab speed calculated by the mill.

However, the actual slab length measurements showed significant differences between the value from the mill and the results of the laser velocimeter. The deviations identified were in a range of 100 mm – 150 mm and sometimes even exceeded 300 mm difference. It must be assumed that the ingot mold lift falsifies the existing measurement made by the plant as the slabs are accelerated and slowed down by the directional drive (Slippage).

SUMMARY

A non-contact laser measurement system was successfully demonstrated for making slab length measurements independent of movement that were more reliable than the data the thin slab steel mill itself provides.

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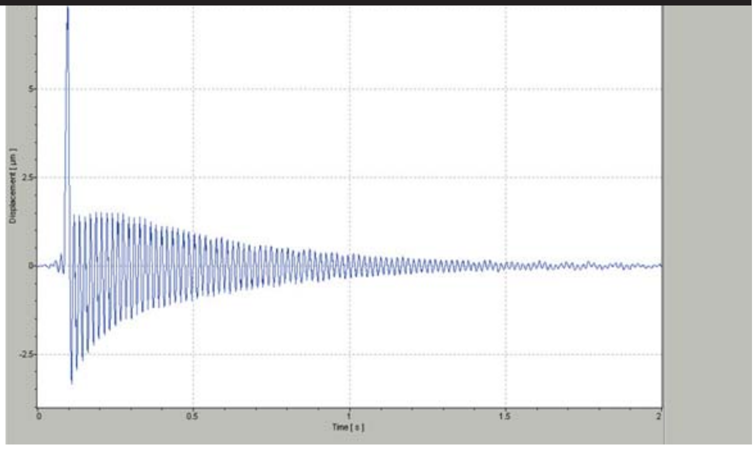
Focus on *MEMS Characterization*

BY ERIC LAWRENCE, POLYTEC PI, TUSTIN, CA USA AND KEVIN SPELLER, APPLIED MEMS, STAFFORD, TX USA

Photograph of several MEMS mirrors Fig. 1



Mirror displacement response to 150 V pulse Fig. 2

Measurements at Applied MEMS using Polytec's Microscope Scanning Vibrometer MSV-300

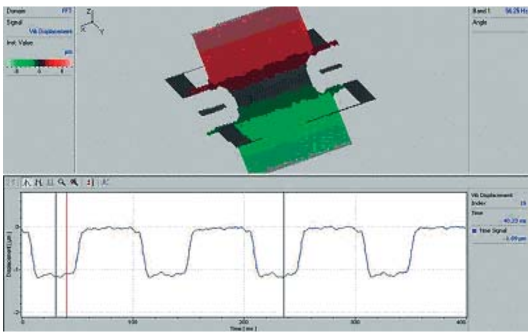
Laser Doppler Vibrometry (LDV) is an established tool for characterization of numerous MEMS technologies such as micro-optics, accelerometers, actuators, gyros, oscillators, and fluidic pumps. While the technology is widely used for research, it is also used in industry as a sensitive tool to test the performance of commercially developed MEMS. An example of this is the work recently performed by Applied MEMS and Polytec PI using the latest Micro Scanning Vibrometer (MSV) technology. Characterization measurements were made for two commercial MEMS devices from Applied MEMS: their DuraScan™ micro-mirror and low noise Si-Flex™ accelerometer.

The Applied MEMS DuraScan™ mirror is an electrostatically actuated MEMS micro-mirror capable of rotation about two distinct axes. The mirror is completely fabricated from single-crystal silicon for the benefits of reduced mirror size (3 mm x 3mm), lower cost and improved performance compared to conventional mirrors (Fig. 1).

Real-time response measurements were made to characterize the actuation dynamics of the mirror as it was rapidly switched from one tilt state to another. Here speed and accuracy are key indicators of the performance. A 150 Volt impulse was used to drive the mirror into its fundamental torsion resonance at 55 Hz (Fig. 2). The ringing that is induced is useful for scanning applications but needs to be eliminated for beam steering and optical switching applications.

Mirror performance was optimized by implementing a patented control technique called Input Shaping™. Controlled step actuation of the mirror was achieved with virtual elimination of resonant vibration response. Polytec's MSV-300 was used to map the device's deflection shape for step motions. The data compiled from this scan measurement was shown as 3D time domain animation to quantify the device's actuation (Fig. 3). The mirror's orientation was switched back and forth many times per second without undesirable vibration effects.

3D animation and time trace of Input Shaped step response Fig. 3



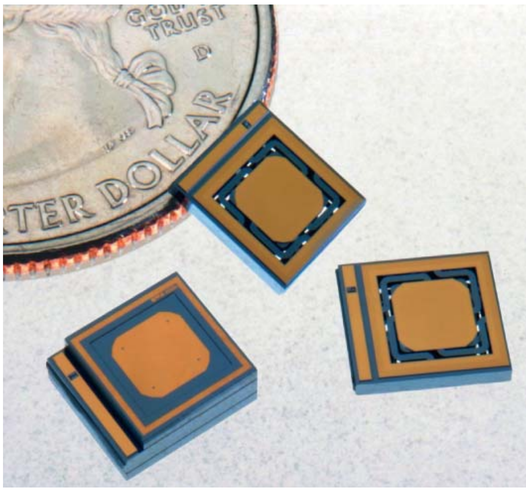
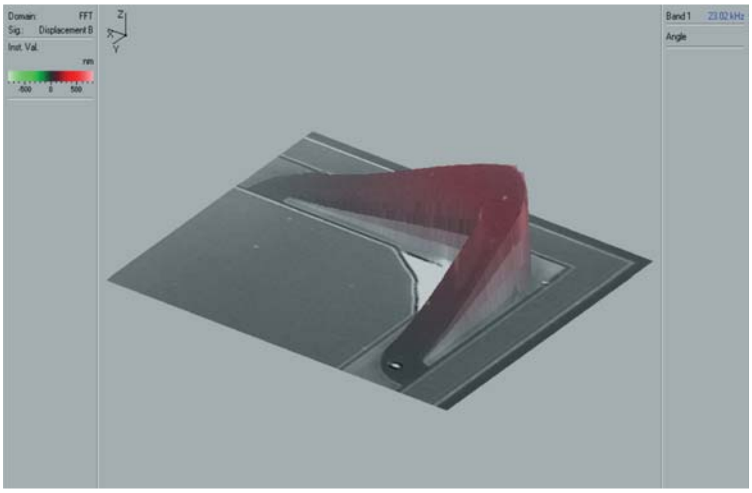


Photo of uncapped MEMS accelerometer Fig. 4



MSV measurement of accelerometer spring elbow at 23 kHz Fig. 5

Characterization measurements were also made on Applied MEMS Si-Flex™ accelerometers (Fig. 4). These devices are stable, robust, state-of-the-art MEMS low-g servo accelerometers with a noise floor near 30 ng/$\sqrt{}$ Hz and a dynamic range of >115 dB. Applications include seismic exploration and monitoring, inertial navigation, and vibration monitoring and analysis.

In the early stages of development, a spurious resonance near 20 kHz was observed in the output of the accelerometer. Although this frequency is well outside of the desired performance band, this mode was suspected as a cause of reduced sensor performance. The source of the mode was unknown at the time. However, there were several suspected causes. Mechanical sensor modes around this frequency were known to exist from FEA simulation, however it was unclear how these modes might manifest in the closed-loop output of the sensor.

Measurements made with the MSV-300 clearly revealed a mechanical resonance of the spring elbow (Fig. 5). Since the LDV measurement was made using only mechanical excitation, electrical causes of the spurious mode could be further eliminated. The scan also revealed additional higher-order modes of the spring arm at frequencies approaching 1 MHz. As a result of the LDV data, the sensor was redesigned to reduce the negative effects of this mode. The later sensor designs led to improved device performance and better yields.

The Laser Doppler Vibrometer is a valuable tool for the development of MEMS devices used in real-world applications. LDV measurements were used for characterization, troubleshooting and design optimization of both MEMS devices. These improvements uniquely shorten design cycles, improve yield and performance, and ultimately reduce the product cost.

CONTACT

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or Kevin Speller at Applied MEMS
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Progress *and Tradition*

The 7th Vibrometer Seminar in Waldbronn, Germany

More than 70 participants arrived in Waldbronn in the fall of 2002 for the 7th Annual Vibrometer Seminar at Polytec GMBH in Waldbronn, Germany. Participants learned about the latest Polytec developments, as well as new and interesting applications for the technology. In the meantime, the Vibrometer Seminar at Polytec has become an annual event.

The following presentations made by Polytec and invited speakers gave an interesting insight into the unusual and diverse world of laser vibrometry:

The World of Vibrometry,
Eric Winkler, Polytec GmbH

Primary Calibration using the Laser Vibrometer, Dr. Holger Nicklich, SPEKTRA Schwingungstechnik und Akustik GmbH, Dresden (see page 8)

Measuring Impact Load using Laser Doppler Interferometers, Dr. Michael Kobusch, Physikalisch Technische Bundesanstalt (PTB), Braunschweig

Laser Vibrometers in Quality Control for Vibration Assessment and Fracture Detection, Holger Hertlin, RTE GmbH

Acoustic Quality Control/Vibrometers in Quality Control by PNA department, Polytec

Vibration Analysis of MEMS,
Dr. Rümmler, Amitronics GmbH, Seefeld

Possibilities of Surface Vibration Measurement on Microstructures by Polytec GmbH

Use of Multichannel Vibrometer Systems for Quality Assurance in Wire Bonders of Microstructures, Mr. Ferber, Fraunhofer IZM, Berlin

Use of Laser Measurement Technology in the Qualification of Pneumatic Products, Mr. Heubach, Festo AG

New Features of the PSV Software 7.3 and VibSoft 3.3 by Polytec

Scanning Vibrometer Measurements on moving objects, Dr. Bendel, Robert Bosch GmbH

Interferometric Refractoscopy to visualize Acoustic and Fluid Phenomena,
Prof. Dr. Zipser, Center for Applied Research and Technology at the HTW Dresden

Laser Vibrometry for Ultrasound Waves-Applications and Detection Limitations for determining the Temperature Dependency of Material Properties in Solids,
Dr. Paul, Behr GmbH & Co. KG

Laser Ultrasonics for structural Health Monitoring, Mr. Hurlebaus, University of Stuttgart

Special Applications: Vibrometers on Rotating Structures and Scanning Measurements on rotating Components using the Derotator
by Polytec product specialists

Nonlinear Laser Scanning Vibrometry,
Mr. Pfleiderer, Institut für Kunststoffprüfung und Kunststoffkunde, University of Stuttgart

Useful Application Advice, FAQs,
by Polytec, and final discussion **Polytec learns from your Application Experiences**

All the presentations listed can be obtained from Polytec.

Vibrometer User Group *Meeting 2003*

in Loughborough, Great Britain

The annual meeting of the British Vibrometer Community took place on January 29th, 2003 at Loughborough University. It was hosted by Dr. Steve Rothberg, the Director of the Wolfson School of Manufacturing and Mechanical Engineering. More than 40 participants from Industry and Academia came together to obtain information on the current developments and diverse application possibilities for the Polytec Vibrometer products.

The event was organized by the extremely capable Polytec-UK subsidiary, Lambda Photometrics. After Roger Traynor of Lambda Photometrics had given a brief overview of the diverse vibrometer applications, it was the users' turn.

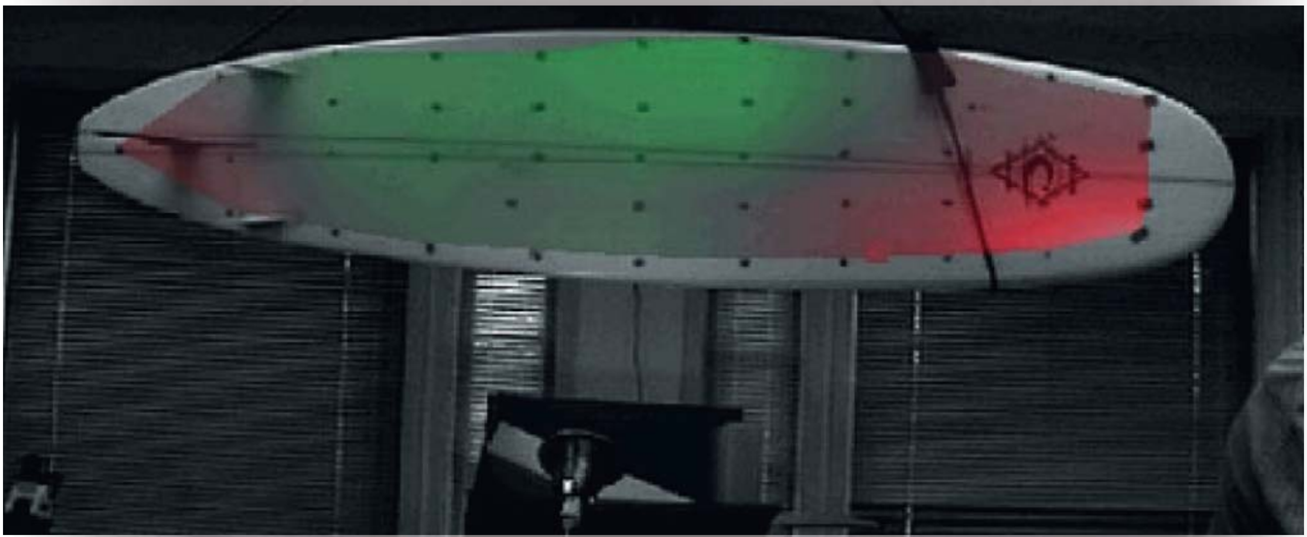
Under the title **Testing and Modeling Dynamic Properties of Composite Train Springs**, Jinping Hou of Reading University reported on the application of LDV technology in the development of train springs. Simon Redfearn of TRW Electric Steering Systems, Holford, presented the potential of non-contact vibration measurement technology in industrial quality control under the title **Production line testing using laser vibrometry**.

Dr. Steven Rothberg, Loughborough University presented **Laser Vibrometer Measurements Directly from Rotating Components**. All participants (especially racing fanatics) enthusiastically received Martin Johansmann of Polytec GmbH's presentation on the interesting subject **HSV-2002 Use for Valve Dynamic Studies in Race & Road Engines**. Dr. Markys Cain of the National Physical Laboratory demonstrated the **Use of the Vibrometer in Piezoelectric Materials Characterization at the NPL** for characterizing materials of technological interest.

Andy Harland and Dr. John Petzing of Loughborough University then gave their presentation **The Application of Laser Vibrometry to the Measurement of Underwater Acoustic Fields**, posing unusual scientific questions that were successfully answered using methods from laser vibrometry. The finale came from Eric Winkler of Polytec who gave an overview of new products and developments at Polytec.

The availability of new information and the open exchanges between users and the Polytec/Lambda Photometrics technical teams made the event a great success for all the participants.

All presentations listed can be obtained from Polytec.



Last Year's PSV Users Meeting
in San Diego, USA

Polytec Vibrometer Users Meetings take place regularly in the USA, as well as in England and Germany. In September 2002 more than 50 Vibrometer users came together for a 2-day Polytec Users Meeting in San Diego. The event was organized under the auspices of Prof. John Kosmatka at the University of California San Diego (UCSD).

The Robinson Hall at the UC San Diego with its excellent technical facilities and typical Californian sunshine provided the ideal background for this event. As most of the participants had traveled from the Western USA, the focus of the presentations was in the area of microstructures and MEMS, aeronautics and civil aviation, computer hard disks and medical applications. The automotive area was covered by a presentation on PSV measurements of motorbikes.

The event was rounded off with presentations by Polytec employees from the USA, England and Germany.

And because the User Meeting took place in California, a reference to Surfing was inevitable: So the last presentation was given the title „Good Vibrations – Modal Survey of a Surfboard". At the next User Meeting in California this subject is to be expanded – the plan is to make operational vibration measurements on the surfboard in the water...

Vibrometer Users Meeting
in the US for Fall 2003

We invite you to attend this year's 2003 Users Meetings to get direct information on the newest developments at Polytec. This year we will be holding the meeting October 27th and 28th in the Detroit area.

Here we will present applications and advances focusing special attention on our PSV VibraScan product. Users are invited to present their own applications and enjoy the stimulating exchanges with other users including presentations on how our products are used by the automotive industry in Europe. A Round Table Forum will take place to discuss requested developments for our products.
The annual User's Meeting in the USA has become a time-honored tradition. For details contact John Foley at Polytec PI, 508-832-3456 x53 or johnf@polytecpi.com

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ECOC www.ecocexhibition2003.com/2003	Rimini, Italy	Sept 22 – 24, 2003
Meascomp 2003 **www.meascomp.com**	**Wiesbaden, Germany**	**Sept 23 – 25, 2003**
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