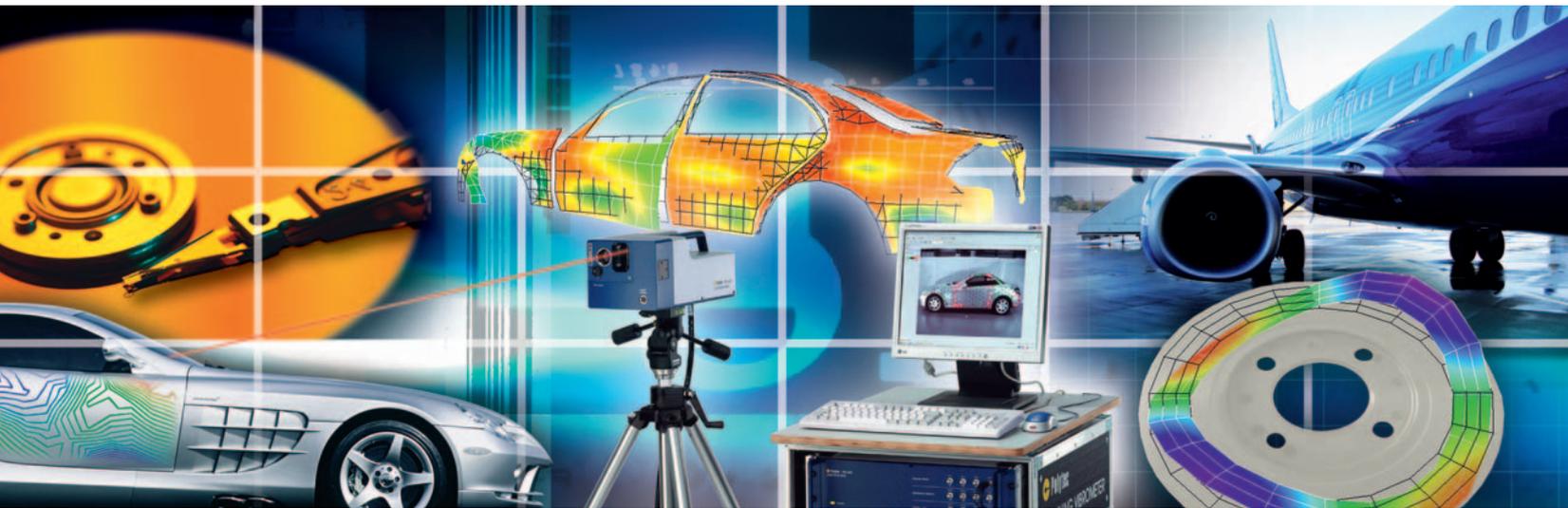




PSV-400 Scanning Vibrometer

1-D and 3-D Vibration Measurement, Imaging and Analysis



**Fast
Accurate
Non-Contact
No Mass Loading**

Vibrations Made Visible

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Involved in Noise, Vibration and Harshness (NVH) Testing and Troubleshooting? Need a rapid, cost-efficient tool for capturing deflection shapes from arbitrary objects in order to improve product development or quality control? The PSV-400 and PSV-400-3D Scanning Vibrometers provide cutting edge measurement technology for the analysis and visualization of structural vibrations. Entire surfaces can be rapidly scanned and automatically probed with flexible and interactively created measurement grids, zero mass loading and no time-consuming transducer mounting, wiring and signal conditioning. The PSV-400 offers technical excellence, ease of use and features, designed for resolving noise and vibration issues in the automotive, aerospace, data storage, micro systems, commercial manufacturing and R&D markets.

Test the “Impossible”

Product design and performance improvement is only as good as the measurement that characterizes the device. Innovative applications reveal the outstanding performance and flexibility of the PSV-400 Scanning Vibrometer family,

regardless of sample size, temperature, location or vibration frequency.

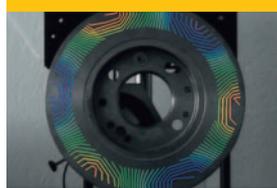
See → pages 10 through 13 for detailed information.

For more info visit
www.polytec.com/int/psv400



Automotive

Body, engine, powertrain and components



Brakes

Hot on the trail of squealing noise ...



Aerospace

High-speed blades, large structures



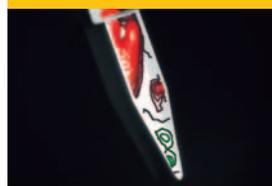
Data Storage

Minute displacements at high frequencies



Small Structures

Micro sensors and actuators in motion



Wire Bonding

Small components at ultrasonic frequencies



Research and Development

and many more applications!

The features described in this document are either standard equipment or optional, depending on the configuration. See page 14 for optional features.



A Powerful Development Tool



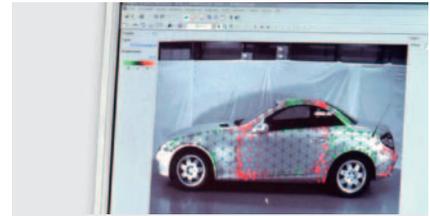
Compact PSV Sensor Head with

- Integrated laser interferometer
- Scanning unit
- Video camera
- Geometry Scan Unit (optional)



PSV Workstation including

- Vibrometer Controller
- Data acquisition
- Data management system
- System cabinet (optional)



Powerful PSV Software that

- Controls the scanners
- Performs data processing
- Provides intuitive & animated data visualization
- Provides interfaces to modal, FEM and other software



At the heart of every Polytec PSV-400 system is the laser Doppler vibrometer – a very precise optical transducer used for determining the vibration velocity and displacement at a point by sensing the frequency shift of back scattered light from a moving surface.

To learn more about laser Doppler vibrometry, please visit www.polytec.com/int/vib-university

Impressive Performance – Convincing Benefits

Accelerate Product Development – Fast ROI

- Sequentially measure the complete spectra for each point and all deflection shapes (ODS) for the surface using broadband excitation
- Find sources of noise and vibration in seconds by single-frequency excitation using FastScan at up to 50 measurement points/s
- Increase throughput with automated testing functions
- Save time and cost without transducer mounting, wiring and signal conditioning
- Quick and easy to set up; integrates with the engineering workflow

Flexibility for New Challenges

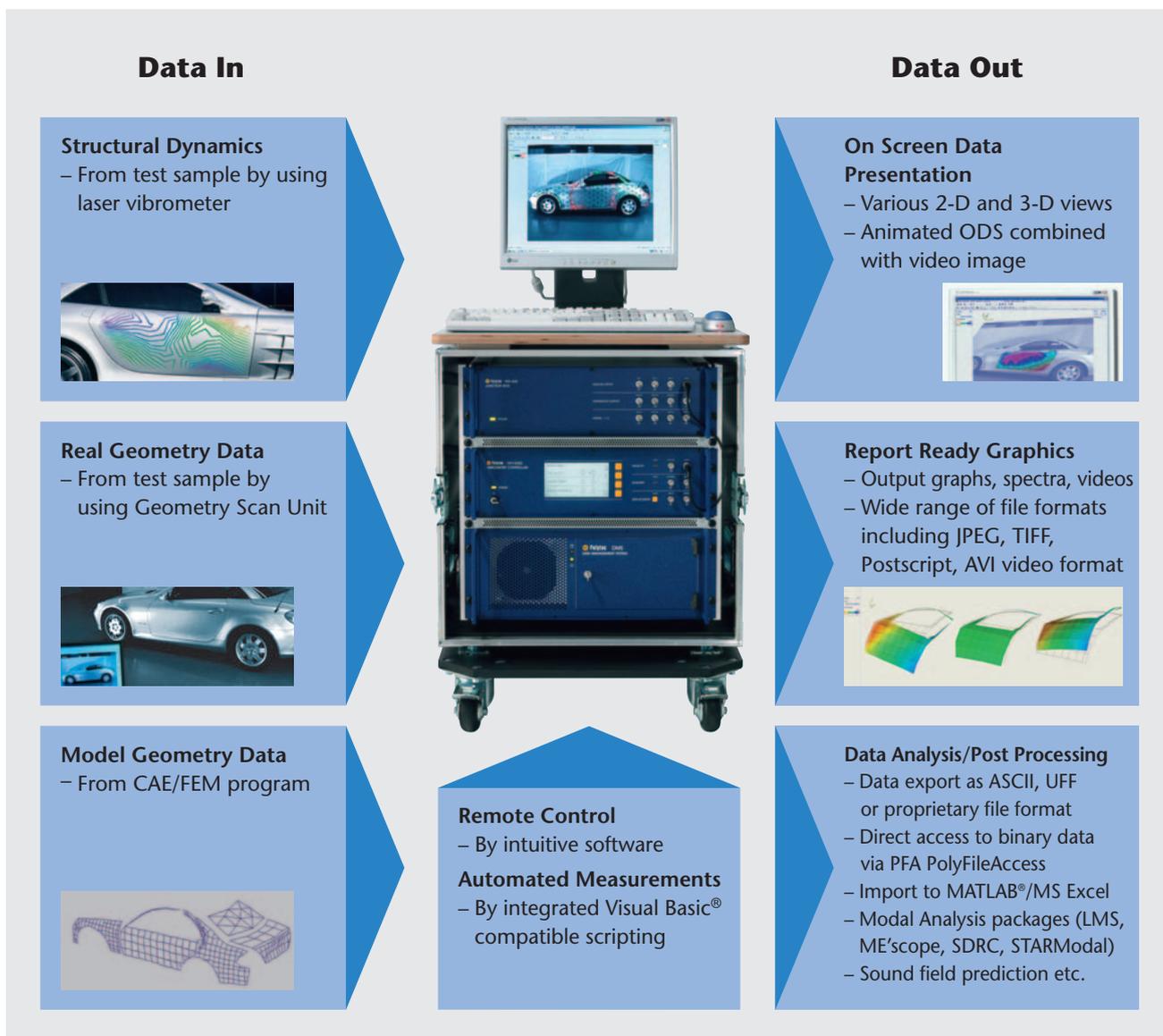
- Broad bandwidth capability – DC to 20 MHz
- Large velocity range – up to 20 m/s
- Flexible sample sizes – mm² to m² – at convenient standoff distances – 80 mm to 100 m
- Geometry Scan Unit measures real geometry of test sample
- High sample grid density with up to 512 x 512 auto-positioned, user-defined measurement points

Data You Can Count On

- Excellent linearity over the whole operating range
- Laser technology is more accurate than conventional contact transducers
- Measurement is non contact, no added mass or stiffness to sample under test
- Results are suitable for QC/QA purposes because they can be referred to calibration standards

Improving the Development Process

– Moving Data to Results



The PSV-400 Scanning Vibrometer is a powerful data acquisition platform that can seamlessly integrate into the engineering workflow and the IT environment. The system provides input interfaces for geometry data from CAE and FEM packages (→ page 6) or from the convenient Geometry Scan Unit. All measurement results are available to third party applications through

various export filters and PolyFileAccess, an open data interface (→ page 9). A powerful post processor is integrated in the software to apply various mathematical operations to the measured data. External software packages can control the PSV remotely by using an integrated Visual Basic® compatible scripting engine.

A Modular System: Meeting Today's and Tomorrow's Needs



With its modular design, the PSV-400 can be configured to optimally meet the data measurement requirements of your application. A wide range of velocity and displacement decoders combined with matching acquisition hardware guarantees the highest performance of the PSV-400. Depending on the chosen configuration (→ see table on page 15), the PSV-400 covers 1-D and 3-D vibration vectors with frequencies from DC to 20 MHz and velocities from 0.02 $\mu\text{m/s}$ up to 20 m/s. Should your measurement requirements change the system can grow with you simply by integrating a new module.

Configuration	
The Basic System: PSV-400-B	<ul style="list-style-type: none"> – Powerful tool for acoustic frequencies, measuring on two channels with 40 kHz bandwidth – Comes with Visual Basic® compatible Script Engine, UFF export, ICP® for reference – Can be customized by a wide range of hardware and software extensions
The Enhanced System: PSV-400-H4	<ul style="list-style-type: none"> – The instrument for ODS analysis and modal testing – Four channels, 80 kHz bandwidth and built-in 3-channel signal generator – Powerful software tools including MIMO function, geometry import, scan options and signal processor
High Velocity Measurement System: PSV-400-H4-S	<ul style="list-style-type: none"> – Based on the PSV-400-H4, for measurement of vibration velocity up to 20 m/s – For more demanding applications like engine development
Ultrasonic Measurement Systems: PSV-400-M2 PSV-400-M4 PSV-400-M2-20	<ul style="list-style-type: none"> – The solution for high-frequency applications up to 1 MHz or 20 MHz, with two or four channels and software options available for PSV-400-H4 – The ultimate tool for ultrasonic vibration mapping. Using the Close-up Unit (→ page 14) allows for measurements even on small structures like disk drives or wire bonding tools



3-D Vibration Vector Measurement:
PSV-400-3D

More Info?
www.polytec.com/int/psv3d

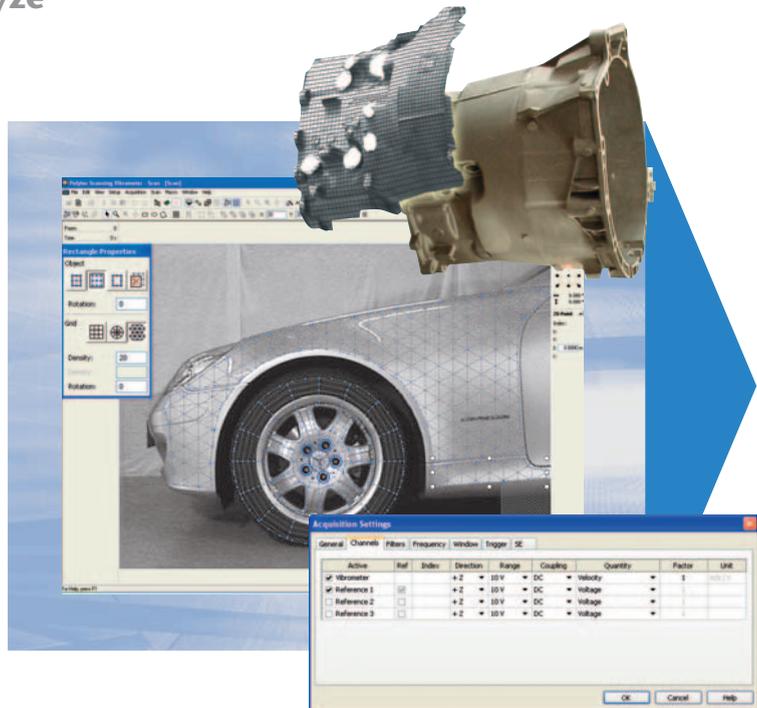
- Three independent sensor heads extend scanning vibrometry to three dimensions to get the complete vibration vector information
- Based on the H4 version with 8 simultaneous measurement channels
- Integral Geometry Scan Unit enables a quick and easy acquisition of 3-D geometry data directly from the sample
- Intuitive 3-D animation of operational deflection shapes with clear separation of Out-of-Plane and In-Plane vector components

Just Point and Scan

Setup • Measure • Visualize • Analyze

Carrying Out a Measurement from Start to Finish

The PSV-400 is easy and intuitive to operate, especially when compared with traditional multipoint vibration measurement methods requiring time-consuming preparation of the test object and sensors. To setup the system, define the geometry and scan grid, and measure. The vibrometer automatically moves to each point on the scan grid, measures the response and validates the measurement by checking the signal-to-noise. When the scan is complete, choose the appropriate frequencies and then display and animate the deflection shape in several convenient 2-D and 3-D presentation modes. These on-screen displays are extremely effective tools for understanding the details of the structural vibration.



Live-Video Assisted Test Setup

The PSV-400 incorporates an interactive video system that helps define scan points in the video image and permits the pointing of the laser beam from the computer desktop.

The coordinates of the laser scanners are matched with the video image either manually using the mouse or automatically using alignment software.

Optional PDA-based wireless control is available for added setup convenience, e.g. for accurate targeting of alignment and reference points.

Easy Definition of the Measurement Geometry

The PSV-400 can work with relative or absolute scan geometry definitions. Scan regions or "objects" are defined directly from the video image using the APS (Advanced Point Selection) mode.

Scan grids with multiple grid densities and coordinate systems (polar, cartesian and hexagonal) each with up to 512 x 512 points can be defined using simple graphical tools such as polygons, rectangles and circles that can be moved, grouped or re-sized. Alternatively, the PSV-400 and the PSV-400-3D can work on geometry data imported from CAE or FEM packages or acquired with the optional laser-based PSV-A-420 Geometry Scan Unit.

Autofocus for Optimum Signal Strength

To assure the best signal quality, the PSV-400 uses a sophisticated autofocus function to maximize the amount of back scattered light collected. For flat surfaces a quick optimization of the focus settings can be established (Fast Mode). For complex shaped objects the Best Mode establishes optimum settings for each individual scan point.

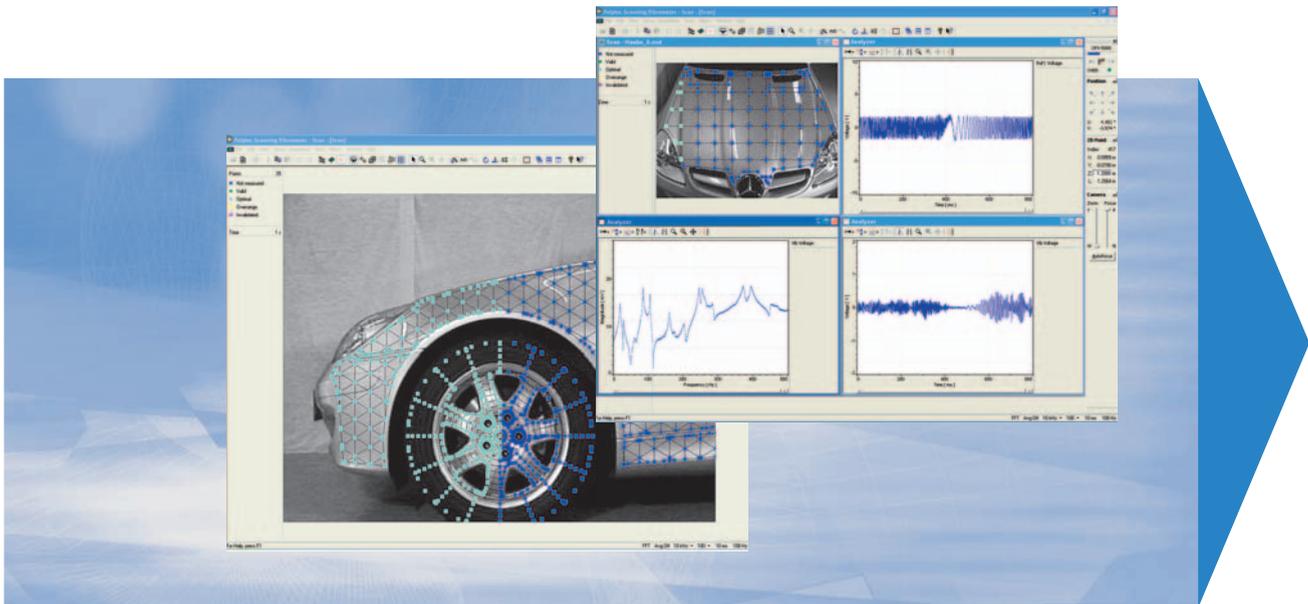
Setting up the Data Acquisition

Prior to data acquisition, the user adjusts settings for the ADC board, OFV-5000 Vibrometer Controller and internal or external arbitrary waveform generator. With the MIMO function, the PSV enables the Principal Component Analysis for separating the responses of different simultaneous excitation channels

Specimen Excitation and Reference Measurement

A precisely defined vibration excitation of the test object is provided by an integrated arbitrary waveform generator under the control of the PSV generator software. Uncorrelated multiple shaker excitation is also possible for MIMO measurements.

Setup · Measure · Visualize · Analyze



Performing the Measurement

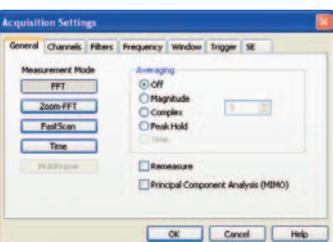
On manual or remote action, the PSV-400 system starts scanning the test object on the predefined measurement grid according to the acquisition settings. A color coding of the scan points in the video image allows for easy monitoring of the status and quality level of each point.

Available scan modes (→ page 14) are

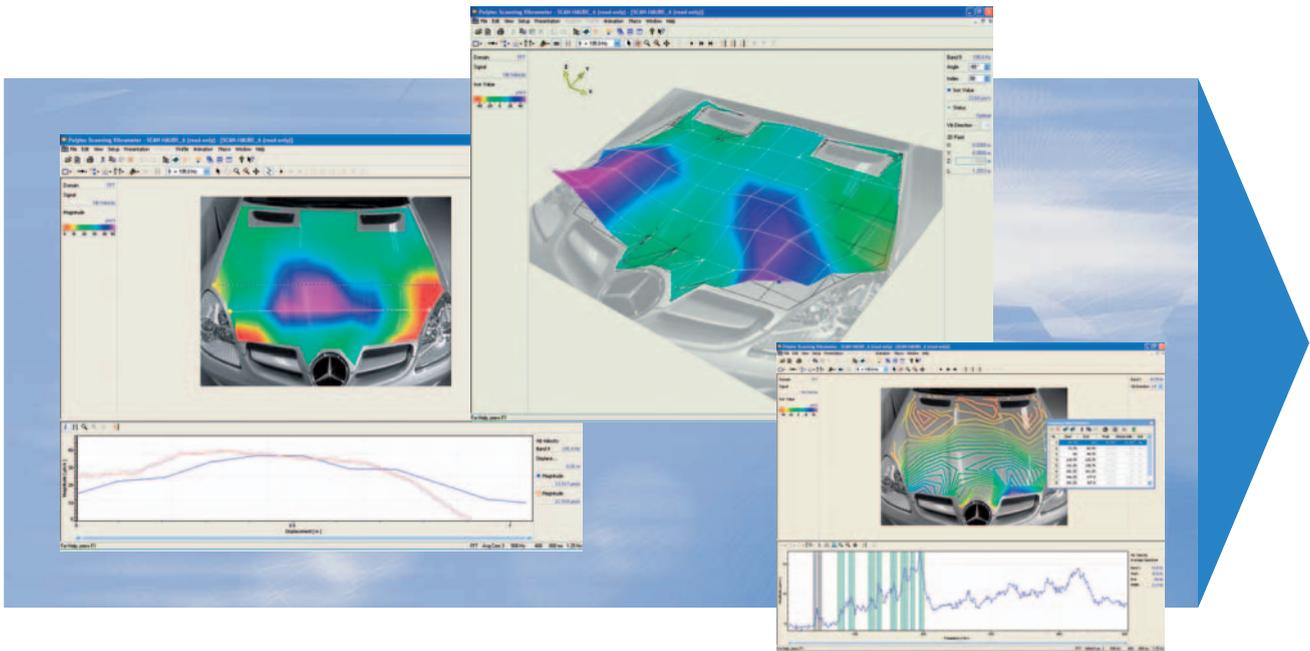
- FFT mode (standard)
- FastScan for very quick data acquisition if the frequency of interest is known
- Time Domain mode for acquiring and viewing time-dependent signals
- Zoom FFT mode for measurements at very high frequency resolution
- Multi-Frame for measurements on combustion engines triggered by ignition timing

During the Scan

- Time traces and frequency spectra are displayed for both the vibrometer and external reference signals.
- Additionally, the FRF (frequency response function) or its estimation H1 and H2 can be displayed. Using the coherence signal, the quality of the measurement can be assessed. All complex spectra can be displayed as amplitude & phase, real & imaginary, or by a Nyquist diagram.
- Averaging and various windowing functions can be applied to the signals.
- Vibrometer data may be displayed in terms of velocity, displacement or acceleration.
- Measurement points are focused automatically and individually.
- Structural data can be displayed in 3-D view.
- PSV-400 ensures optimum data quality by incorporating a sophisticated signal quality evaluation algorithm called Signal Enhancement (SE) and a software-controlled dither motion of the laser spot known as Speckle Tracking.



Setup · Measure · Visualize · Analyze



Identify Frequencies of Interest

After the scan is complete, PSV-400 displays the averaged power spectrum. With an easy-to-use graphical tool the user selects frequencies of interest from this or any number of individual scan point spectra. After that, the operational deflection shapes are calculated. The "cursor" mode allows the display of data at the specified frequency on the geometry of the object by simply mouse-clicking points on the spectrum.

Use Powerful Presentation Modes

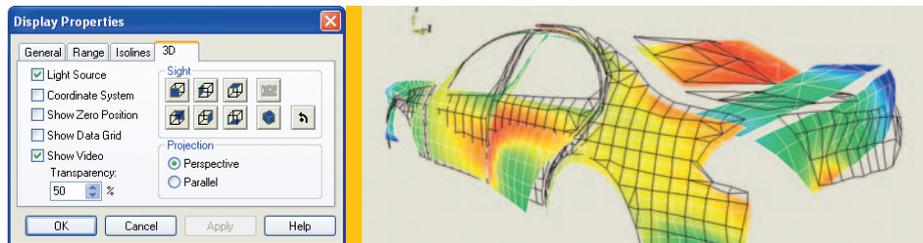
Results may be shown in many different formats including 3-D and 2-D color maps superimposed over the stored video image, contour line plots and profiles. All displays can be animated as long as a phase reference signal was present during the scan. While the animation is running, the user may always change the presentation mode, view, amplitude scaling, and magnification by using the mouse. Additionally, the user can view one or several cross-sections of the data surface.

Three-Dimensional Measurements

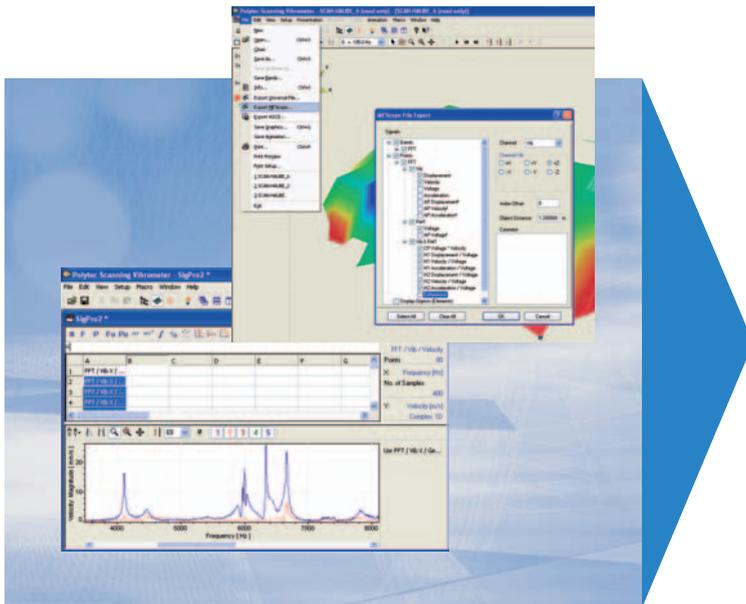
Measurements performed with the PSV-400-3D are especially useful and impressive. In the 3-D representation of vibration data, the user can show the vibrations of the object individually in X-, Y- and Z-direction allowing for clearly separation of in-plane and out-of-plane motions. Several data sets can be combined into one file (stitching).

Time Data Animation

Transient events, for example a settling response, can be displayed by animation of time domain data.



Setup · Measure · Visualize · Analyze



Export Data to Your Specific Application

Any screen display can be written to a range of standard graphics formats or to an ASCII file. Animations can be saved in standard movie format (AVI) for replay on any computer. Measurement data can be provided for post-processing in Modal Analysis, CAE & FEM correlation, sound field prediction and power flow software packages using export Filters for Universal File Format (UFF), ME'Scope, MatLab® and ASCII. FRF's calculated in a MIMO measurement setup can be used to perform a modal analysis on the data e.g. with Vibrant's ME'Scope or other software packages.

Keep Track of Your Measurements

The project browser permits inspection of folders and files of the file system, including network folders. Shortcuts to any folders of the file system can be added to the browser. Files can be directly opened from the project browser. The active folder of the browser is used as default path for all file open and save dialogs. This allows for a project oriented workflow. All measurement and related files such as animations, graphics, macros can be organized in a user definable folder or folder structure.

Analyze and Customize Measurement Results

The Polytec Signal Processor is the user interface to the math library included in the PSV software. Designed as an easy-to-use spreadsheet, measurement data from different sources can be post processed by simple drag and drop operations. Data can easily be shown in one plot, subtracted from each other, and so on. Various operations can be applied including FFT, inverse FFT, digital filters, windowing functions, basic math function (+; -; *; /), Integration, differentiation, resampling or extracting data. The operations can be applied to the complete sets of scan data. The results are stored as User Defined Data Sets (UDDS).



Applications from Small to Large



The PSV-400 Scanning Vibrometer is used to study objects of very different sizes including large automobile bodies, airplane fuselages, ship engines and buildings as well as tiny silicon micromachines, hard disk drive components and wirebonders. Demanding applications such as measurements on hot running exhausts, rotating surfaces, underwater objects, delicate structures or ultrasonic devices are all made possible by the PSV-400.

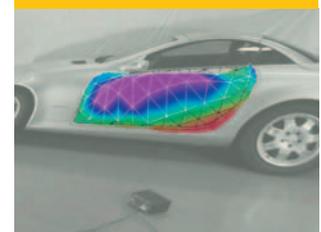
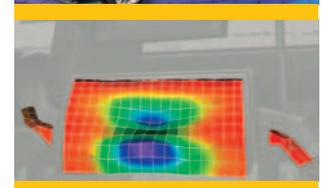
Automotive Applications

To certify that a new part meets noise and vibration specifications, automotive engineers favor testing instruments that are easy to set up and operate, and that can exchange data with existing CAE equipment and software. Polytec's Laser Vibrometers are widely used both for structural dynamics measurements in the R&D labs and for quality control purposes in the production process. The PSV-400 provides time saving measurements without mass loading regardless whether on large areas, hot components, rotating parts, light weight surfaces, or at high frequencies.

www.polytec.com/int/automotive

Benefits of PSV-400 and PSV-400-3D:

- Data import and export compatible with major CAE and modal analysis systems
- Geometries can be either imported from CAE models or directly measured by the Geometry Scan Unit for benchmarking purposes
- Measurement of full cars from one position due to Autofocus function
- Principal Component Analysis during MIMO testing with multiple uncorrelated signal generators
- Measurement of both in-plane and out-of-plane data by using PSV-400-3D



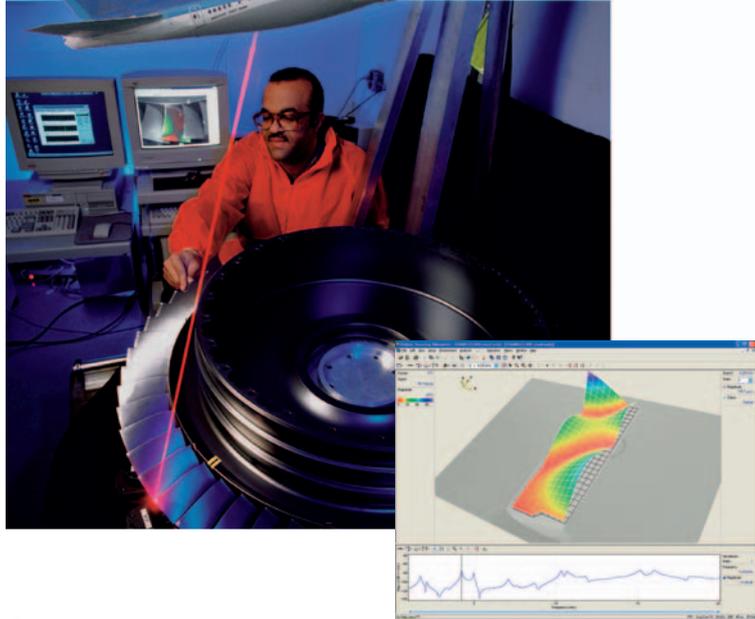


Brake Investigations

All major brake manufacturers use Polytec vibrometer systems for measurements of brake noise, squeal and modal response. This includes the 1-D Scanning Vibrometer as well as the Polytec 3-D Vibrometers (scanning and single point) and fiber optical systems. Measurements on rotating surfaces under operating conditions require high frequency resolution and a large number of sampling points.

Benefits of PSV-400 and PSV-400-3D:

- Non-contact method for measurements on moving surfaces at high velocity
- PSV-400-3D measurements reveal both in-plane and out-of-plane vibrational component
- Scans can be triggered with PSV-A-430 Acoustic Gate Unit
- FastScan option for periodic transient events
- Measurements can be performed via mirrors where optical access is difficult



Aerospace Development

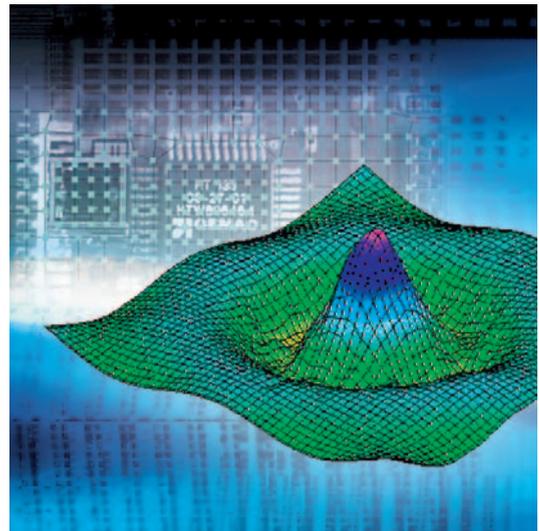
Typical aerospace applications include design verification, characterizing airframe components for production and quality control, and evaluating aging aircraft structures for maintenance and repair. The PSV enables real-time analysis of structural modifications: e.g. fuselage panels can be scanned, treated with damping material, and then immediately re-scanned to view the effect. Measurements on aircraft wings and turbine blades can be performed for modal analysis and subsequent FEM-validation. The PSV-400 is also the ideal tool for measuring surfaces of large objects difficult to reach with contact methods.

www.polytec.com/int/aerospace

Benefits of PSV-400 and PSV-400-3D:

- High spatial and frequency resolution for modal analysis on turbine blades with frequency resolution as small as 0.001 Hz utilizing Zoom-FFT
- Fatigue testing of blades and other aerospace components at very high vibration levels up to 20 m/s (PSV-400-H4-S)
- Large stand-off distance for Laser Vibrometer and Geometry Scan Unit, up to 50 m for measurements on typical surfaces and up to 100 m on surfaces that have been enhanced with retro-reflecting materials

Applications from Small to Large



Data Storage

In designing hard disk drives, one of the challenges is to understand how mechanical interactions affect head positioning. Methods used for design optimization and quality control must be fast, highly sensitive and precise. When verifying a new drive design, fast testing time is paramount. Laser Doppler Vibrometers have been effectively used for many years in design of data storage media. Disk and tape drives and their components encompass a wide range of dynamic applications for the PSV-400.

The example shown above depicts an actuator-suspension element when tested at the drive level. The bending mode (left) is relevant because it can introduce error to the data transfer rate in the drive. Torsional modes (right) are important due to their contribution to off-track misregistration errors.

www.polytec.com/int/datastorage

Benefits of PSV-400:

- High resolution for resolving displacements in the picometer range
- High frequency bandwidth and internal signal generator for efficient resonance testing up to the MHz range
- Digital velocity and displacement decoders for displacement measurements in the frequency range up to 350 kHz at excellent resolution

Small Structures

MEMS devices are widely used in video and computer projection systems, ink jet printers, automobiles and process technology. There is a high demand for appropriate measurement tools in product development, optimization and quality control applications. With regard to micro sensors and actuators (micro pumps, nozzles, valves, drives, mirrors), motion and structural vibrations are of high interest. These structures are much too small to attach transducers. Any contact with a sensor would invalidate the measurement.

Benefits of PSV-400:

- Resolution of spatial details down to several μm and displacements in the nanometer range by using Close-up Unit and micro-scan lens
- Easy operation and high-speed measurements allow the tuning of MEMS components during the development process
- Step response behavior can be visualized and optimized with the Time Domain software

For even smaller objects ($<1 \times 1 \text{ mm}$) Polytec offers microscope-based systems.

www.polytec.com/int/microsystems



Wirebonders

Wire bonding is the technology to make semiconductor contacts, e.g. for all computer and other electronics chips, MEMS devices and power semiconductors in the automotive industry. Bond integrity is critical to maintaining the semiconductor performance, reliability and to ensure a long life-time of the final product.

The PSV-400 is applied to optimize the design of bonding machines, ultrasonic transducers, wire bonding capillaries and power bonder wedges. The bonding process at a frequency of 40 kHz to 200 kHz is examined for identifying and solving quality problems with the wire bonding machine.

Benefits of PSV-400:

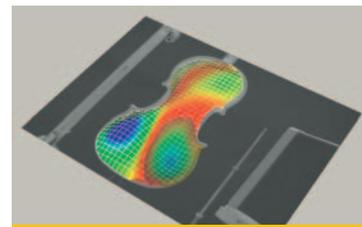
- High frequency non-contact displacement measurement with excellent time and spatial resolution
- Because of zero mass loading, there is no effect on the vibration characteristics of the capillary
- The large and variable working distance allows easy access to the wirebonder
- Direct displacement measurement is available with optional DD-400 integrator module

Research & Development Applications

How do heart valves vibrate? How do insects communicate to each other? Any process where vibrations occur can be measured by laser vibrometry, often the one and only method that can cope with the task. Engineers and scientists involved in medicine, biology or civil engineering use Polytec Vibrometers to study natural and technical processes without contact. In the manufacturing of parts & goods, engineers take advantage of the PSV-400 as a flexible vibration measurement tool for design and redesign of products as well as for fast, reliable in-line and end-of-line quality control.

Benefits of PSV-400 and PSV-400-3D:

- Universal tool that covers a diversity of object sizes from small biological samples to medium-sized power tools and appliances (toothbrushes, vacuum cleaners, washing machines ...) to large buildings and ship engines
- Rapid, non-contact measurement, free of feedback, works on moving parts, on delicate structures, through transparent materials and on points that are difficult to access



Enhancing the Performance

Measuring with the PSV-400 can be made even more efficient. Powerful accessories extend the capacity of the system, and special software options allow for a high-performance, flexible data acquisition, processing and handling.

Find more detailed information on www.polytec.com/int/psv400

Hardware Accessories		
PSV-A-420 Geometry Scan Unit	Laser-based distance sensor for the direct optical acquisition of 3-D geometry data from the sample under test.	
PSV-A-410 Close-up Unit	For close-up measurements, particularly on small parts.	
PSV-A-430 Acoustic Gate Unit	Activates the gate input if a noise exceeds a certain threshold (e.g. for enabling brake squeal measurements)	
PSV-A-T18 Vertical Test Stand	Motorized positioning of PSV scan head for small part testing (e.g. HDD, DVD, etc.).	
PSV-A-T11 Pan/Tilt Head	Motorized pan/tilt head for remote-controlled positioning the PSV scan head.	
PSV-A-010 System Cabinet	19" housing for the Data Management System, Vibrometer Controller and Junction Box.	
PSV-A-408	Accessory package providing 4 additional channels with ICP® (for H-systems only)	

Software Features and Options (Choice)	
APS Professional	For arbitrary definition of measurement points and individual object properties.*
APS Pro Extended	Support of autofocus and Focus Scan mode (determines and stores the best focus position for each individual scan point).*
High Resolution Scan	Software extension to allow a high-resolution 512 x 512 point density for each object.*
Geometry Data Import	Geometry Module for importing geometry data to the PSV software for defining the scan points. Standard on the PSV-400-3D.
Internal/external Signal Generator	Internal arbitrary signal generator supporting a variety of output waveforms.*
FastScan	Fast scan routine (up to 50 scan points/s) for analyzing the response of structures at a single frequency.*
Time Domain Data	Time domain data are acquired while scanning. The data can be averaged and animated during acquisition. Optional for all systems.
Zoom FFT	Significantly increases frequency resolution for selected frequency bands. Optional for all systems except PSV-400-B (not available).
Multi Frame	For triggered measurements on combustion engines. For H-systems, optional.
Signal Processor	The user interface to the math library included in the PSV software, designed as a easy-to-use spreadsheet.*
Principle Component Analysis	For MIMO measurements. For H4 and M4 systems, optional.
Data Export to ME'scope	Optional for all systems.

* Standard on all systems (except PSV-400-B)

Technical Data

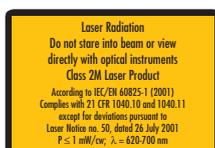
General Specifications	
Working distance	> 0.4 m to about 100 m (≥ 80 mm accessible by using close-up unit)
Laser class	Class 2 He-Ne laser, 633 nm (visible beam), < 1 mW, eye-safe
Sample size	Several mm ² up to m ² range
PSV-I-400 Sensor Head	Contains vibrometer sensor model OFV-505, high precision scan unit, color video camera with Auto Focus and 72x Zoom
OFV-5000 Vibrometer Controller	Equipped with analog (PSV-400-B) and additional digital velocity decoders M2-20: with analog displacement decoder; Velocity ranges: 10 to 1000 mm/s/V (analog); 1 to 50 mm/s/V (digital); 0,2 mm/s/V to 50 mm/s/V (digital, H-Systems and PSV-400-3D)
PSV-W-400 Data Management System	Industrial PC equipped with DVD-Recorder, 19" LCD Display, 100 MB Ethernet network connection, signal generator, hardware for data acquisition, and operating system Windows® XP

PSV-400 Configurations	
PSV-400-B	Basic Scanning Vibrometer 2 channels, 40 kHz, 10 m/s
PSV-400-H4	High End Scanning Vibrometer 4 channels (8 optional), 80 KHz, 10 m/s
PSV-400-H4-S	High Velocity Scanning Vibrometer 4 channels (8 optional), 80 KHz, 20 m/s
PSV-400-M2	Wide Bandwidth 2 Channel Scanning Vibrometer 2 channels, 1 MHz, 10 m/s
PSV-400-M4	Wide Bandwidth 4 Channel Scanning Vibrometer 4 channels, 1 MHz, 10 m/s
PSV-400-M2-20	20 MHz Scanning Vibrometer 2 channels, 20 MHz, 10 m/s
PSV-400-3D	3D measuring High End Scanning Vibrometer 8 channels, 80 KHz, 10 m/s Geometry Scan Unit

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p. 1, 8: DaimlerChrysler AG. The Mercedes SLK courtesy of S&G, Karlsruhe;
p. 2, 11: Greg Roberts, Pratt&Whitney



More Info?

For more detailed information, please see attached documents

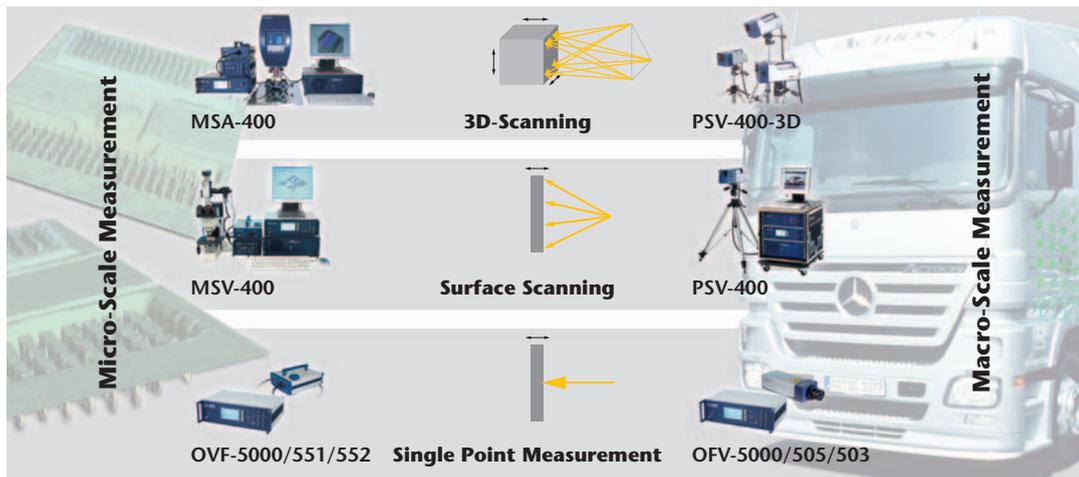
- PSV-400 Technical Data Sheet
- PSV-400-3D Data Sheet
- PSV Accessories Data Sheet
- PSV Soft Data Sheet
- PSV Application Notes
- PSV Info/Demo CD

Documents can be ordered at Lm@polytec.de

or downloaded from our website www.polytec.com/int/psv400

Polytec's Modular Vibrometer Family

Measuring vibration vectors in one, two or three dimensions, on either microscopic or macroscopic scale? For all types of vibration measurement tasks there is a customized solution with Polytec Vibrometers. All systems are based on the superior OFV-5000 Vibrometer Controller, a choice of powerful signal decoders, and high-performance sensor heads. Hence, modules can be changed and the systems can be upgraded to meet new measurement requirements. The product range is completed by single-box industrial vibration sensors and special purpose vibrometers.



Proud to be Number One

Founded in 1967, Polytec GmbH is an ISO-9000 certified manufacturer supplying customers with laser Doppler measurement solutions containing legendary German quality & engineering. All of our Scanning Vibrometer systems are developed and manufactured completely in-house. Engineering such a sophisticated product requires a truly multidisciplinary company.

Polytec's long-standing reputation and undisputed performance advantages are well known. We are very proud of the Polytec Scanning Vibrometer. Its design and construction demonstrate our expertise in opto-mechanics, electronics, computer hardware & software, as well as applications knowledge in the field of mechanical engineering.

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