

Dynamic 3D Testing



of Brake Systems using Laser Vibrometry

Dr. Heinrich Steger

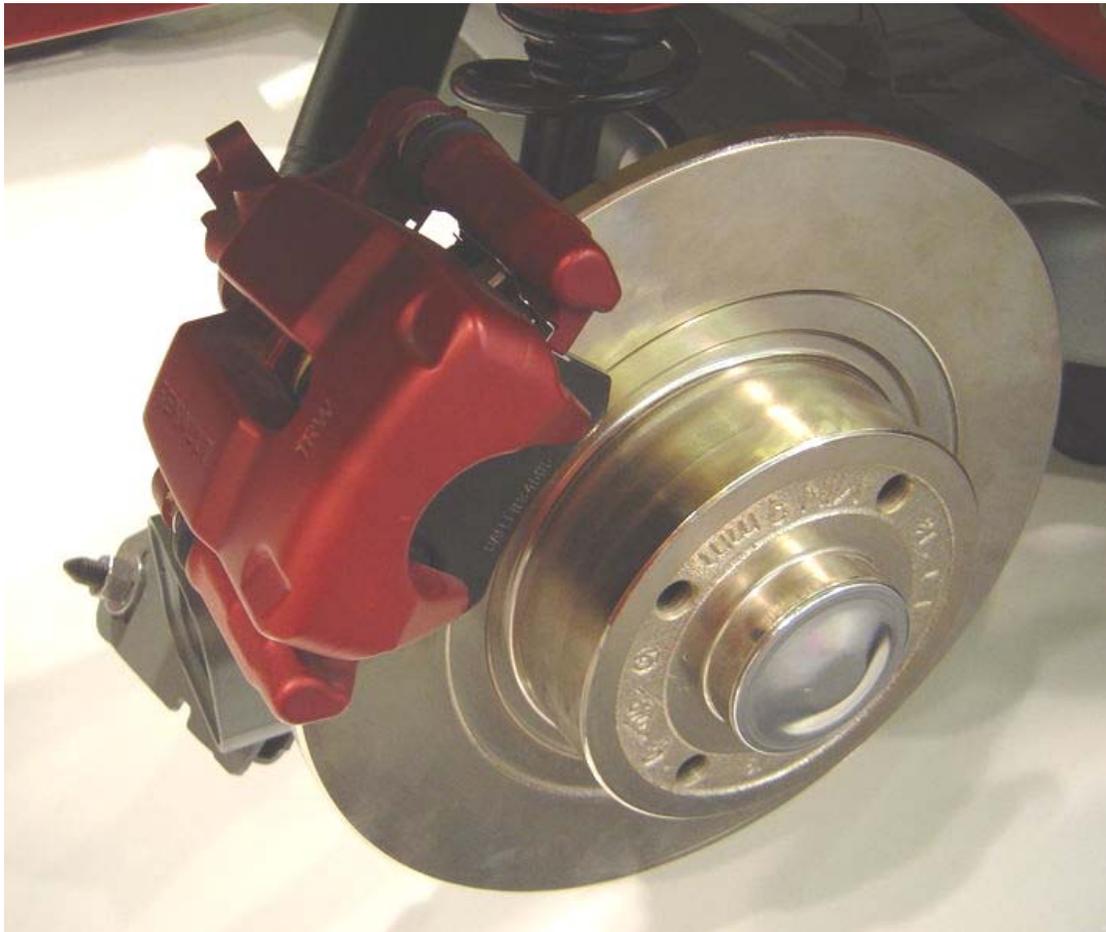
Innovative Braking 2006, Frankfurt, 03.04.2006

The Target: Quiet Braking



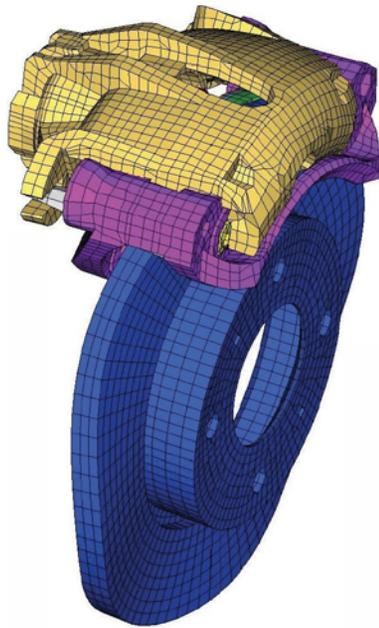
The Challenge: Knowing the Dynamics

$$\mathbf{M} \ddot{\mathbf{q}} + \mathbf{D} \dot{\mathbf{q}} + \mathbf{K} \mathbf{q} = \mathbf{f}(t) \quad \Rightarrow \quad \text{Select appropriate Approach}$$



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Numerical

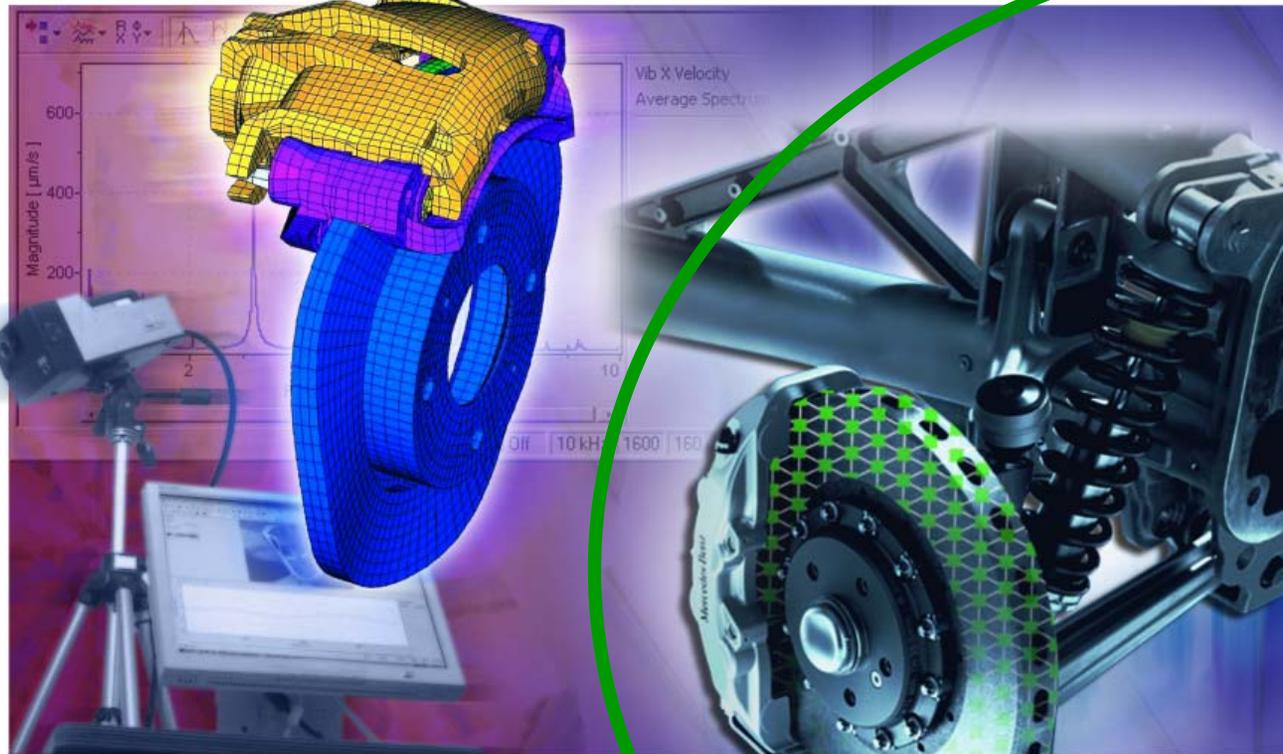
*Analytic solution of
vibration equations
for all relevant
operational conditions*

*⇒ Definition of
optimum system
parameters*

The Challenge: Knowing the Dynamics

$$\mathbf{M} \ddot{\mathbf{q}} + \mathbf{D} \dot{\mathbf{q}} + \mathbf{K} \mathbf{q} = \mathbf{f}(t)$$

⇒ Select appropriate Approach

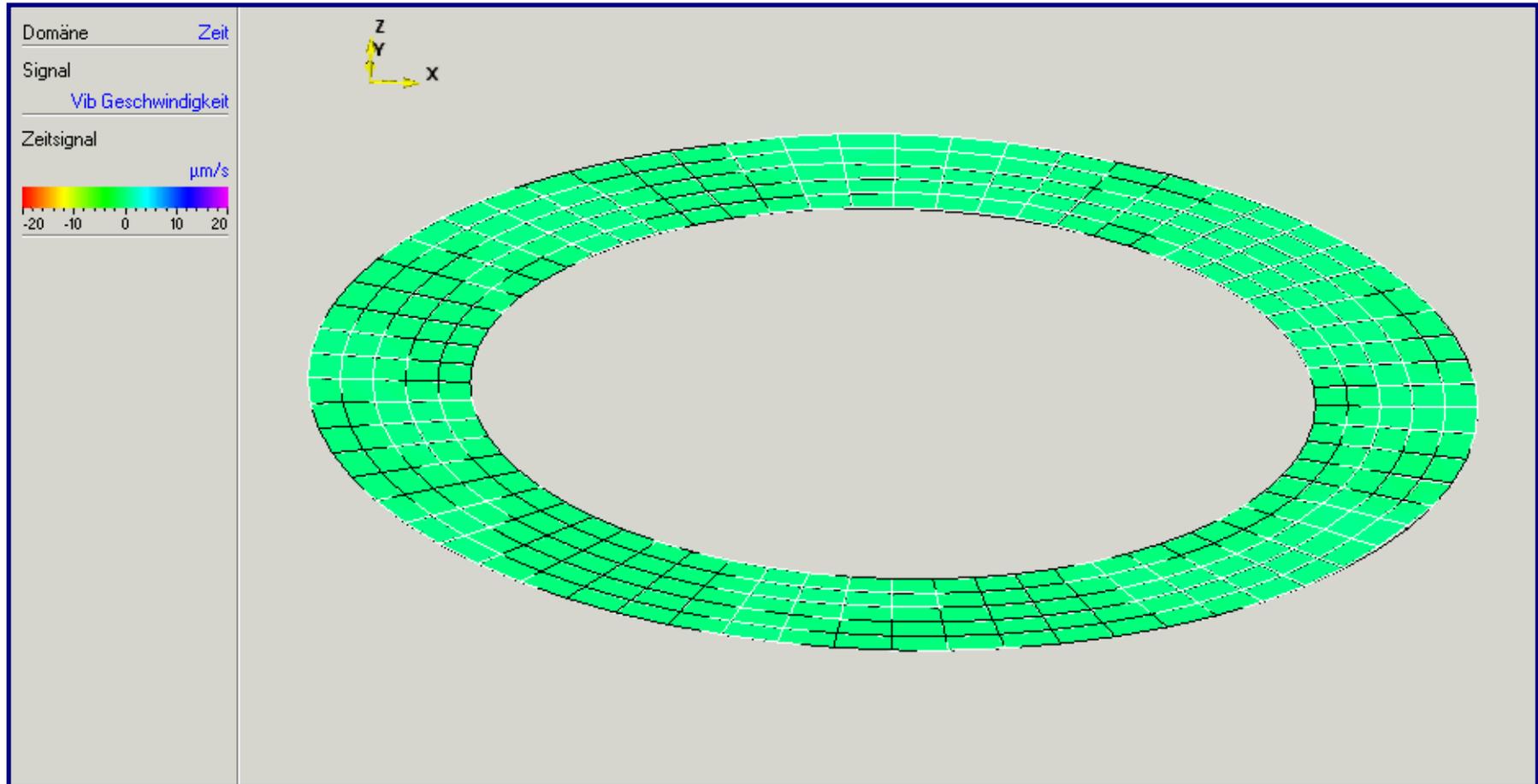


Experimental

Measurement
based
modification

Optical Vibration Measurement

Non-contact, rapid, flexible, precise



Overview

- **Who is Polytec?**
- Principles and Advantages of optical 3-D Vibration Measurement
- Deflection Shape Measurements for Brake Squeal Analysis
- Efficient Integration into the Engineering Workflow

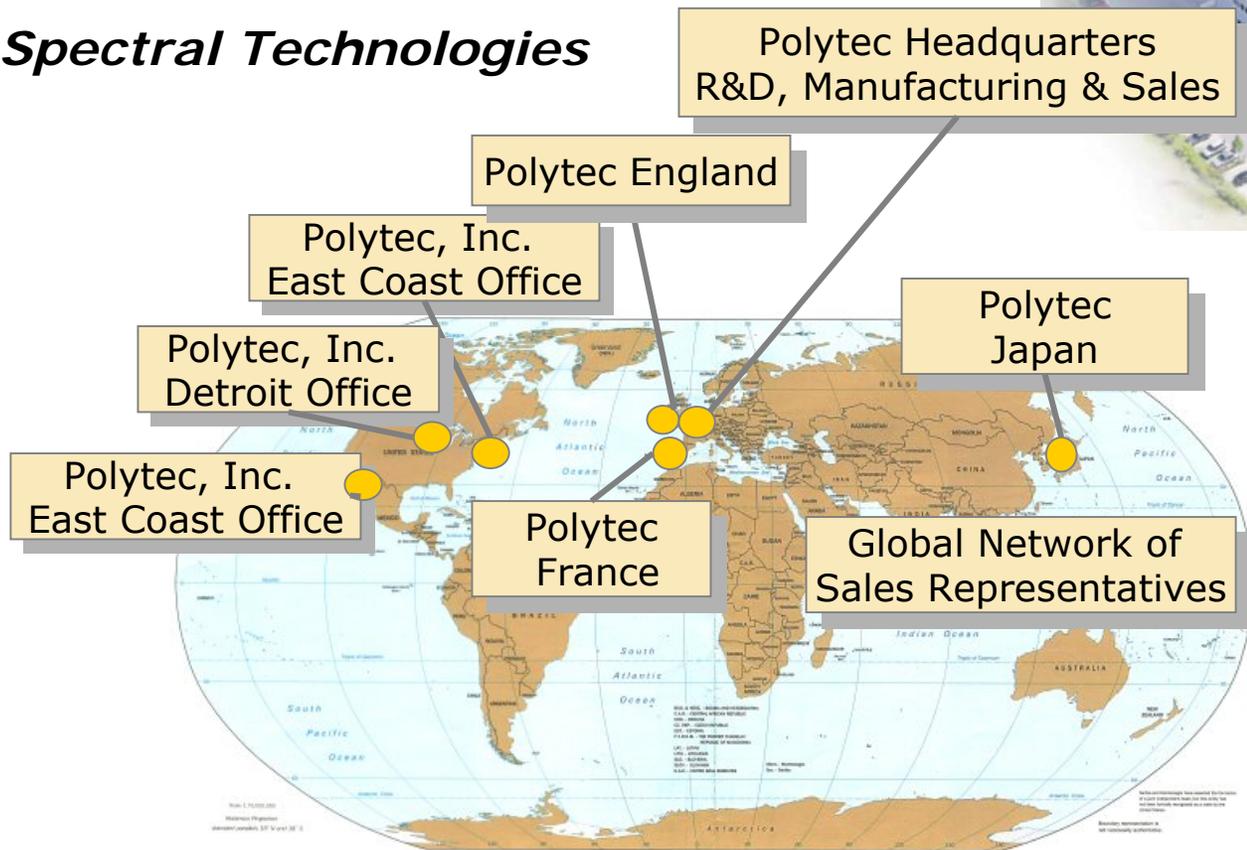
Polytec, Waldbronn

Business Units

Laser Measurement Systems

Photonics

Spectral Technologies



1967 Foundation

Polytec today

250 MA worldwide

40 MA R&D

Laser Measurement Systems



Non-contact vibration measurement Applications

- Single point or full field scanning
- 1- or 3-dimensional
- On macro- and microstructures
- In R&D and production environments

- Automotive
- Aerospace
- Data Storage
- Microsystems
- Transportation
- Engineering
- Audio and Acoustics
- Biology & Medicine
- ... and in your field

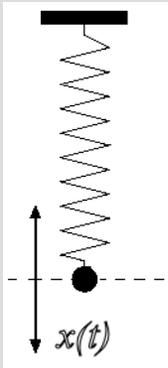
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Measuring Mechanical Vibrations

Idealization: simple

Mass point



- Frequency
- Amplitude
- Phase
- Damping



Reality: complex

Structure

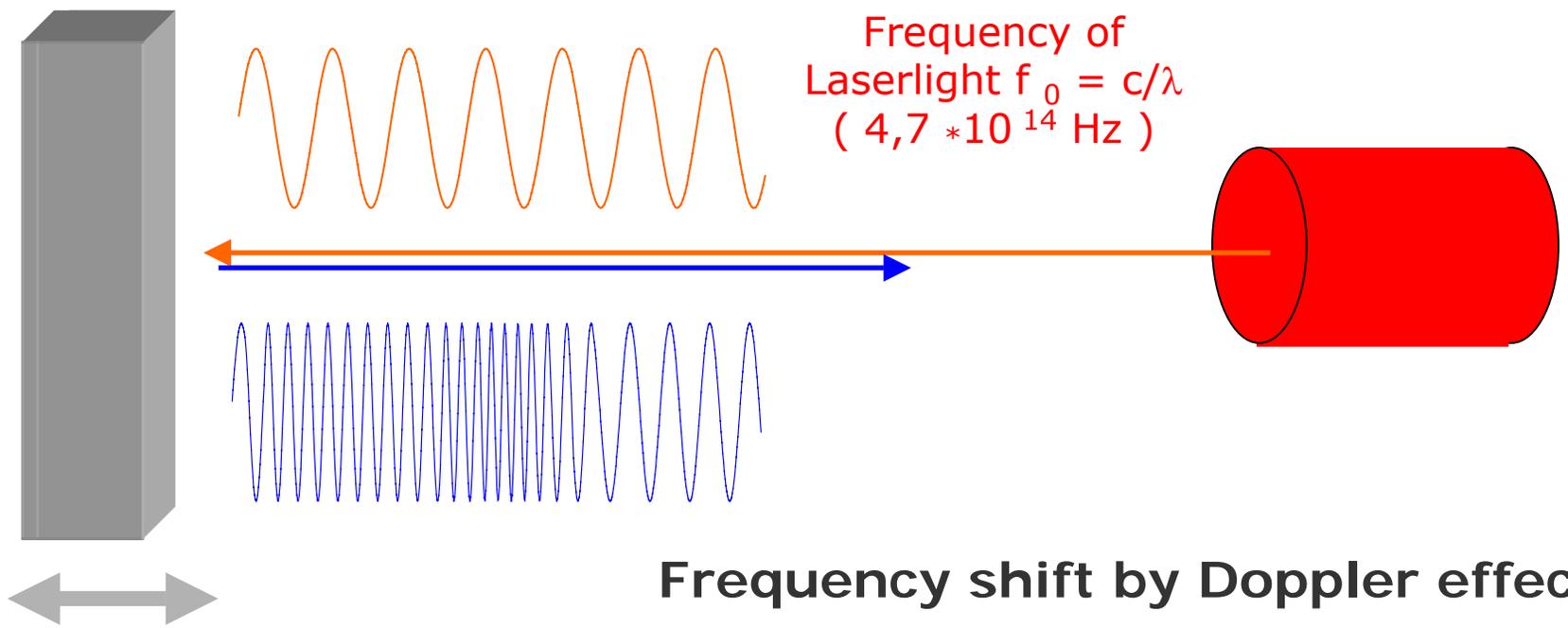


- Spectrum
- Deflection shapes
- Phases
- Damping

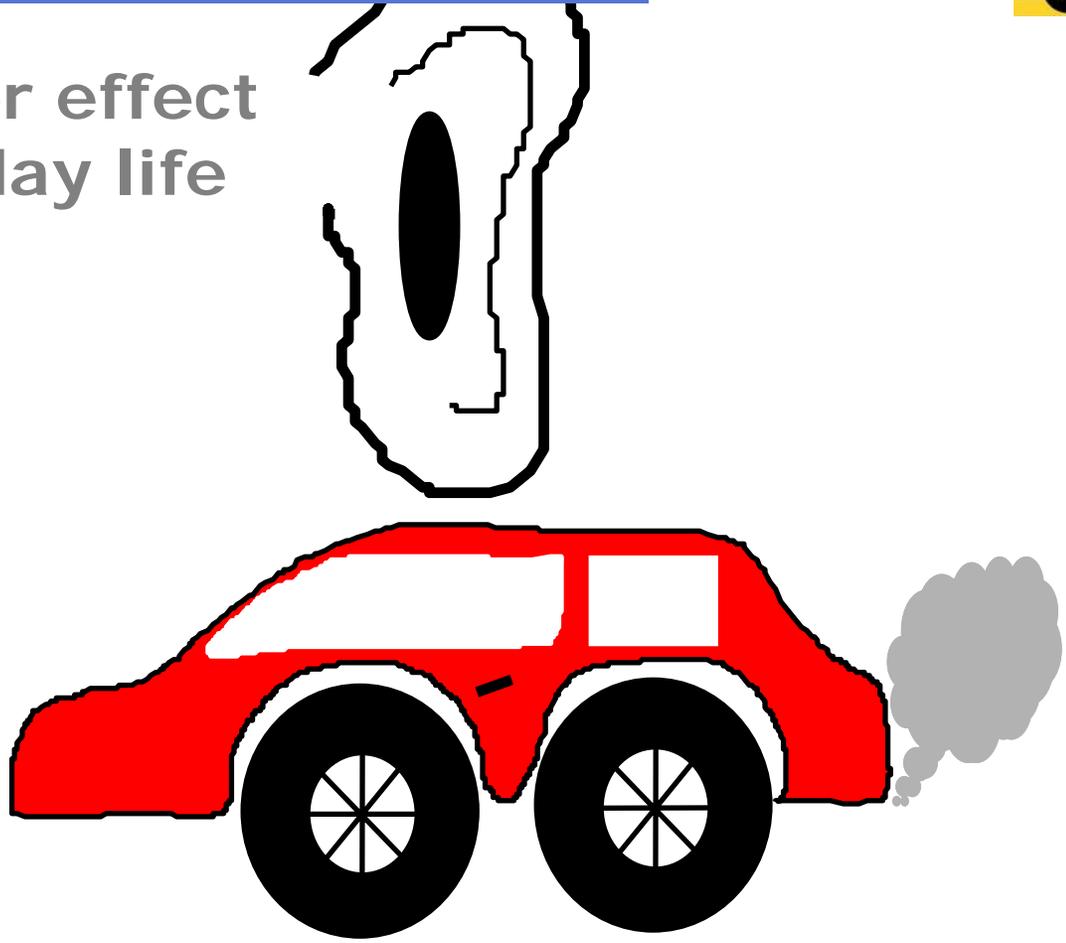
The Doppler effect with Laser light

vibrating object

He-Ne Laser
<1 mW (633 nm)

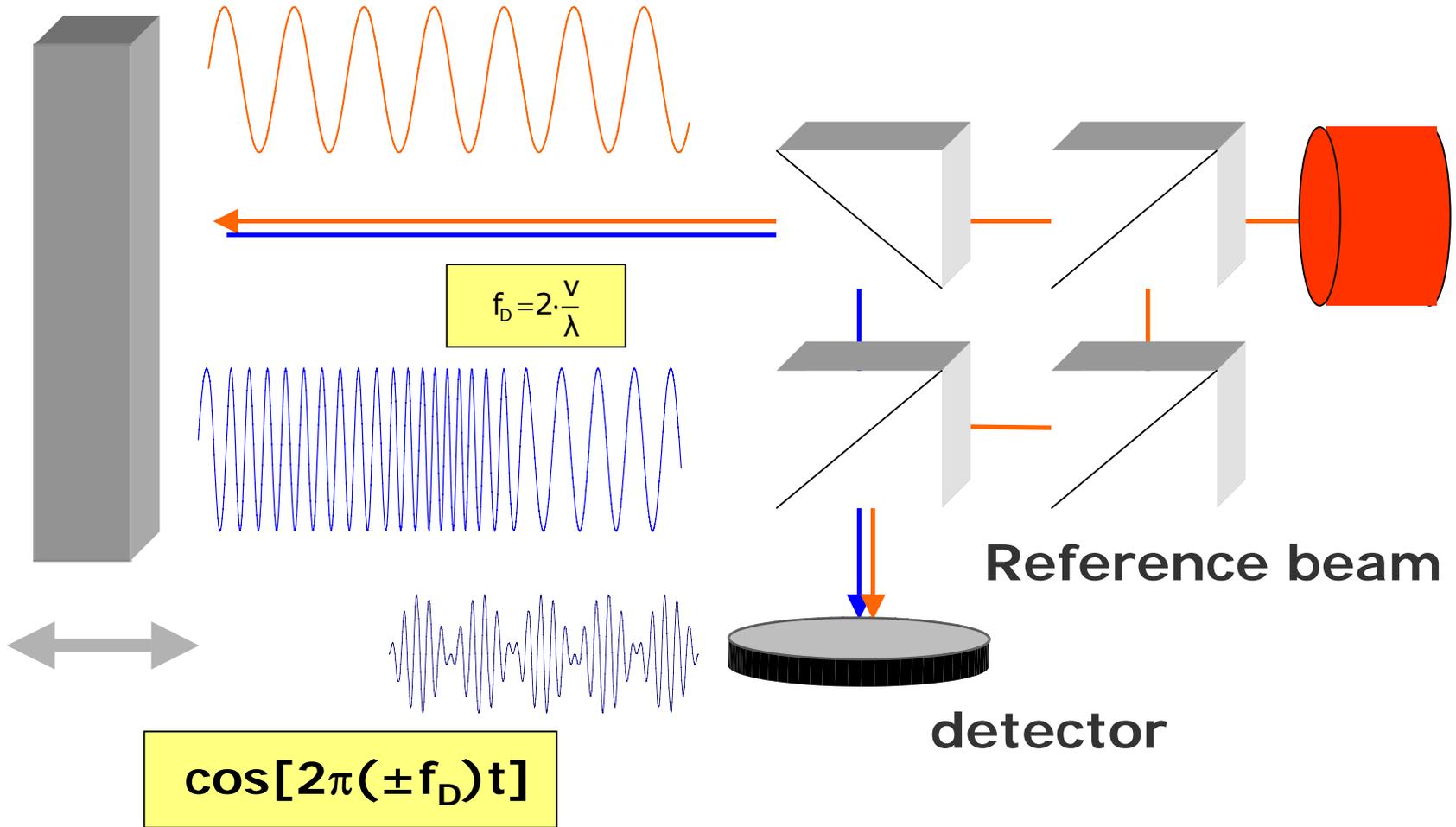


The Doppler effect
in every day life



Frequency shift can be heard directly

How does a vibrometer operate?



Where is Vibrometry used?



... for Comparison:

Bathroom Scales: 100g – 100kg	3 orders of mag.
Multimeter: 1mV – 1000V	6 orders of mag.

f Frequency: 0 Hz – 30 MHz

dr(t)/dt Velocity: 5 nm/s–30 m/s **10 o.o.m**

Δr(t) Displacement: 2 pm – 10 m **13 o.o.m**

d²r(t)/dt² Acceleration: 10⁻⁸ g – 10⁷ g

Where is Vibrometry used?

Applications are unlimited!!



Automotive
Aerospace



Microstructures

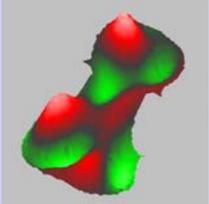


Data Storage



Production
Testing

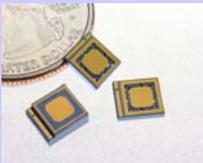
Non-contact Vibration Measurement



- Precise measurement of structural dynamics and structure borne sound
- No massloading, reactionless measurement
- Measurement of many sample points in a short time



- Measuring on sample points difficult to access
- Measurement on soft, filigran, jagged or hot structures



- Measurement on microstructures
- Acquisition of high frequencies

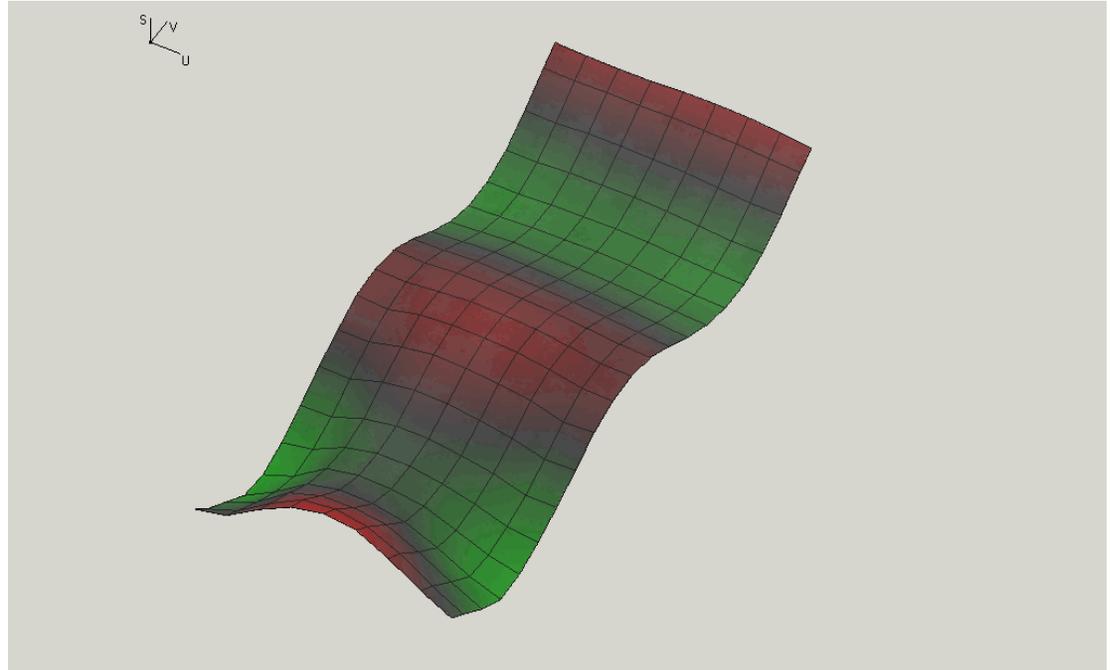
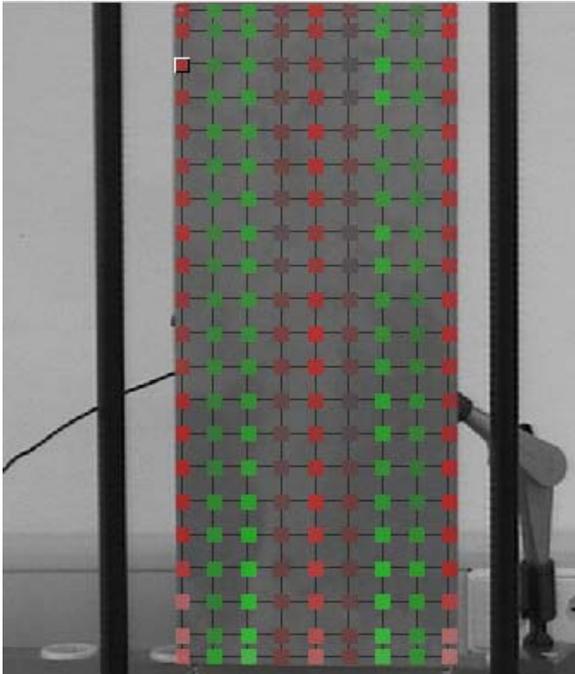


- Measurement from large distances
- Independent from material properties



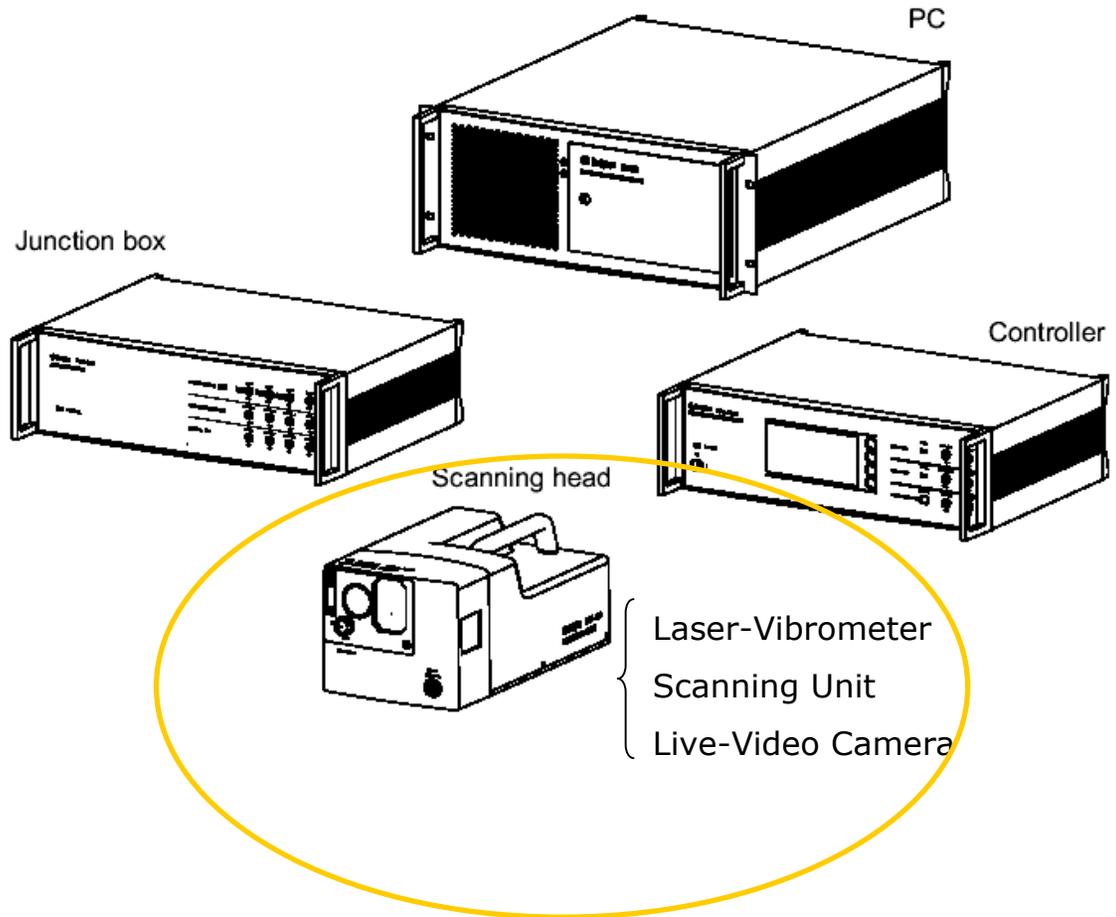
- Arbitrary number of sample points
- Large Bandwidth and high sensitivity: ... nm ... pm

From Single-Point to Full-Field Vibration Measurement

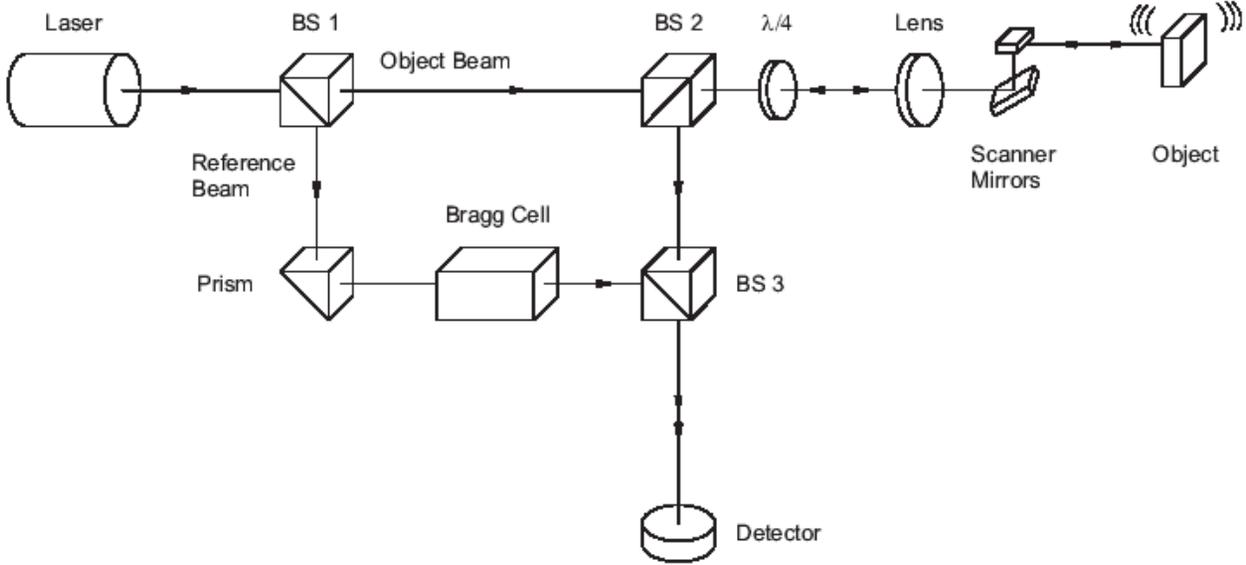
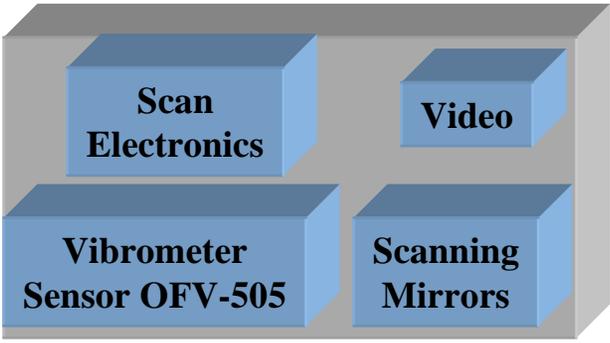


- Sample many scan points in a short time
- Up to 512 x 512 sample points in a grid
- Animated visualization of deflection shapes
- Intuitive and simple Operation

Setup and Components

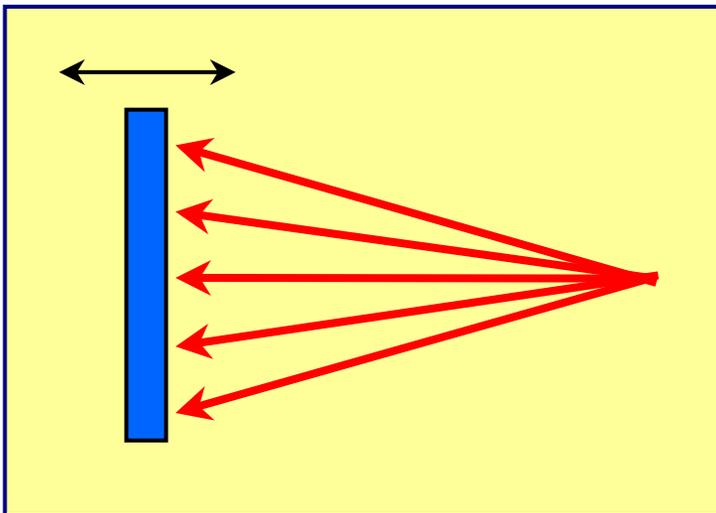


Setup of the PSV-I-400 Sensor



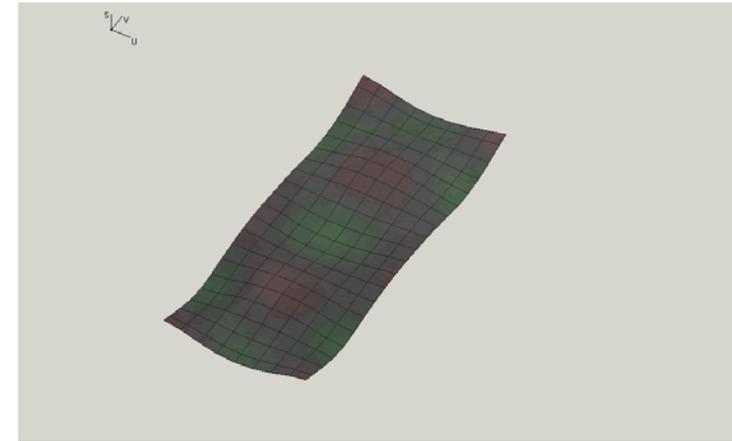
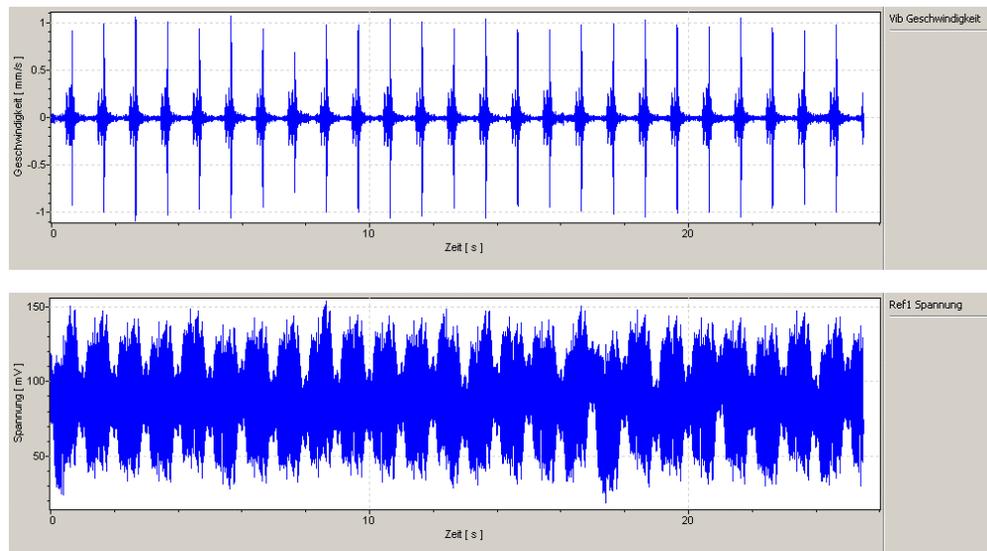
Scanning Vibrometer

Gain insight into structural dynamics and structure borne sound through full-field vibration measurement and mapping



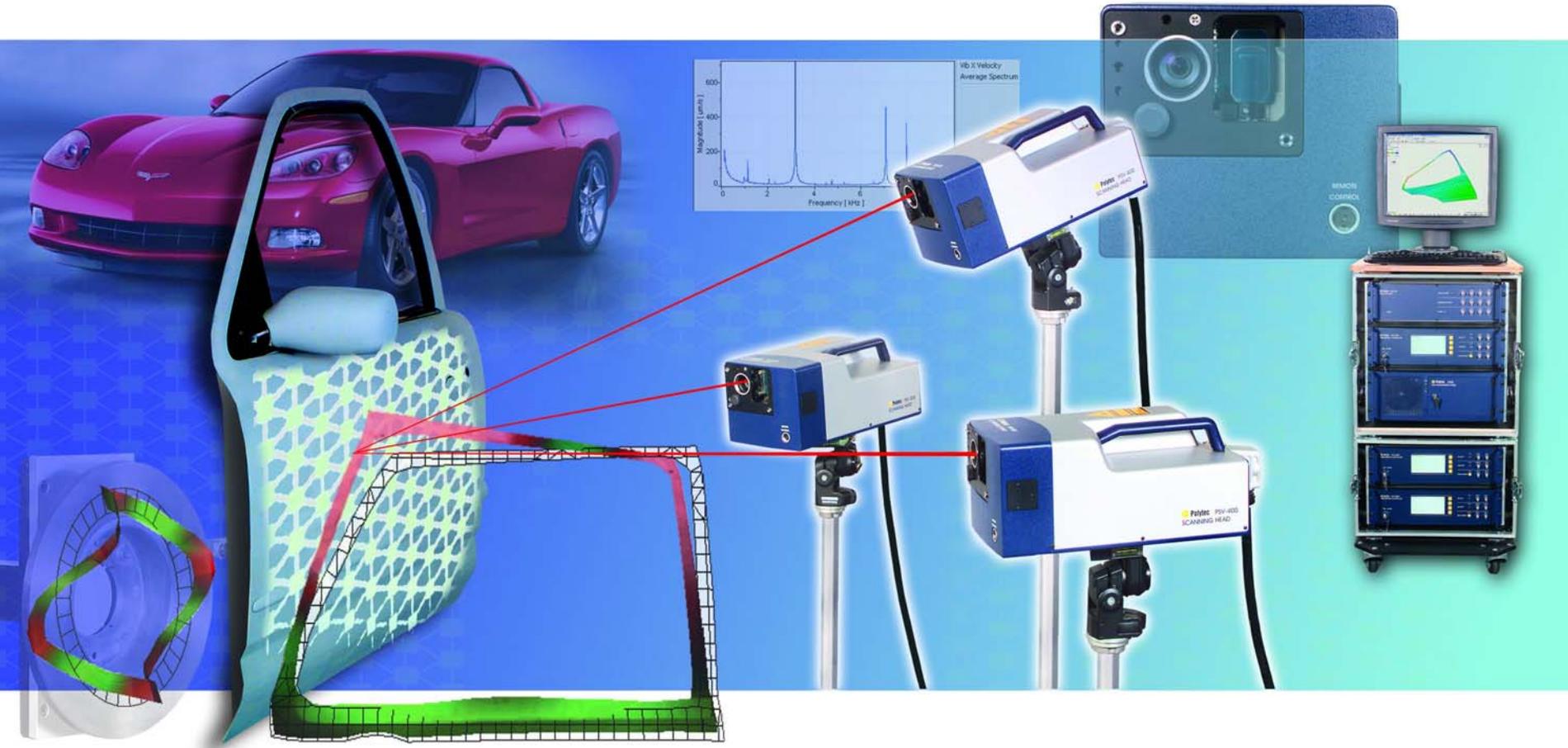
- The measurement beam of the scanning vibrometer scans the testobject on a predefined grid.
- At each sample point a complete measurement is performed within milliseconds.
- The phase relation among the sample points is established through the simultaneous measurement of a reference signal (e.g. excitation).

Principle of Operation



- Measurement of $v(t)$ at all scan points and subsequent FFT transformation
- ➔ Amplitude and *rel.* Phase at each sample point
- ➔ Deflection of the surface of the test object

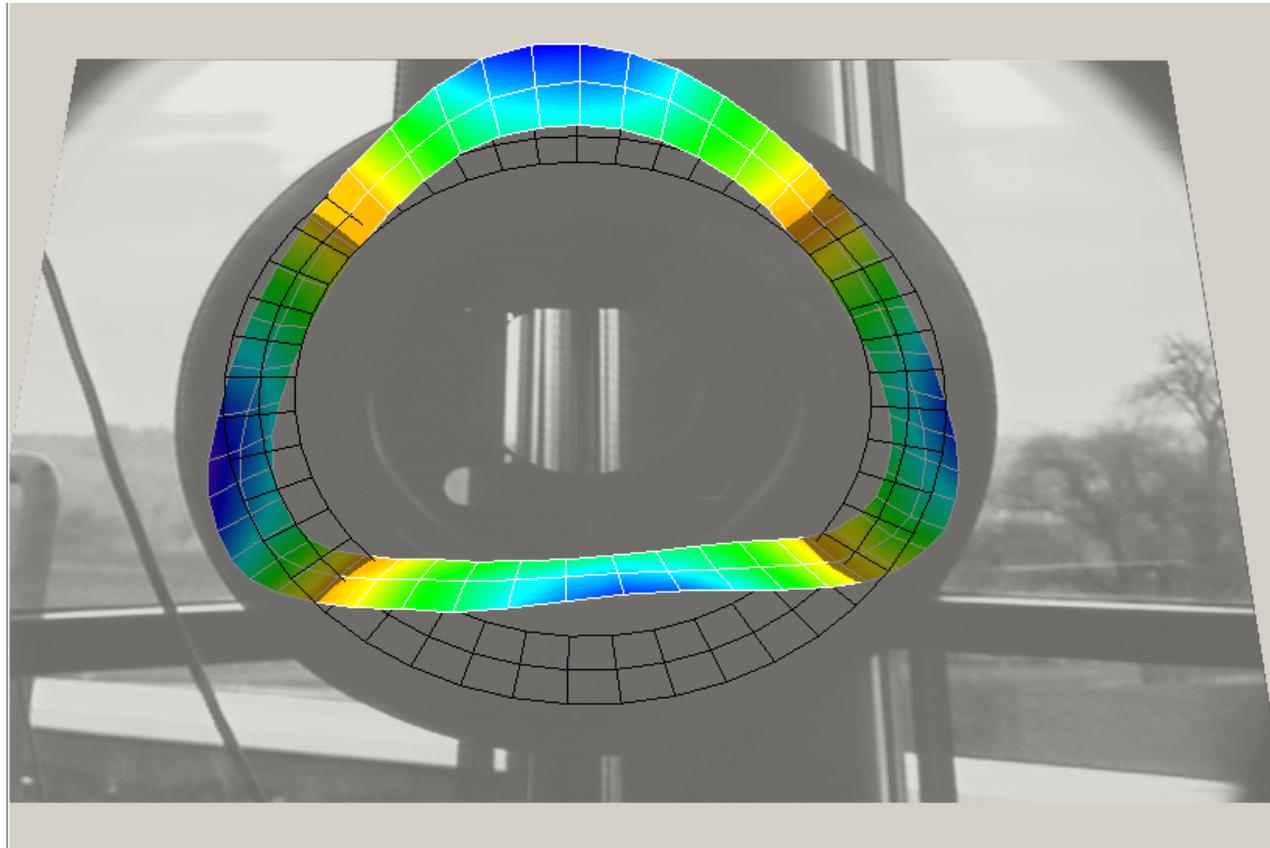
3D Scanning Vibrometer System



Function principle of the 3D-SLDV

- 3 Vibrometers measure on the same point, each from a different direction
- Acquisition of all components of the vibration vector
- Measured data is transformed into the Cartesian coordinate system of the measured object





- Download Polytec Scanviewer from:
http://www.polytec.com/eur/158_7778.asp and
perform your own ODS analysis of brake disc example
data

Benefits of a 3-D Scanning System

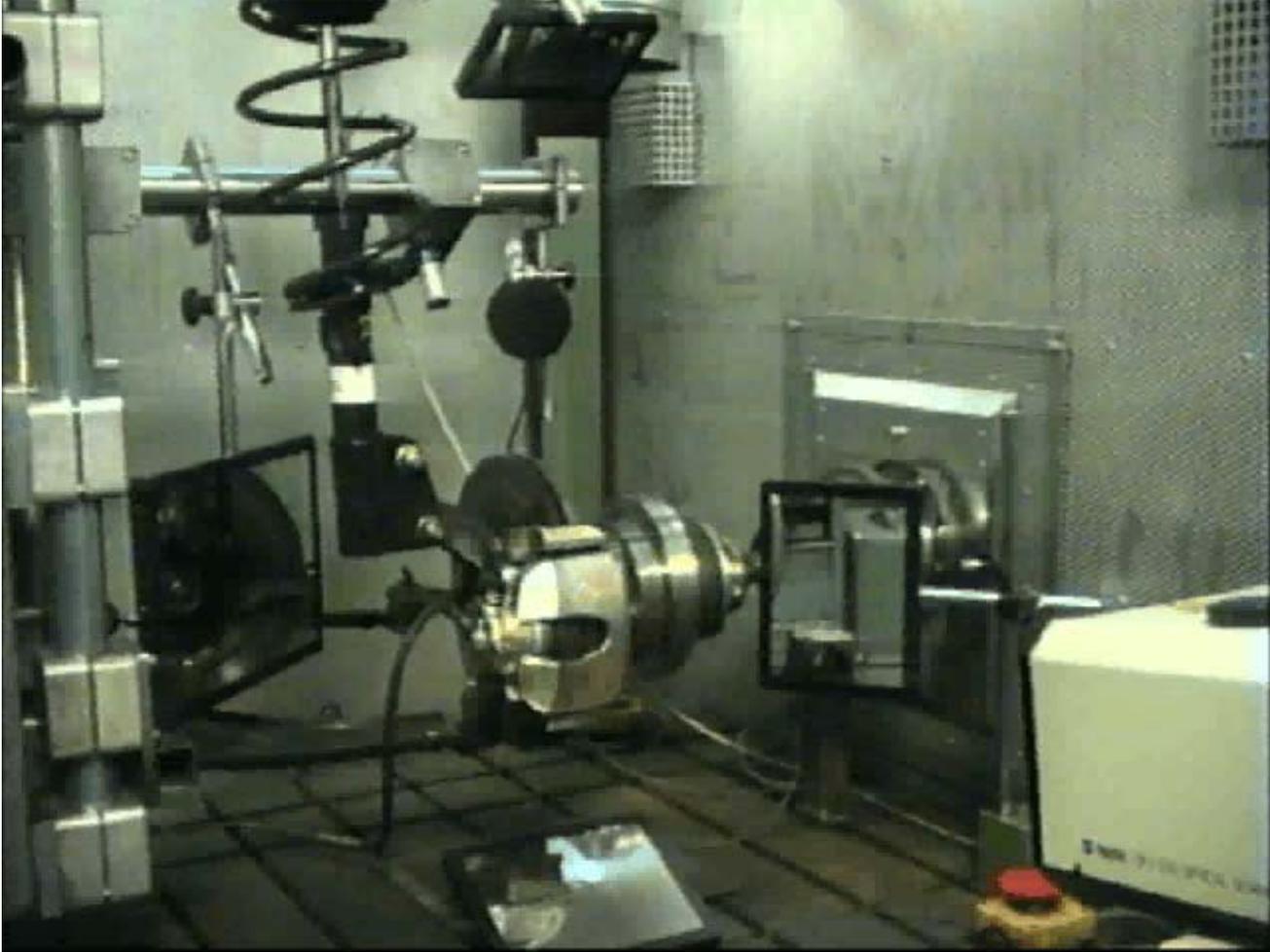
- 3D data output for modal analysis
- Separation of in- and out-of plane results
- Simple sensor-to-object alignment
- High spatial resolution
- Fast
- No mass loading
- Intuitive 3-D animation of the measurement results



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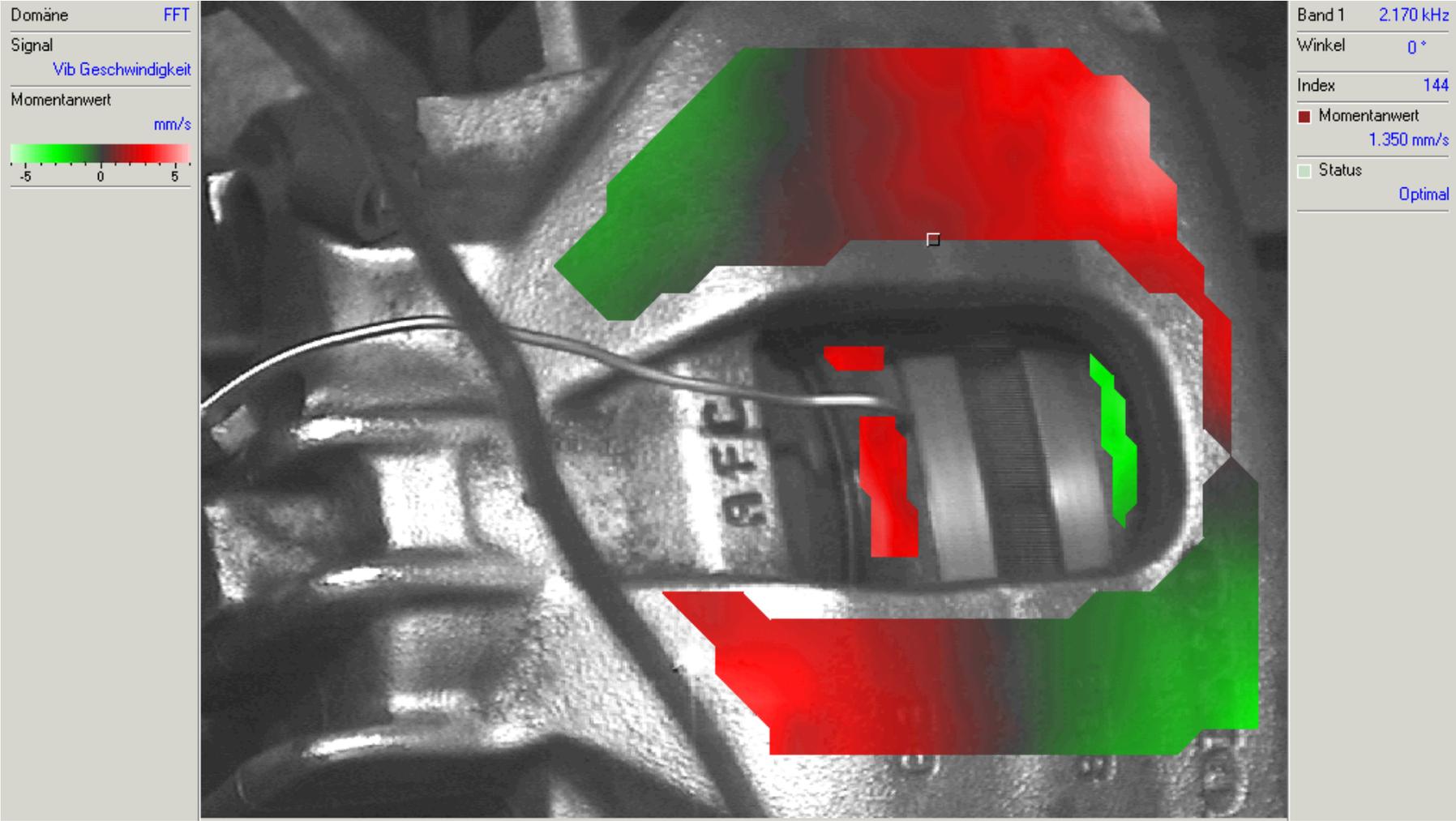
Example 1: Stationary parts



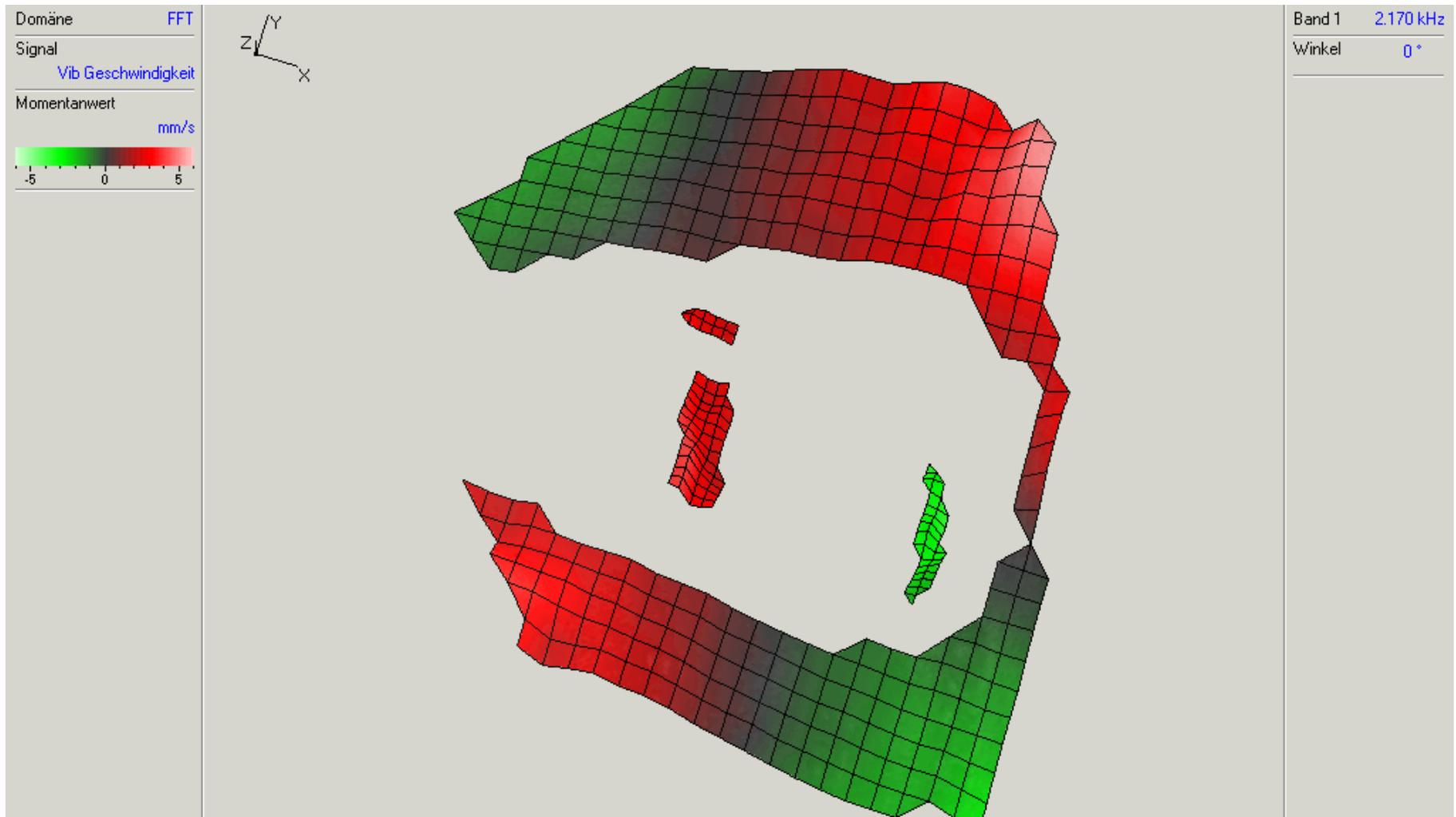
Laser Vibrometer
Scanning the
squealing brake

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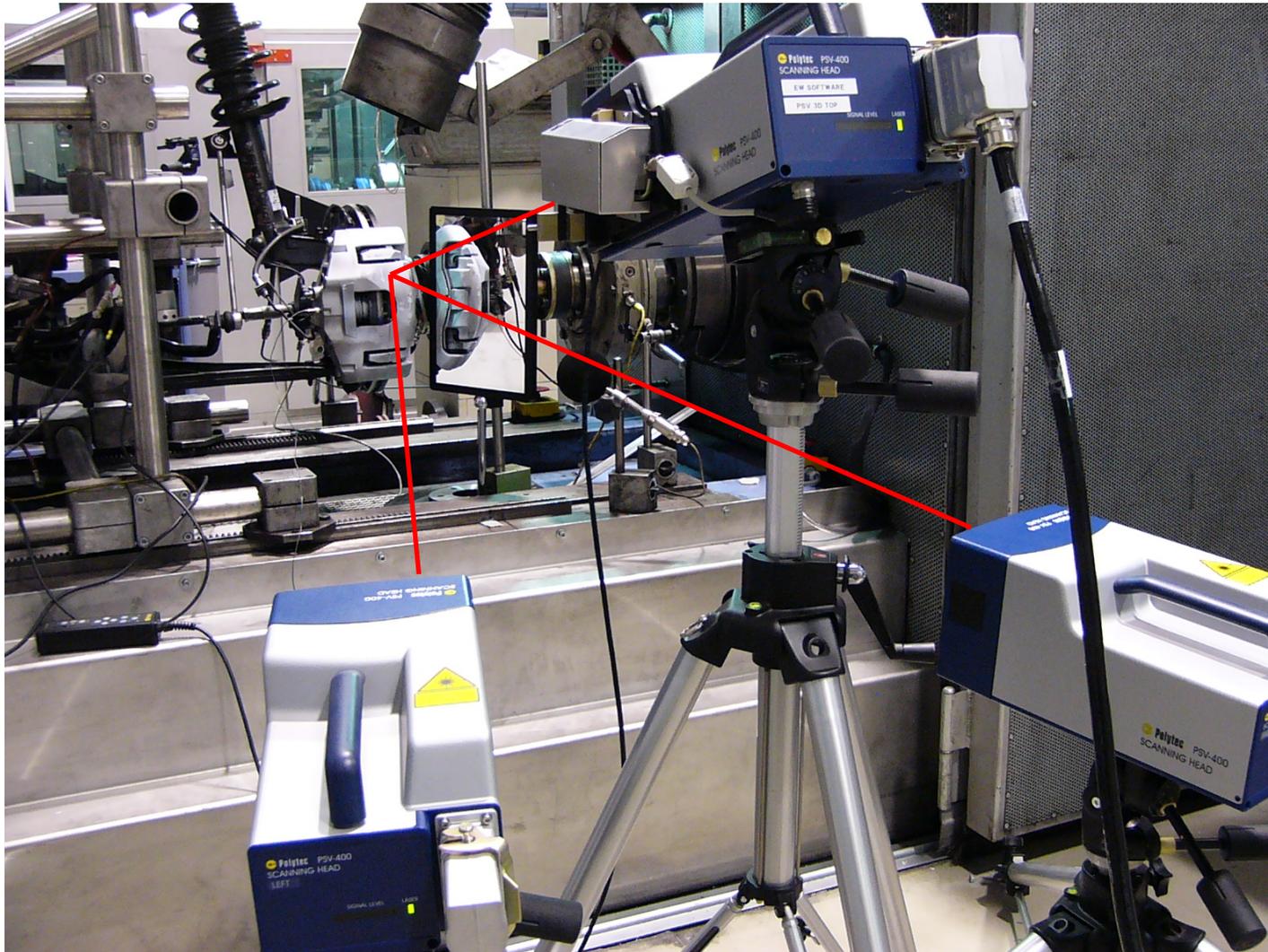
Example 1: Stationary parts



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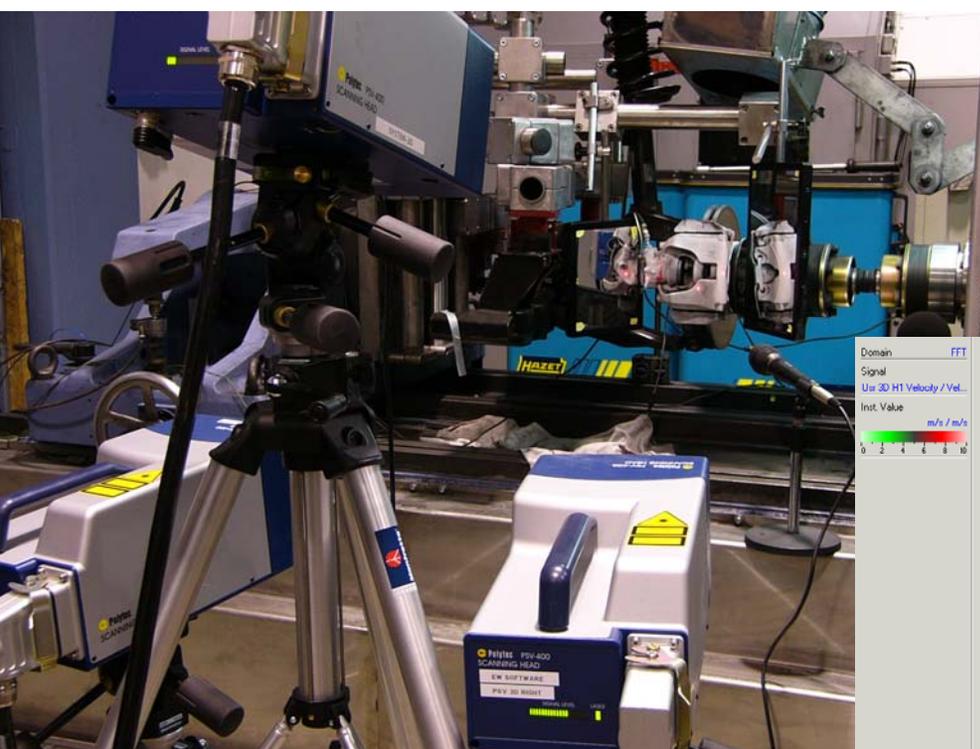


3D Measurement at Dynamometer

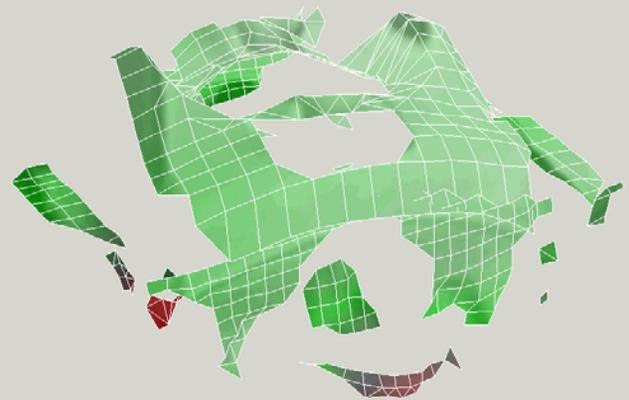


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Measuring Squealing with PSV-3D



Domain: FFT
Signal: Use 3D H1 Velocity / Vel...
Inst. Value: m/s / m/s
Color scale: 0 to 10

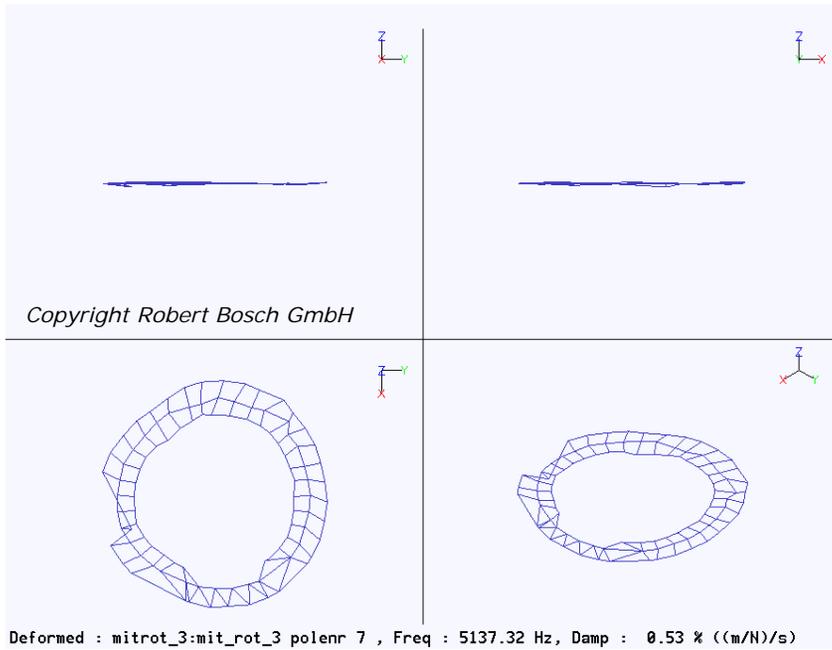


Frequency: 1800.00 Hz
Frame: 1
Angle: 0°

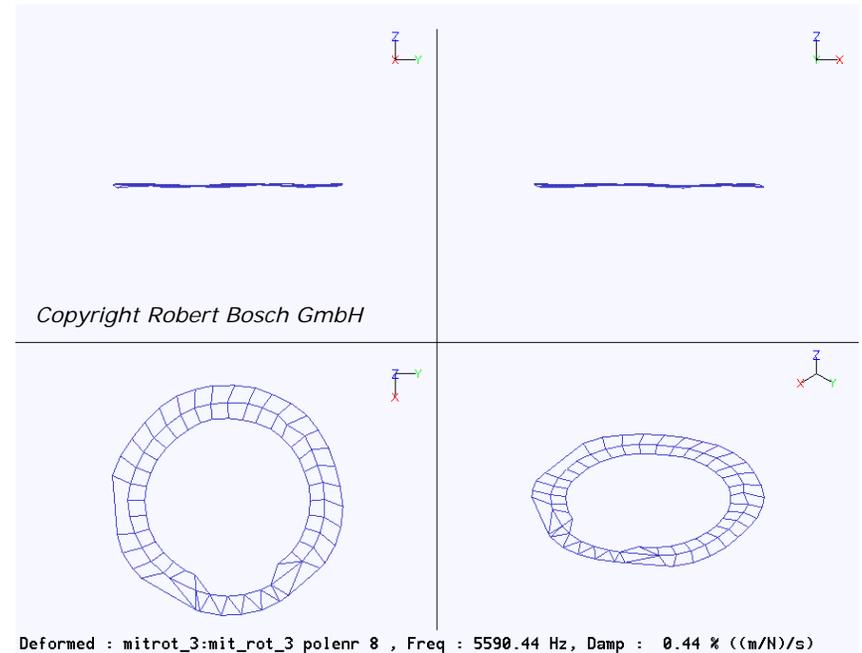
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Example 2: Measuring Rotating Disc

Step 1: Experimental Modal Analysis



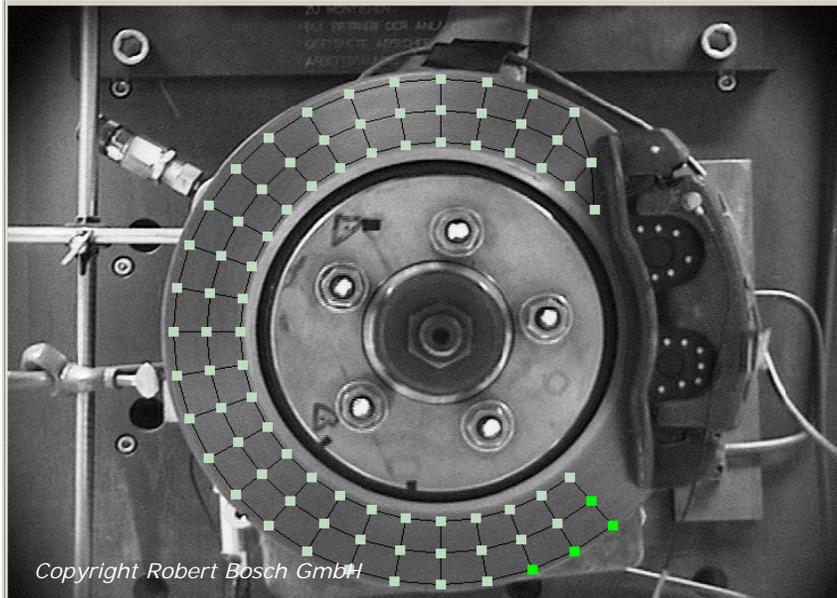
Mode 1: 5100 Hz



Mode 2: 5600 Hz

Example 2: Measuring Rotating Disc

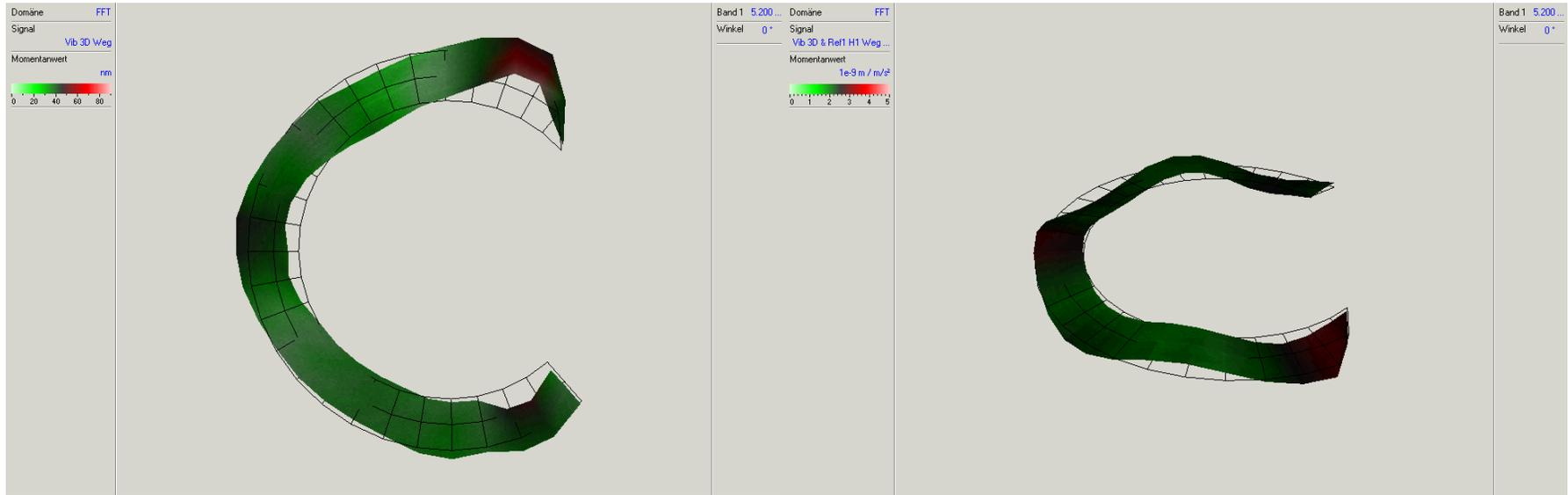
Step 2: Operational Deflection Shape Measurement (Squealing condition: 4 rpm; $p = 4$ bar)



Typical operational conditions are reproduced on the brake dynamometer

Example 2: Measuring Rotating Disc

Measurement of 3D vibration response under operating conditions



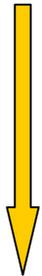
Result: Mode 1 and 2 approach each other in the frequency domain, instability near 5 kHz causes squealing!

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Development Process

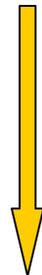
■ First Design Phase



- Numerical Approach: Analytic Solution
- Definition of optimum System Parameters
- No Prototype necessary, but extensive



■ Availability of Prototype



- Experimental investigation
- Determination of System Parameters
- Effective and proven method
- FE Korrelation: Verification of FE Model, Model Update
- Design modification



Integrating the Scanning Vibrometer



Real Geometry Data

measured with integrated Geometry Scan Unit



Model Geometry Data

from CAE / FEM programme



Time Saving

Measurement

Workflow



On Screen Data Presentation

animated ODS combined with video image

Data Analysis & Post Processing

Modal Analysis, FEM correlation, Sound field prediction

Report Ready Graphics & Video Data

various formats supported



Thank you very much
for your attention!

For more detailed information
please visit

<http://www.polytec.com>