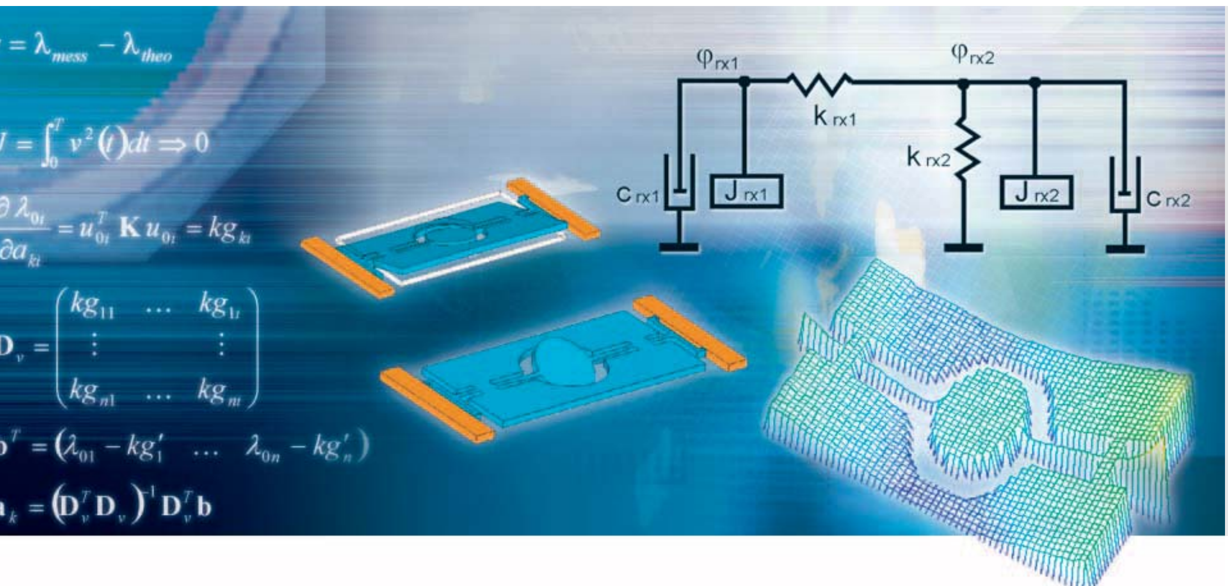
Validation of MEMS Models



Field of Application

- A Aerospace
- B Audio & Acoustics
- C Automotive
- D Data Storage
- G General Vibrometry
- **M MEMS & Microstructures**
- P Production Testing
- S Scientific & Medical
- T Structural Testing
- U Ultrasonics

Laser Vibrometry Helps to Improve Microstructure Simulations

Computer simulation is essential to the development of MEMS devices. Good simulation models must be tested and refined through comparisons with precise experimental data. This validation data characterizing the mechanical response of a MEMS structure are easily acquired through a combination of a Polytec Laser Vibrometer and a Wafer Probe Station.

Micromechnical Scanners

In bar code scanners, tiny mirrors move the light across the bar code several hundred times per second. Made from a mosaic of dark and light patches, two dimensional „bar codes" require scanning in both the X and Y directions to read them, significantly increasing the scanning speed and laser beam quality requirements. Laser projection systems produce video images by modulating the brightness of the laser beam during a very fast area scan of the screen.

Such laser displays make the highest demands on scanning speed and beam quality. For example, in one second, up to 48,000 lines are written. The mirror surface must remain very flat, even while the scanner is working, to prevent distorting the laser beam. At the same time, these mechanical components should be small, robust and inexpensive. Such micromechnical scanners (Figure 1) have been developed at the Fraunhofer IZM Institute in cooperation with the Center for Microtechnology at the Chemnitz University of Technology.

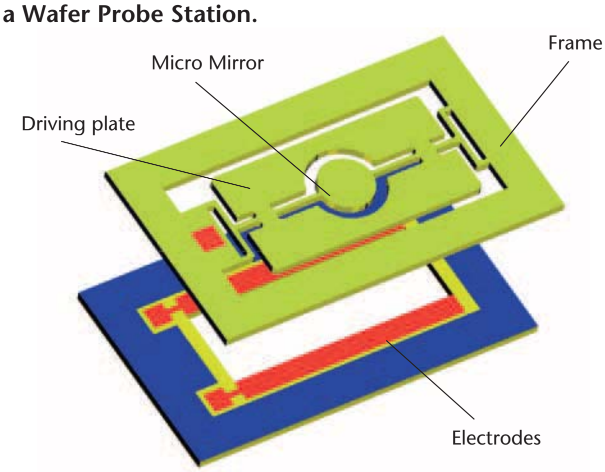


Figure 1: Construction of a micro scanner

The dimensions of these mechanically moving parts range in size from several microns to a few millimeters. To efficiently produce these high performance mirrors, manufacturing methods and lithography technology from the semiconductor industry are used. The mirrors are mechanically driven by an electrostatic field produced between two electrodes.

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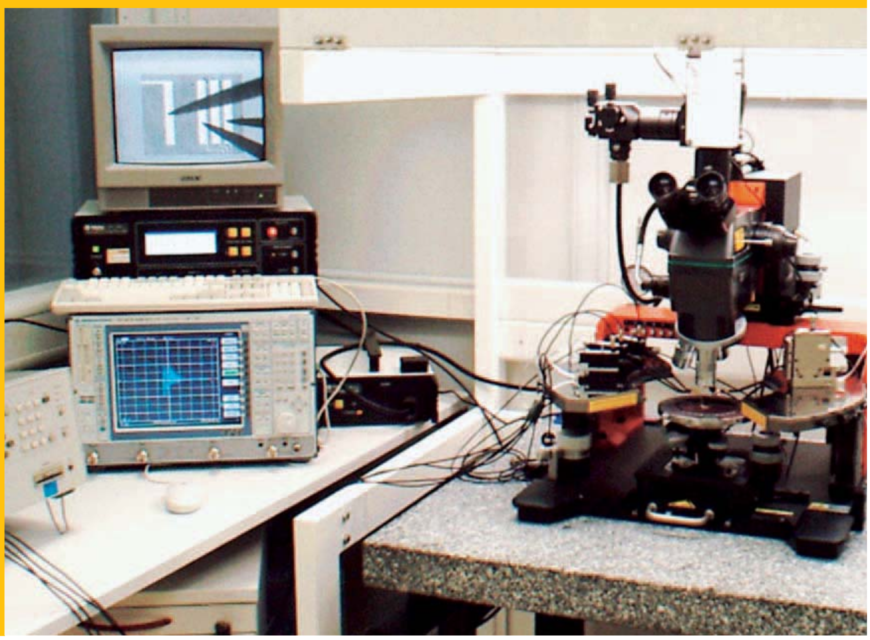

Simulation of MEMS Properties

During the design and development of MEMS devices, numerous mathematical simulations must be made. The manufacturing processes are too expensive, too complex and too time consuming for experimental trial and error. The accurate prediction of system response in the design stage is only successful if validated simulation models are available. Thus, in some cases, quite complex models are used to predict the interaction of electrical quantities with a multitude of physical quantities. Whether the MEMS components can reach the target specification after manufacturing primarily depends on the accuracy of the simulation, as it serves as a basis for dimensioning. It is therefore very important to test the validity of simulation models through comparisons with experimental data and then to fine-tune these models. For an undertaking of this kind, reliable measurement data on MEMS devices must be acquired and parameters that validate the simulation models must be extracted from the data.

Parameters Relevant to Manufacturing

Another task is to measure parameters which are relevant to manufacturing. Information on the process parameters currently available and their effects on geometric quantities and material parameters of the MEMS components are necessary for controlling the manufacturing process. The difficulty is that a wide range of measurement data must be reduced to the small amount of information necessary to control the manufacturing process. To solve this problem, processes to adapt model parameters are also still being developed and used. These can be used for example to determine the thickness of layers or the mechanical stress in the materials of the MEMS components. Prerequisite is a qualified measurement technology which accumulates data from wafer-level MEMS components at any stage of the manufacturing process.

Experimental Setup

The measurement data obtained from MEMS components mainly contains information on the dynamic deformation of movable components in the form of time series or frequency response functions. A combination of a Polytec Laser Vibrometer and a Wafer Probe Station (Figure 2) has proven to be an excellent technique for optically detecting the mechanical movement of MEMS structures.

Because of optical probing, the measurement procedure has minimal influence on the device. The diameter of the laser beam on the test sample is in the range of a few microns, enabling the measurement of even very small structures such as single cells of micro mirror arrays.

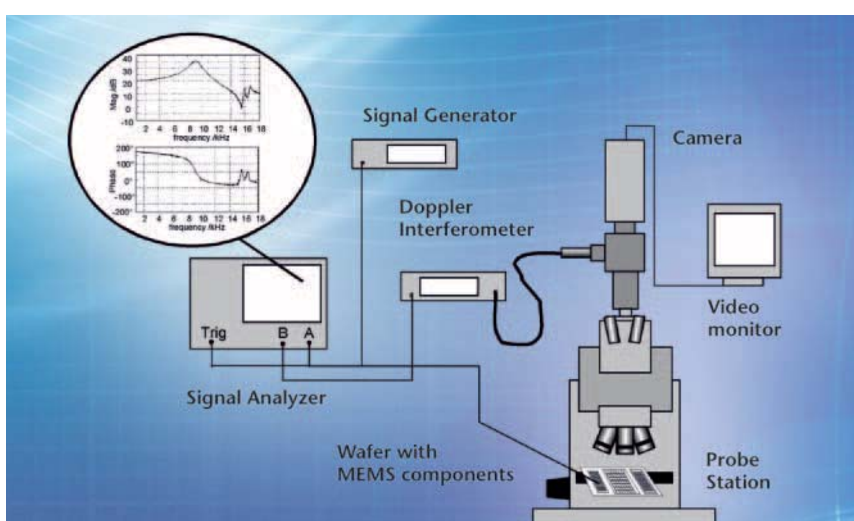

Figure 2: Probe station with Polytec Microscope Scanning Vibrometer

Simulation – Measurement – Parameter Adaptation

After an FEM analysis of the MEMS device, numerous simulation models are generated which describe the mechanical behavior at a large number of geometric locations. Since it is possible to allocate six degrees of freedom to each location, the results can reflect the behavior of a mechanical system with a large number of degrees of freedom and resonance points. Practically, for such an ensemble of points, only a few degrees of freedom have real meaning. To reduce the order of these models, techniques are used to make models with lumped elements that can be measured to verify the accuracy of the model.

In parallel, experimental data is taken on MEMS components excited to induce mechanical vibrations. The vibration amplitudes are typically between several hundred picometers and a few microns. Recording both the excitation signal and the resulting system response provides the input signals from which the frequency transfer functions is derived. Finally, the parameters of the order reduced model are adapted for a best fit to the measured system response data. To make the adaptation, the evaluation of resonance frequencies, the comparison with the model's eigen frequencies and the least squares fitting method are used. The question regarding the accuracy of the simulation can be answered after a comparison between the calculated and the measured reaction, or by comparing the model parameters before and after adaptation. The adapted model can be used to simulate the behavior of the MEMS components, taking various outline conditions as a basis.

The material or geometry parameters can be determined quantitatively and can be referred to for process control.

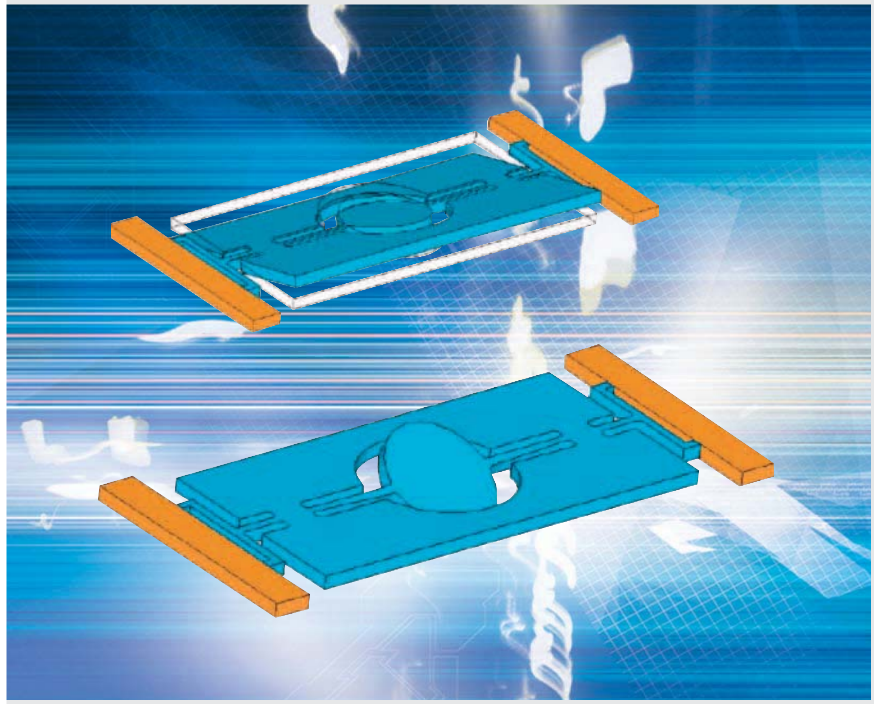

Figure 3: First (top) and second (down) natural deflection shape of the scanner

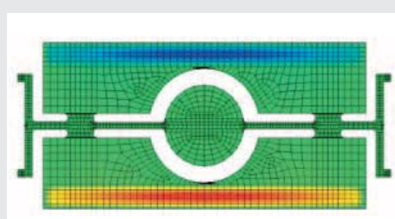

Figure 4: FEM analysis of damping by air flow, pressure distribution

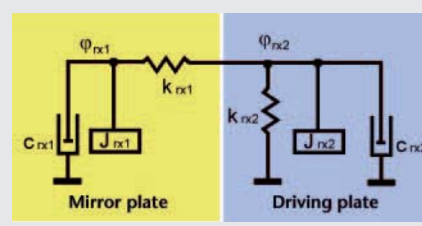

Figure 5: Model after reduction of order

Example: MEMS Scanner

The task is to experimentally determine the stiffness and geometry of the torsion bands which flexibly connect the micromirrors, driving plate and the frame with each other and to determine the mechanical damping caused by the air flow. As a first step, a finite element model of the scanner is set up (Figure 3) and the eigenfrequencies, deflection shapes and mechanical damping caused by the air flow are numerically analyzed (Figure 4).

A reduction of the model order leads to a simple model with lumped elements (Figure 5).

As a second step, the frequency transfer functions are measured at different locations on the MEMS scanner and the eigenfrequencies are read (Figure 6).

Finally the eigen value residuum is formed from the difference between the calculated and the measured eigenfrequencies and the stiffness matrix is corrected using the least squares method. After this procedure, it contains the stiffness of the torsion springs adapted by the behavior of the sample. The damping matrix can be adapted by referring to the calculated and the measured vibration amplitudes as a final step.

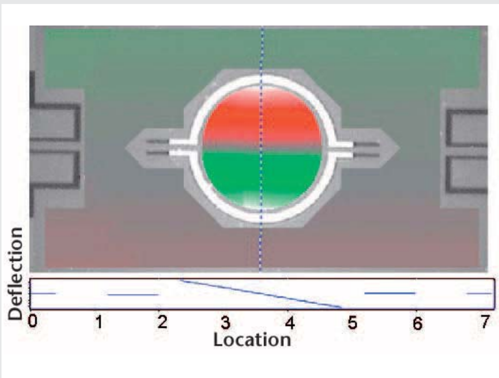

Figure 6.1: Measurement results with the Microscope Scanning Vibrometer: deflection shape

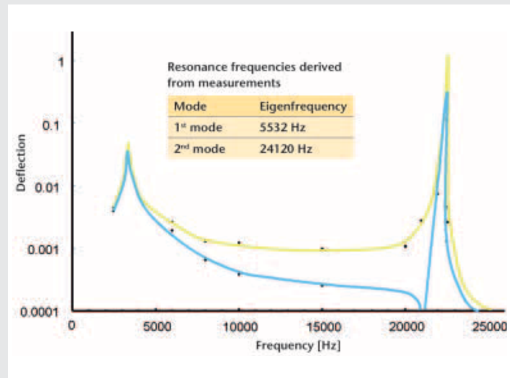

Figure 6.2: Measurement results with the Microscope Scanning Vibrometer: transfer function

Summary

The geometry and material parameters of micromechnical components are determined by processing measurement data and simulation data using model parameter adaptation. A Laser Doppler Vibrometer and a Wafer Probe Station allow efficient data acquisition. The researchers at the Fraunhofer IZM are working in cooperation with their colleagues at Polytec to fine-tune this measurement technique and adaptation of parameters.

For more information about Polytec Microscope-based Systems and their application to MEMS characterization, please contact your local Polytec sales/application engineer or visit our web page **www.polytec.com/microsystems**

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