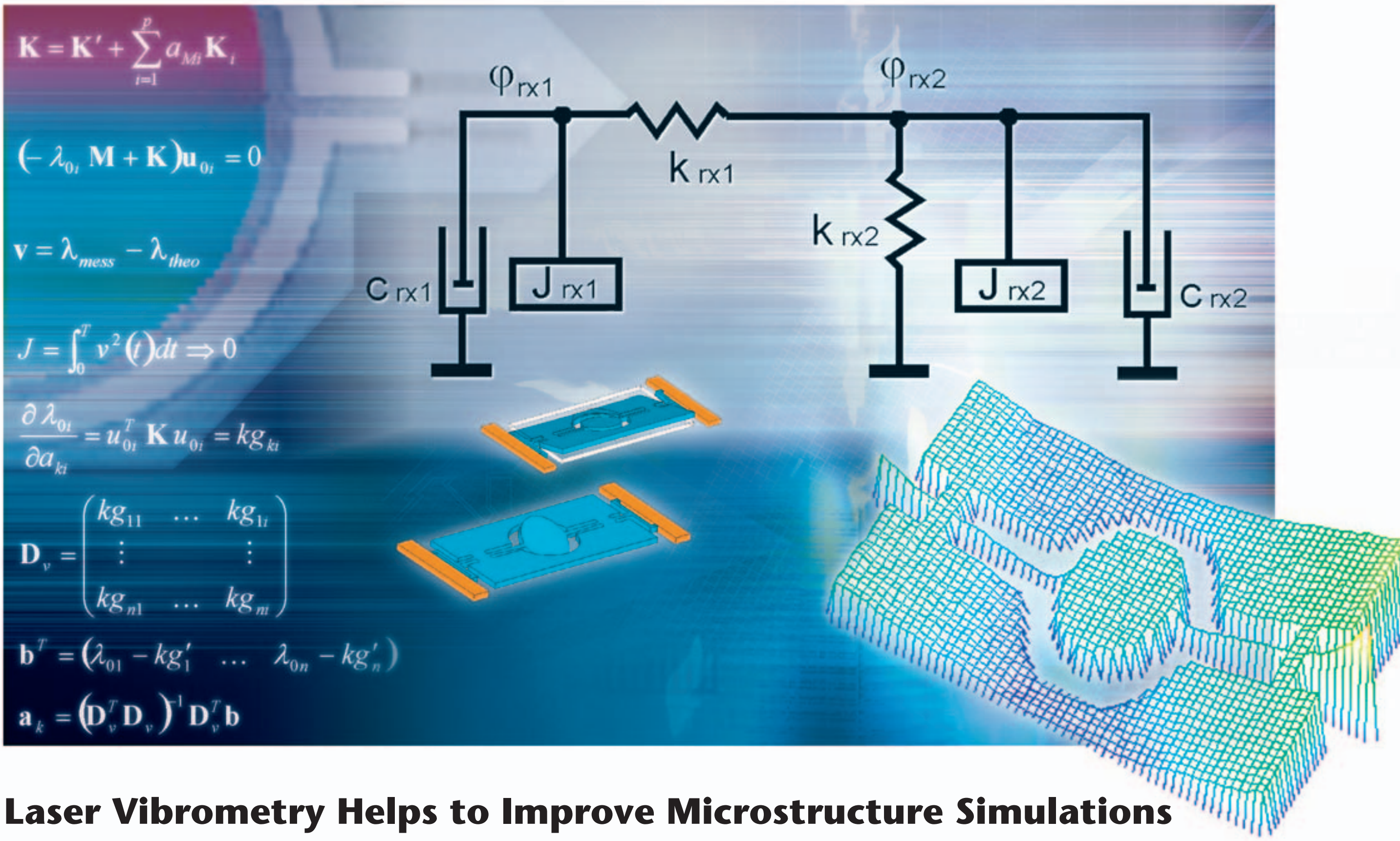
Just How Precise are *Simulation Models?*



Laser Vibrometry Helps to Improve Microstructure Simulations

Computer simulation is essential to the development of MEMS devices. Simulation models are tested and refined through comparisons with precise experimental data. The data validating the model and showing the mechanical response of the MEMS structure is easily acquired through the combination of a Polytec Laser Vibrometer and a Wafer Probe Station.

Micromechnical Scanners

Tiny mirrors focus the light in bar code scanners up to several hundred times per second across the bar code. Scanning two-dimensional codes, made up like a mosaic of many dark and light fields, already requires significantly higher scanning speed and laser beam quality. Another development allows the use of a laser to project images. Just like an electron beam in conventional picture tubes, a laser beam is run across the image surface and its brightness is modulated.
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 have been developed at the Fraunhofer IZM Institute in cooperation with the Center for Microtechnology at the Chemnitz University of Technology (Figure 1).

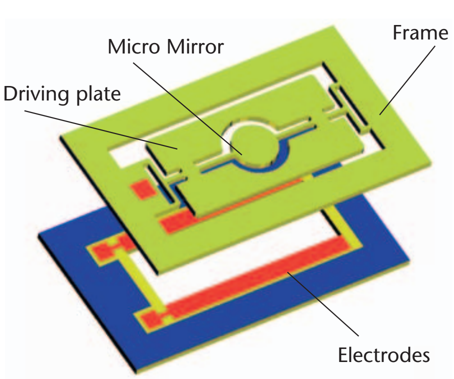


Figure 1: Construction of a micro scanner

To produce the mirrors, manufacturing technology from the electronics and semiconductor industry can be used. The dimensions of mechanically moving parts range between several microns and a few millimeters.
By generating an electrostatic field between electrodes within this scanner, the small mirrors can be mechanically driven.

Simulation of MEMS Properties

During the design and development of these 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 suitable 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 metrologically determine 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 needs to 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 also allows to obtain measurement 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 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 structures within MEMS components.

Because of the optical sampling, the measurement procedure very little influences the MEMS device. The diameter of the laser beam on the test sample is in the range of a few micrometers, so that even very small structures such as single cells of micro mirror arrays can be tested.

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

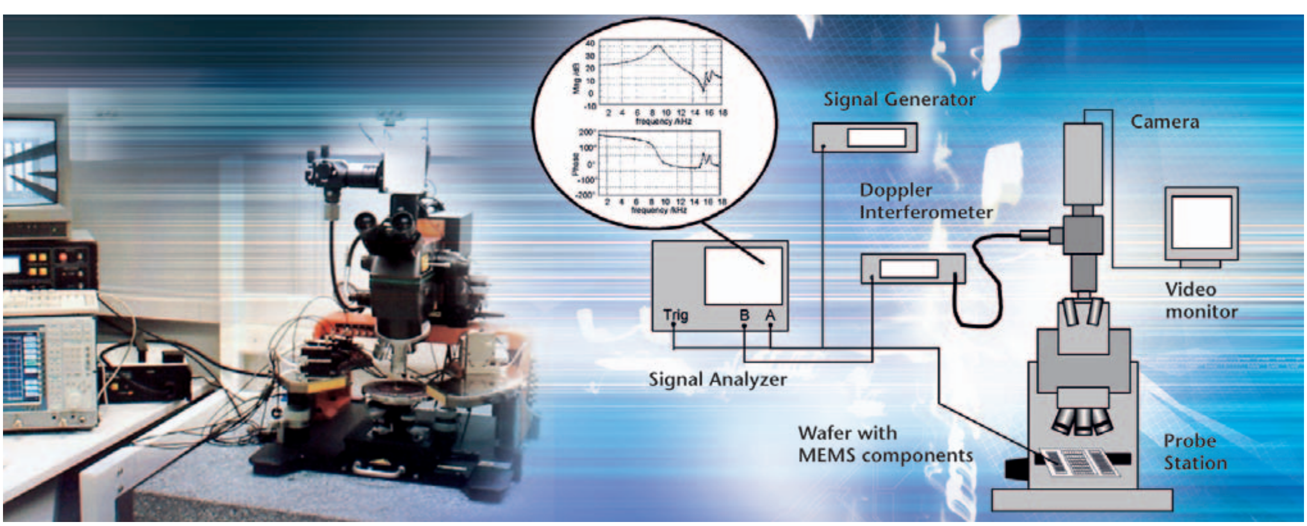


Figure 2: Probe station with Polytec Microscope Scanning Vibrometer

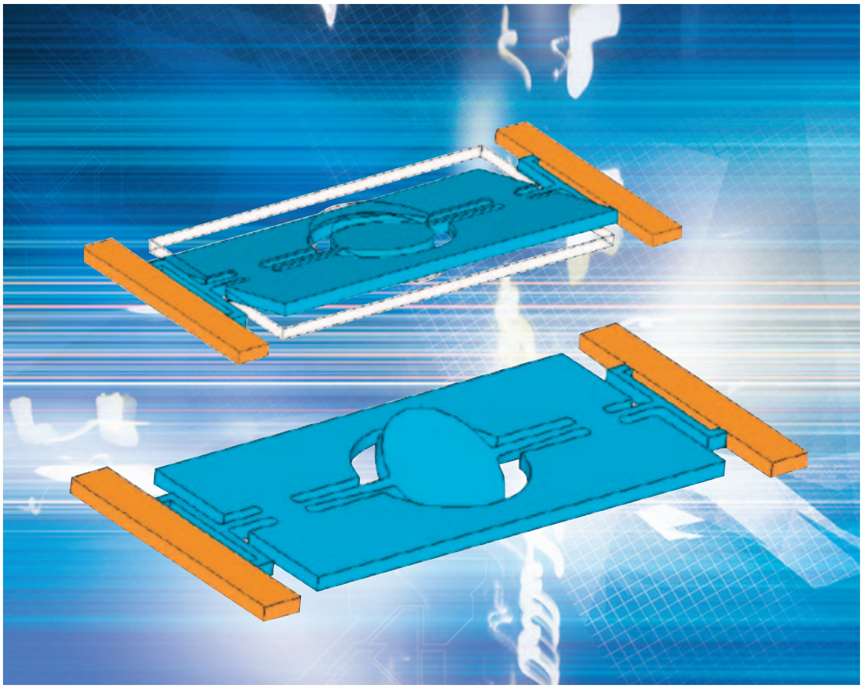


Figure 3: First (top) and second (down) natural deflection shape of the scanner

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.

Example: MEMS Scanner

The task is to experimentally determine the stiffness and geometry of the torsion bands which flexibly connect the micro-mirrors, 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.

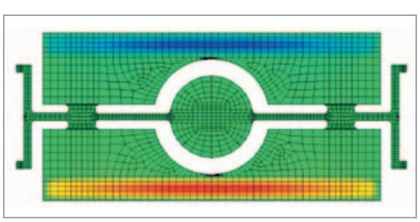


Figure 4: FEM analysis of damping by air flow, pressure distribution

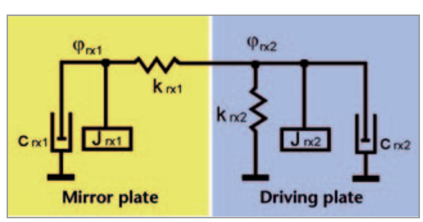


Figure 5: Model after reduction of order

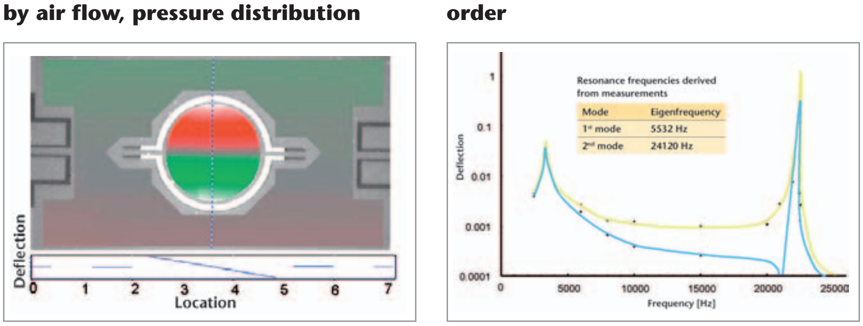


Figure 6: Measurement results with the Microscope Scanning Vibrometer, left: deflection shape; right: transfer function

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.

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