Eigenfrequency-App for University Laboratory Education

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INTRODUCTION: Laboratories are essential parts of the engineering education at a University of Applied Science. Students get the chance to practically apply concepts taught in theory lectures.
Sometimes the lab experiments require additional theoretical background. This is particularly true for experiments which combine topics from different disciplines. For example students of electrical engineering are familiar with the working principle of a strain gauge [1]. But, for applying this sensor for Eigenfrequencies measurements, e.g. of a steel girder (cf. Fig. 1-3), the students should have also an idea about resonant modes of such a 3D structure.

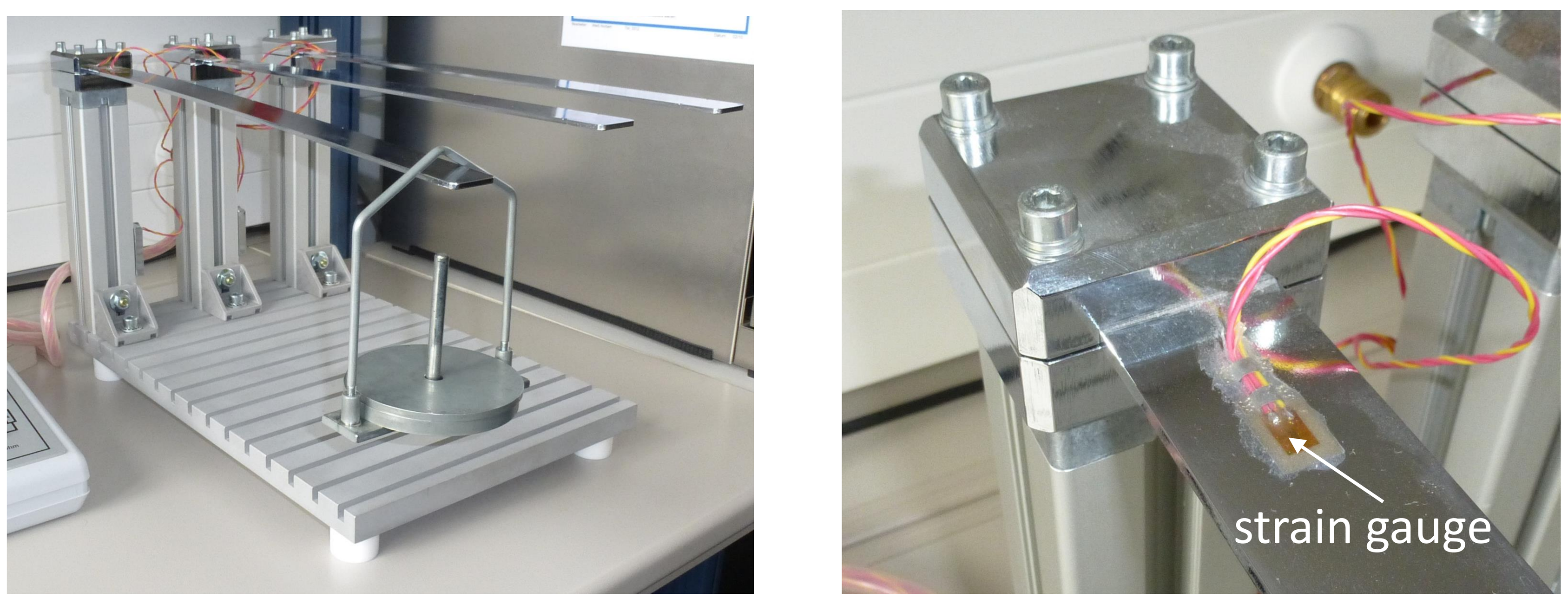

Figure 1. Laboratory setup for Eigenfrequencies measurements. Left: three steel girder with quarter-, half-, full-bridge measurement circuits. Right: details of the quarter-bridge strain gauge assembly.

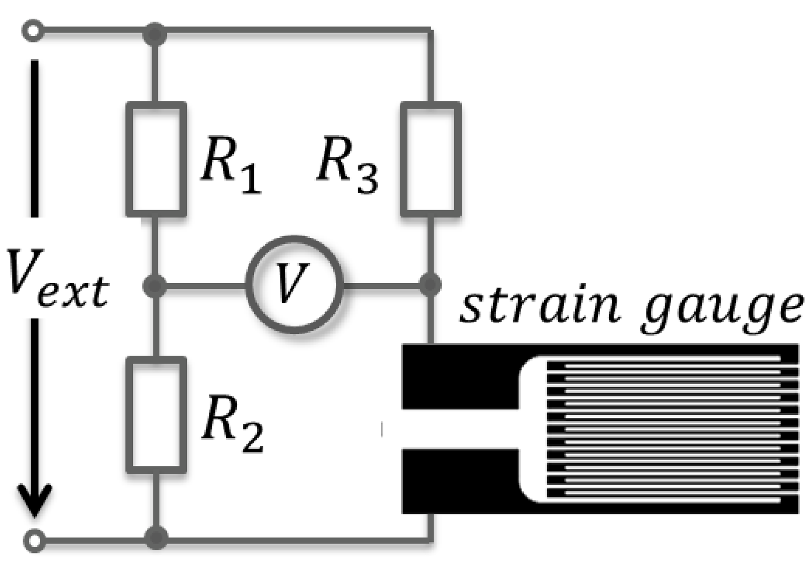

Figure 2. Quarter-bridge measurement circuitry.

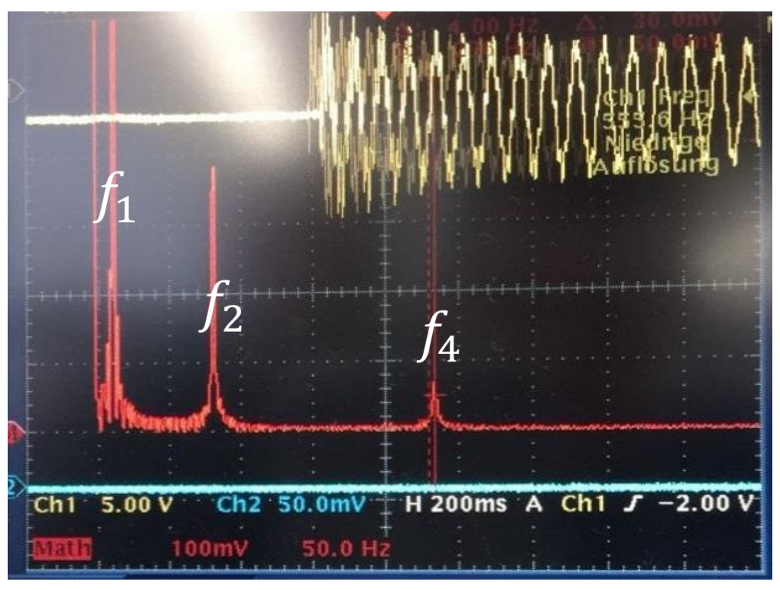

Figure 3. Measured data for Eigenfrequencies f_1, f_2, f_4.

COMPUTATIONAL METHODS: The resonant modes with Eigenfrequencies ω are defined by the PDE for the displacement field $\boldsymbol{u}$ of the girder [2]:

$$-\rho\,\omega^2\,\boldsymbol{u} = \nabla\cdot\boldsymbol{S} \text{ with } \boldsymbol{S} = \mathrm{C}(E,\nu):\epsilon_{el} \qquad (1)$$

The COMSOL model setup is straight forward: Solid Mechanics interface with a Fixed Constraint boundary condition; parameterized block geometry to represent the steel girder; material defined by Young's modulus E, Poisson's ratio ν, density ρ; Physics-Controlled Mesh of fine size and an Eigenfrequency study.

RESULTS: The realized app allows to visualize six resonant modes (Fig. 4), which can also be animated. In order to adapt the simulation model to the lab-setup, the students adjust values for the geometry and the material properties of the steel girder.

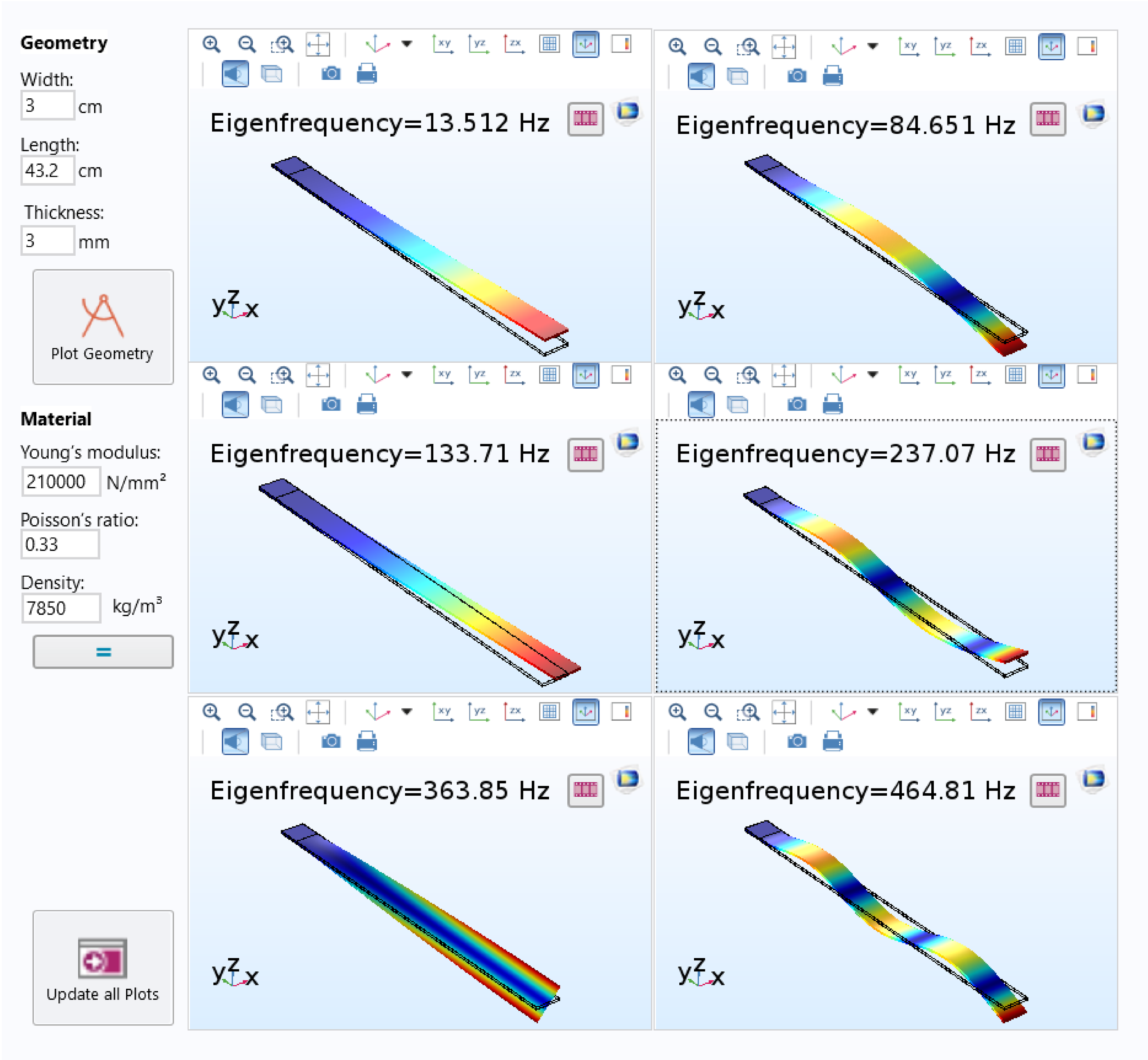

Figure 4. Eigenfrequency-App

Table 1. Simulated versus measured Eigenfrequencies: measurement with lab-setup possible ☺ or not possible ☹.

Simulated Eigenfrequency	$f_{1-sim} =$ 13.5 Hz	$f_{2-sim} =$ 84.7 Hz	$f_{3-sim} =$ 133 Hz	$f_{4-sim} =$ 237 Hz	$f_{5-sim} =$ 364 Hz	$f_{6-sim} =$ 465 Hz
Quarter-bridge	$f_{1-meas} =$ 13.5 Hz	☺	☹	☺	☹	(☺)
Half-bridge	☺	$f_{2-meas} =$ 84 Hz	☹	☺	☹	(☺)
Full-bridge	☺	☺	☹	$f_{4-meas} =$ 236 Hz	☹	(☺)

CONCLUSIONS: The developed app provides results in reasonable accordance with experimental data. Students can answer essential questions like: "Which frequencies can be measured with the strain gages lab-setup?" or "How should a particular Eigen-frequency be excited?". The app also allows for a proof of reasonability for the experimentally determined frequencies values. Overall, based on the simulation results, the students are able to plan and perform the experiments more systematically and gain more vivid insight to the learning content.

REFERENCES:

[1] C. W. De Silva, Sensor Systems: Fundamentals and Applications, Taylor & Francis Inc, 2016
[2] Comsol User's Guide: Structural Mechanics Module