

resonance frequency of the assembly should be adjusted to the vibration-frequency of the machine. For this purpose, two steel blocks of variable height h_{mass} can be mounted on the free end of the beam. The geometrical dimension are given as:

- $h_{\text{Piezo}} = 1 \text{ mm}$; $w_{\text{Piezo}} = w_{\text{bar}}/2$; $l_{\text{Piezo}} = 4 \text{ cm}$
- $h_{\text{bar}} = 2 \text{ mm}$; $w_{\text{bar}} = 1.8 \text{ cm}$; $l_{\text{bar}} = 8 \text{ cm}$
- $h_{\text{mass}} = \text{variable}$; $w_{\text{mass}} = w_{\text{bar}}$; $l_{\text{mass}} = 1 \text{ cm}$
- $w_{\text{offset}} = w_{\text{bar}}/2$; $l_{\text{offset}} = 5 \text{ mm}$

To save simulation time, the mesh shall be optimized. Thereby, all lines along the x -axis shall have a mesh size of $dx = 5 \text{ mm}$, all lines along the y -axis a mesh size of $dy = 4 \text{ mm}$ and all lines along the z -axis a mesh size of $dz = 0.25 \text{ mm}$. In order to apply a structured mesh using bricks, you can first perform the meshing with quadrilateral elements in the x - z -plane and then extrude the mesh in z -direction.

The main objectives of this project are:

- Learn the concept of piezoelectric energy harvesting
- Design the energy harvesting device
- Analyze the impact of a load connected to the harvester

1 Preparation and modeling hints

- 1.1. Model the geometry as depicted in Fig. 1. Thereby, keep all parameters variable and exploit symmetries where possible to speed up your simulations. Make sure to use an appropriate element type for the meshing.
- 1.2. The energy harvesting device can be regarded as rigidly connected at the “fixation” to a vibrating machinery.
- 1.3. You can perform harmonic simulations for all of the tasks.

2 Analysis and design tasks

Consider first the open circuit, i.e., neglect the resistors R:

- 2.1. Determine the mechanical resonance frequency of the beam by means of a harmonic analysis in the frequency range from 10 Hz to 1000 Hz. For this purpose, observe the mechanical displacement at the tip of the harvester (observer node). As excitation, apply an acceleration of 1 m/s^2 in z -direction at the other side of the beam (marked as fixation/excitation in sketch). Please fix both x and y component at this excitation surface (it shall only move in z -direction). The electrodes closer to the aluminum bar shall be grounded, whereas the opposing electrodes have an unknown potential. In addition to the mechanical displacement at the tip, compute the electric impedance of the piezoelectric patches. What kind of electric resonance (resonance or anti-resonance) is found at the mechanical resonance frequency?
- 2.2. Tune the resonance frequency of the assembly to 150 Hz by choosing an appropriate height h_{mass} of the mass blocks (height should be between 2 mm and 7 mm).

After tuning the resonance frequency to roughly 150 Hz consider the effect of the two resistive loads R connected to the harvester. Unless otherwise specified, operate the device at its resonance frequency:

- 2.3. Use a *Electrical Circuit* physics in Comsol to model the resistors. This lumped parameter circuit can then be connected to the *Electrostatic* physics of the Finite Element model using a *Terminal* node on the electrodes of the piezoelectric patches. For information on how to use these features inspect the “piezoelectric energy harvesting” example in the Comsol *Application Libraries* and/or read the manuals.
- 2.4. Investigate on the effect that R has on the harvesting device by assigning the following values: $1 \times 10^{-16} \Omega$, 10Ω , 100Ω , 1000Ω , 10000Ω and $1 \times 10^{16} \Omega$. You can even add more/other values if you deem appropriate.
- 2.5. Analyze the RMS power output of the harvester in dependence of the load R and the frequency f . Is there a point of maximum power output?

3 Presentation

Prepare for a **ten minutes** presentation followed by a **five minutes** discussion. Your presentation should consist of the following blocks:

- 3.1. Introduce yourselves (names, fields of studies).
- 3.2. Motivate and introduce the topic, i.e., what is this project about, how does the shown sensor/actor/assembly work in practice, what is it used for, what are the main objectives.
- 3.3. Present the major aspects of your modeling and analysis, i.e., what quantities were analyzed, are there any analytic estimates, what major difficulties had to be solved, how did you overcome these difficulties, etc.
- 3.4. Show and discuss your results in a descriptive way using graphs, screenshots, videos, etc.
- 3.5. Give a short conclusion.

Some remarks

- **Brainstorm a concept** on how to proceed and think about the desired goals and how you can achieve them. Focus on the relevant aspects of the project.
- **Start early** with your project and meet regularly to work together and/or exchange ideas. You might be able to distribute some tasks inside your group.
- The task description is rather **vague on purpose** and has room for your own interpretations. If you face uncertainties, e.g., regarding the choice of some parameter, discuss in the group first and think about reasonable choices. Only if this does not help, contact your supervisor.
- Present your project milestones to your supervisor **once or twice** during the course of the project. Discuss your “almost” final slides with your supervisor **before the first** deadline. Keep in mind, that you might need to make substantial changes and/or more simulations after this discussion.
- You can/should use Matlab where you deem it useful.
- When making animations, make sure to fix the color range of surface plots.

Submitting your project

One member of the group must hand in the

- Comsol `.mph` file and
- the slides for the presentation, either as a PowerPoint or PDF document.

Upload the above files **before the second deadline** to the project section on StudOn:
<https://www.studon.fau.de/exc3189285.html>.

Important: Make sure to delete all results and meshes from the Comsol file before handing in. This reduces the file size. Refer to the Comsol Tutorial on how to do this.