Experimental and numerical study of a magnetic pendulum

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Abstract. An experiment has been performed on a magnetic pendulum, which interacts with an electromagnet. The free non-linear vibrations of the pendulum-magnet system are studied to identify and analyse the system's characteristics. Due to the presence of the electromagnet, a modulation of the pendulum's natural frequency is observed. A mathematical model is formulated that is able to reproduce the experimental results.

Introduction

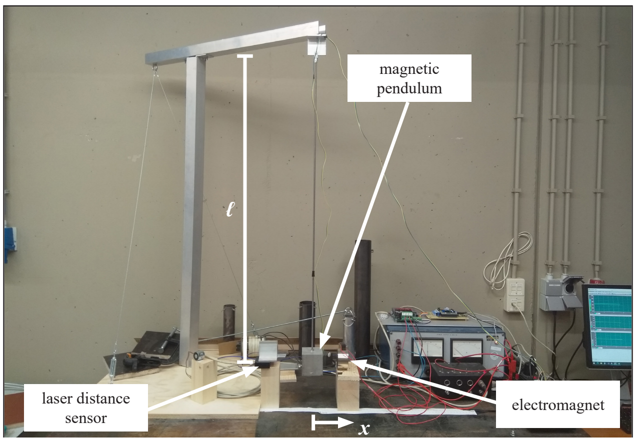
Increasing demand for energy from renewable resources has led to a spectacular increase in the number of offshore wind turbines planned to be installed [1]. Installation using floating vessels is critical to meet the demand, as such allows for faster installation in deeper water. Undesired motion of the payload caused by vessel motions is one of the limiting factors for operations. Current methods to reduce the motion of the payload are based on tugger line systems [2, 3], which can only apply a pulling force. Ideally, the load can be pushed and pulled to improve the control. Therefore, an alternative system is investigated here, which is based on magnetic interaction of the payload and an magnetic actuator.

Experimental setup

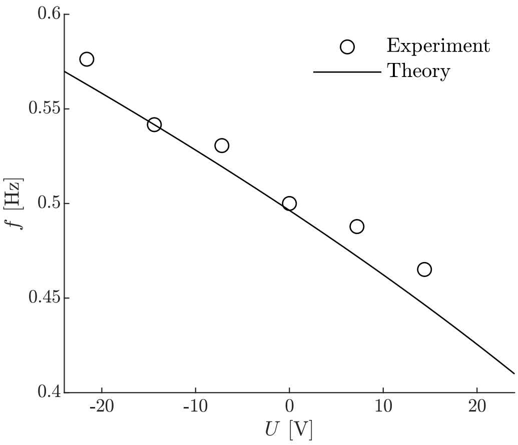
For a proof of concept, an experimental setup has been designed an built (Figure 1a), which consist of a pendulum with an aluminium mass to which a permanent magnet is attached at its side. The pendulum can be excited by an electromagnet, which is on the same axis as the poles of the permanent magnet. To register the motion of the suspended mass, a laser distance sensor is employed. To characterise the system and to calibrate a model for the distance-dependent magnetic interaction, the free vibrations of the pendulum in the presence of the electromagnet are analysed.

Results and discussion

When no voltage is supplied to the electromagnet, the natural frequency of the pendulum is $f = 0.49\,\text{Hz}$ and its equilibrium is $x = 0\,\text{m}$. For different constant supplied voltages, the data shows that the equilibrium point shifts away from $x = 0\,\text{m}$ and that the fundamental frequency of free vibrations is modulated due to the action of the magnet (Figure 1b). The experimental data is in good correspondence with results from the numerical model of the system. Using the model, it is shown that the observed modulation results from the non-linear nature of the magnetic interaction between the two magnets.



(a) Setup of the magnetic pendulum.



(b) Modulation of the pendulum's natural frequency with varying voltage of the electromagnet.

References

[1] WindEurope. Offshore Wind in Europe. Key trends and statistics 2019. Technical report, WindEurope, 2020.
[2] Zhengru Ren, Zhiyu Jiang, Zhen Gao, and Roger Skjetne. Active tugger line force control for single blade installation. *Wind Energy*, 21(12):1344–1358, 2018.
[3] Zhiyu Jiang. Installation of offshore wind turbines: A technical review. *Renewable and Sustainable Energy Reviews*, 139:110576, 2021.