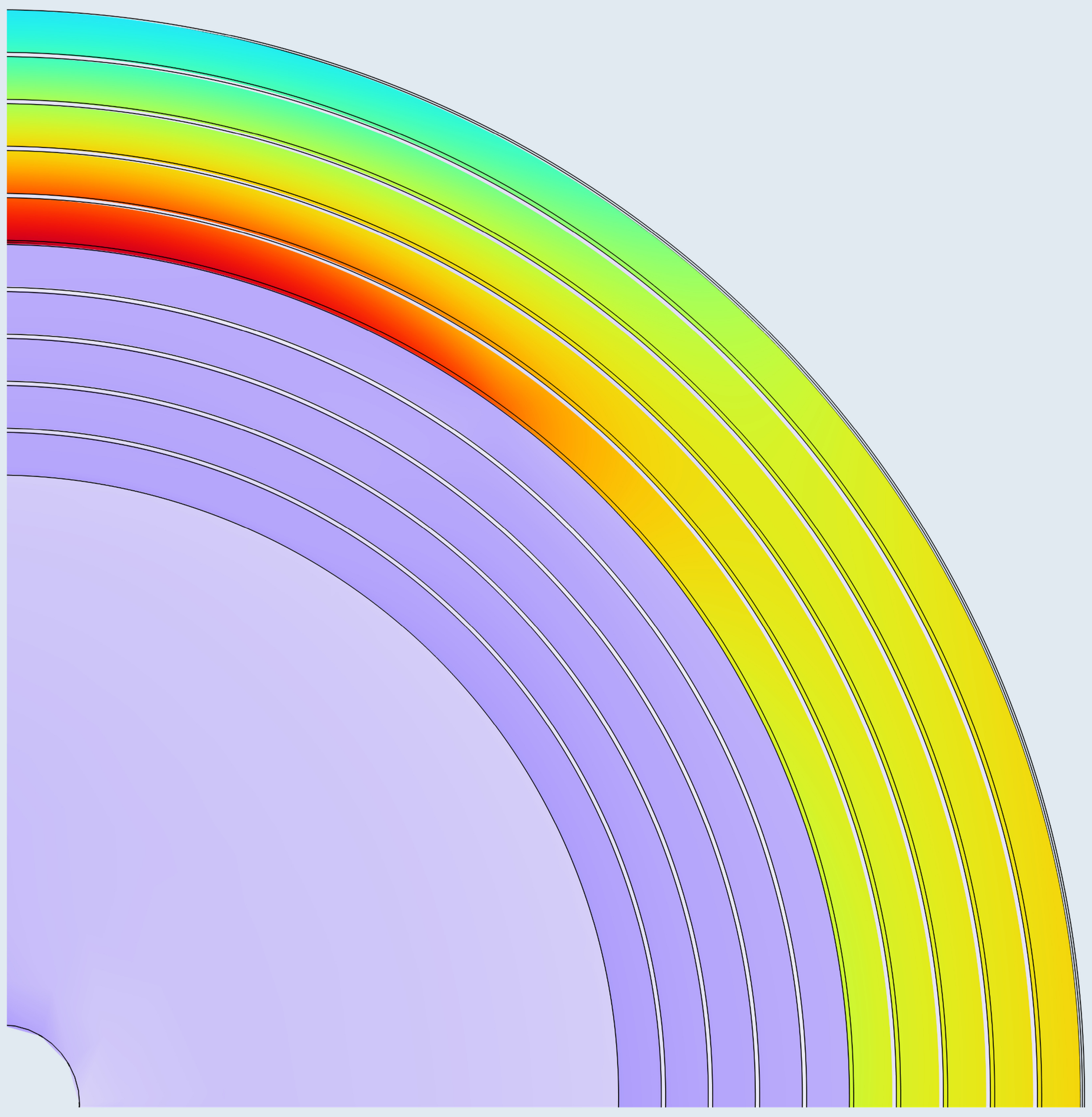

Simulation of an Explosive Resistant Flywheel Energy Storage Device Based on a Steel Strip Spiral

An innovative new kind of flywheel is presented. It consists of a glued thin spiral steel strip with a thickness of about a quarter of a millimeter, which is coiled up on an aluminum core and centered by a shaft.

J. Sotrop, S. Hummert, L. Fromme

Faculty of Engineering and Mathematics, Hochschule Bielefeld – University of Applied Sciences and Arts (HSBI), Bielefeld, Germany

Introduction

Sustainable energy storage is essential for a successful energy transition towards renewable energies. Advanced future power grids will consist almost exclusively of instable and variable sources like solar and wind power. However, fluctuations can be problematic for the power grids, as they are destabilizing the frequency. Therefore, regulating components such as energy storages must be integrated into the grids. Standard electrochemical storages like lithium-ion batteries are expensive, ecologically problematic and have a short lifetime based on their charging or discharging cycle. One efficient way to stabilize the frequency of a power grid is by means of flywheels. Current, flywheels are made of bulk material or carbon fiber reinforced plastic (CFRP) discs. However, the large-scale use of state-of-the-art flywheels are slowed down due to the safety requirements. In case of a defect the energy stored in the flywheel will be released explosively. To overcome these safety issues, an innovative new kind of flywheel is presented. The flywheel consists of a glued thin spiral steel strip with a thickness of about a quarter of a millimeter, which is coiled up on an aluminum core and centered by a shaft. In case of material failure, the steel strip spiral unreels and disintegrates which results in a smooth transition of the stored kinetic energy. Thus, the explosively is defused.

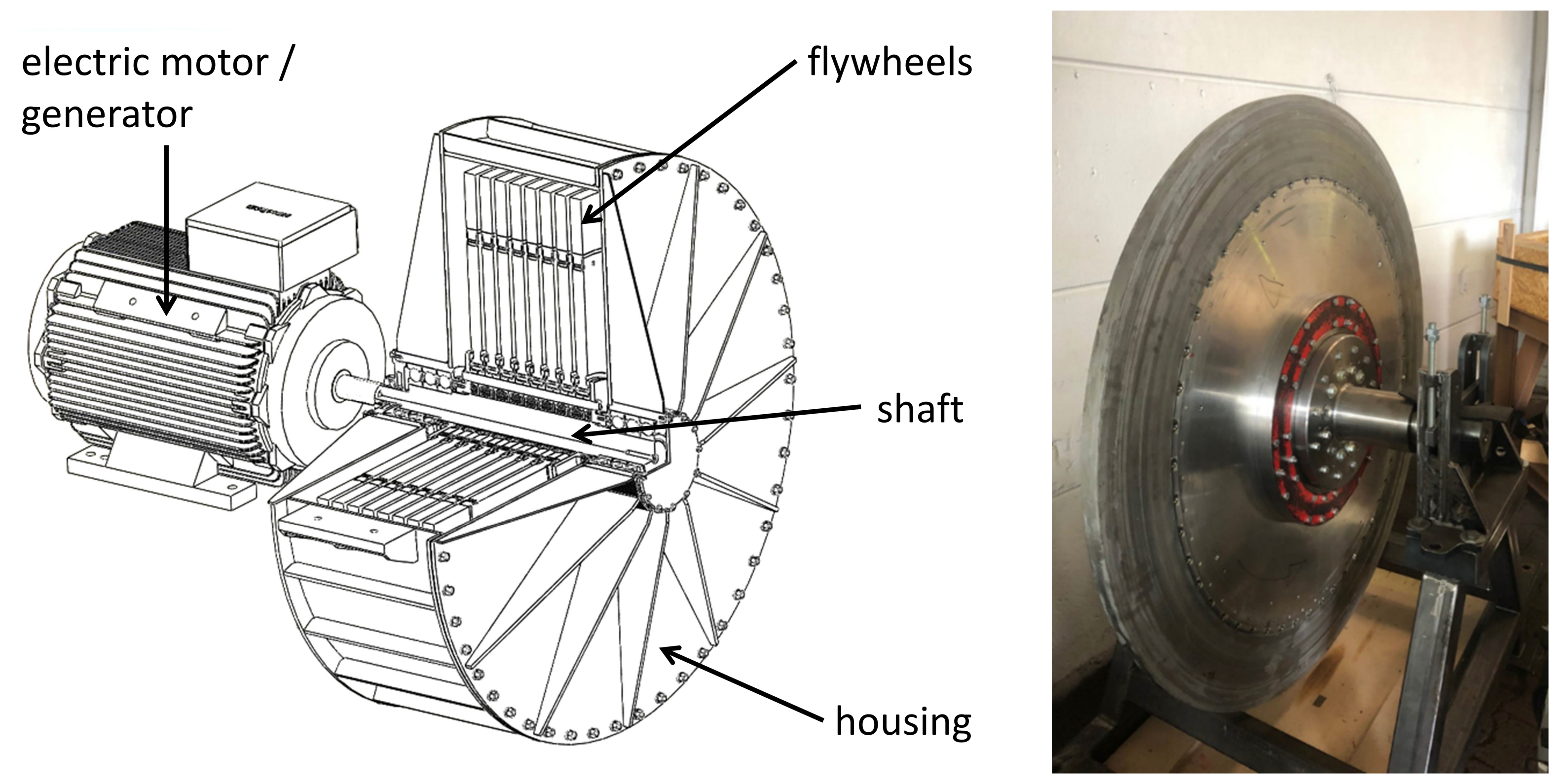

FIGURE 1. Left: Structure of the flywheel energy storage system with housing and electric motor. Right: Flywheel configuration with the spiral steel strip segment, the aluminum core, and shaft.

Methology

COMSOL Multiphysics® was used to create a numerical model of the novel flywheel energy storage (FES) device based on a steel strip spiral. The model is set up parameterized to represent many design possibilities. These parameters are material (Young's modulus and Poisson's ratio of steel as well as adhesive) and geometry parameters (number of turns, inner and outer diameters, and aspect ratio of steel and adhesive). The flywheel consists of up to 2000 turns, which poses a great challenge for the creation of a numerical model due to a high aspect ratio. The complete setup is generated by a JAVA® method using the API, since a manual selection is no longer practicable due to a high number of domains. The model is implemented as 2D- as well as 3D-geometry and the adhesive is explicitly represented as a domain. The Structural Mechanics Module was used to simulate the deformation of the flywheel under rotation up to 5500 rpm. Eigenfrequency studies were performed as well as contact studies to see the effect of an adhesive detachment.

Results and Outlook

In this project, a numerical model of an explosive resistant flywheel was developed and analyzed. The key question was to identify the mechanism of the failure during operation due to detachment of the spiral steel strip. The mechanical behavior of the flywheel was investigated for different design possibilities. Six critical eigenfrequencies in the range of about 30 Hz to 90 Hz were identified. In case of resonance at one of these frequencies a detachment of one inner single spiral could occur. The acting forces are then exceeding the tensile stress of high strength steel and tear up the loose steel strip. This could lead to breakdown of the entire flywheel. Hence, critical operational parameters of the flywheel are revealed, which is a major step toward reliable industrial development. Experimental work is in progress to verify these numerical results.

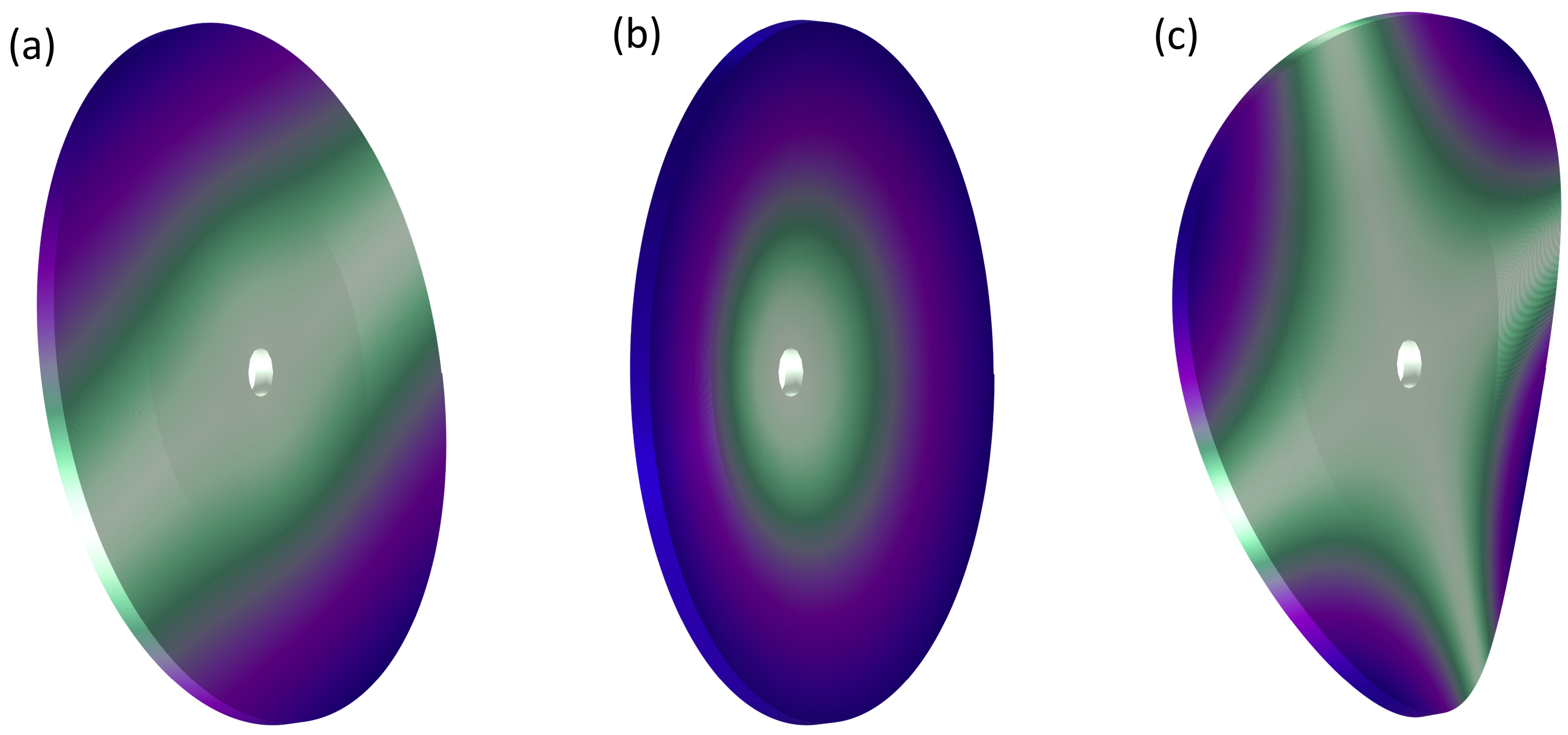

FIGURE 2. Eigenmodes of the flywheel with 100 spiral turns that correspond to eigenfrequencies at 37.3 Hz (a), at 56.8 Hz (b), and at 76.1 Hz (c).

REFERENCES

K. Steinbacher, S. Röhrkasten, *An outlook on Germany's international energy transition policy in the years to come: Solid foundations and new challenges.* Energy Research & Social Science, vol. 49, pp. 204-208, 2019.
K.M. Tan, T.S. Babu, V.K. Ramachandaramurthy, P. Kasinathan, S.G. Solanki, S.K. Raveendran, *Empowering smart grid: A comprehensive review of energy storage technology and application with renewable energy integration.* Journal of Energy Storage, vol. 39, p. 102591, 2021.
M. Amiryar, K. Pullen, *A Review of Flywheel Energy Storage System Technologies and Their Applications.* Applied Sciences 7, no. 3, pp. 286-296, 2017.

Hochschule Bielefeld
University of Applied Sciences and Arts

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