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HIGH PERFORMANCE FLYWHEEL TECHNOLOGY FOR ELECTRIC ENERGY STORAGE USING MAGNETIC BEARINGS

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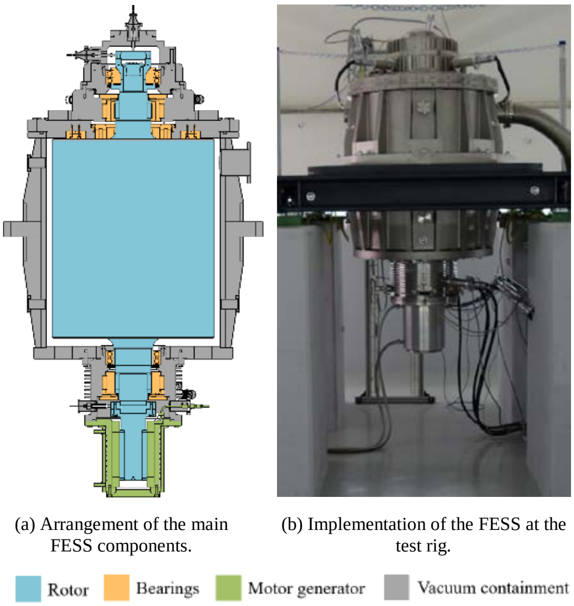
1. Introduction

Flywheel energy storage systems (FESS) provide the typical energy storage application approaches, as exemplary presented in [1-2]: grid services, industrial applications and renewable integration. In the presented work, the development and implementation of a FESS is summarized. The design process as well as the manufacturing and assembly of the system were carried out by researchTUb GmbH in collaboration with the Institute for Production Engineering and Laser Technology from the Technical University Vienna. Furthermore, a test rig was established, which provides the possibility to investigate and optimize the flywheel prototype under laboratory conditions.

2. Flywheel setup

When building a FESS, one of the main task is reducing losses, mainly caused by mechanical and aerodynamic friction. Therefore, it is common to apply a vacuum environment in combination with contact-free electromagnetic bearings, to overcome these major drawbacks. A general overview of the FESS highlights Fig. 1a. The rotor (blue) is supported by a bearing system (orange), consisting of one axial- and two radial supports. The axial bearing holds the rotor in levitated position, whereby an electro magnet in combination with permanent magnets generates the bearing force. However, the two radial bearings consist of contact free electromagnetic bearings and mechanical touchdown safety bearings, which support the rotor in case of an emergency shutdown, caused by a magnetic bearing failure. The rotor is spinning in a vacuum chamber (grey) under high vacuum conditions. The pressure level of 10^{-6} mbar is generated by combining a rotary vane pump and a turbomolecular pump. The rotor material is high-strength forged steel, normally applied in the field of power generation machinery. A customized synchronous motor generator (green) with embedded magnets drives the system. Tab. 1. resumes a selection of the technical main data of the actual FESS configuration.


(a) Arrangement of the main FESS components.

(b) Implementation of the FESS at the test rig.

Fig. 1. Flywheel Energy Storage System (FESS).

Rated power	20	kW
Capacity	20	kWh
Power/ Capacity ratio	1	-
Rotor mass	2.200	kg
Length/ Diameter ratio	1,23	-
Maximum speed	> 10.000	rpm
Minimal bearing air gap	0,15	mm

Tab. 1. Selection of the technical main data.

3. Flywheel design process

The design process of a FESS represents a multidimensional and multidisciplinary optimization problem. Describing the complex design process with regard to an optimized mechanical solution in conjunction with cost optimization and grid integration, would go beyond the scope of this paper. However, the basic design task is shortly described following. The main principle of a FESS is to store energy by a rotating mass, characterized by its moment of inertia *I* and its angular speed ω:

$$E_{kin} = \frac{1}{2} I \omega^2 = \ldots = \frac{1}{4} \rho \; \pi \; \omega^2 l \; R^4 \tag{1}$$

The right site of Eq. (1) represents the solution for the specific case of a thin disk with $l << R$. Further, the maximum mechanical stress is of interest [3]:

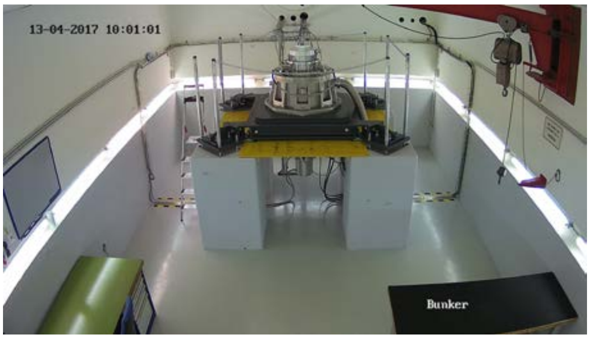
$$\sigma_{\max} = C_1 \rho \omega^2 R^2 \tag{2}$$

As can be concluded from the stated equations, the geometry, the stored energy and the occurring stress state of the gyrating mass can be described by four basic parameters: density ρ, speed ω, disk thickness l and radius R. Thereby, the radius has a stronger influence on the kinetic energy, with the power of 4, as the rotating speed (power of 2), and both have the same strong influence on the stress state (power of 2). By exemplary assuming a constant amount of energy, doubling the radius, reduces the rotating speed to ¼. Hence, the design process of the FESS considers a broad range of disciplines, e.g. rotor dynamics, vibration analysis, temperature field calculation, fracture mechanic analyses and also manufacturing boundary conditions, to name only a few. To meet these requirements, various analytical and numerical calculations were carried out to finalize the presented solution. For the numerical investigations, ANSYS Mechanical V16 was applied to perform the mentioned multidimensional and multidisciplinary calculations.

4. Flywheel test rig

For prototype testing purpose, a customized test rig has been established in a former material testing bunker. This bunker provides a safe testing environment, for maximum speed tests, emergency shut down investigations, rotor drop tests, etc. Apart from the flywheel setup discussed above, multiple auxiliary systems had to be developed, e.g. the vacuum equipment, the motor generator cooling system, a condition monitoring system, as well as the control unit and control cabinet with electrical grid integration elements. Fig. 2a. shows the ground floor of the test rig with its control station (left), control cabinets (right) and the bunker with its moveable ceiling elements (in the front). These elements provide an appropriate accessibility for the overhead crane during the assembly of the system when opened and as well as the mentioned safe testing environment when closed. In Fig. 2b. the test rig basement (bunker) is depicted, with the actual FESS configuration and its machine frame and machine foundation.

(a) Test rig ground floor.



(b) Test rig basement (bunker).

Fig. 2. Impressions of the FESS test rig.

5. Conclusion and Outlook

This paper presents the structural approach, basic considerations and a test rig description for a FESS developed and established. The presented FESS has already been commissioned and actually, endurance tests are being performed. Based on the test findings, it is intended to elaborate optimization potentials and to pave the way for further improvements with the final target of establishing a system ready for market entry.

References

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