Energy Storage Flywheel Rotors – Mechanical Design

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Definition: Energy storage flywheel systems are mechanical devices that typically utilize an electrical machine (motor/generator unit) to convert electrical energy in mechanical energy and vice versa. Energy is stored in a fast-rotating mass known as the flywheel rotor. The rotor is subject to high centripetal forces requiring careful design, analysis, and fabrication to ensure the safe operation of the storage device.

Keywords: flywheel energy storage ; high-speed rotors ; mechanical design ; manufacturing ; analytical model-ing ; failure prediction

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Between 2019 and 2020, the generation of solar energy grew by 26.0 TWh (24.1%) and 37.1 TWh (16.6%) for the two largest global consumers of energy, the Unites States of America and the People's Republic of China, respectively. Over the same timeframe, the growth in energy generation from wind for these two countries was correspondingly 42.0 TWh (14.1%) and 61.2 TWh (15.1%) [1]. For perspective, the total electricity generation of Canada was 643.9 TWh in 2020. Renewable energy generation capacity is expected to continue to increase rapidly as energy demands and pressure to reduce environmental impacts grow [2]. Additionally, the cost of renewable energy production has been falling dramatically over the last half decade [3], which further increases demand. However, as renewable energy production increases the intermittency from these sources necessitates significant energy storage capacity to meet demand at any particular moment [4].

Compounding the intermittency issue is the separation between peak power demands from residences and businesses and peak power production from renewable sources [5]. What is now recognized as the "Duck Curve" shows the difference between hourly demand and renewable energy production [6]. Energy consumption has been shown to peak in the mornings and evening while energy production typically peaks around midday, especially for solar photovoltaic systems.

Energy storage is among the largest obstacles facing modern energy grids as they transition to new renewable sources of energy while attempting to maintain both power supply and power quality. As the demand for renewable energy sources increases and the costs of that energy decrease, the economic and environmental benefits of maintaining large-scale energy storage systems increase [7]. The plethora of energy storage options [8] includes flywheel energy storage systems (FESS). FESS are among the oldest forms of energy storage, having been used to regulate power output in stone drills as early as 1000 BCE [9]. While the principal concept of flywheel energy storage, i.e., a large mass spinning on an axis, has changed little in the intervening millennia, the materials, control systems, and applications have continually evolved.

Modern high-speed flywheel energy storage systems have a wide range of applications in renewable energy storage, uninterrupted power supplies, transportation, electric vehicle charging, energy grid regulation, and peak shaving. They are recognized for a number of advantageous characteristics, including high charge/discharge rates, expected lifetimes of greater than 20 years, and specific energies in excess of 100 Wh/kg [5]. They are also unaffected by cyclic degradation or depth of discharge effects common to traditional electrochemical batteries, and their cycle efficiency can be up to 95% [10][11]. As can be inferred from the above applications, the advantage of FESS over more common energy storage technologies, such as electrochemical batteries and pumped hydro storage, is that FESS facilitate applications requiring high power and high specific energy [12][13]. FESS have faster response times than both electrochemical batteries or pumped hydro. Compared to batteries, FESS do not require the same level of delicate control over power and temperature, and, due to their high cycle lifetime and deep depth of discharge, FESS require less installed capacity than batteries while still meeting demand [7].

This is not to say FESS are an ideal solution to address all energy storage challenges. FESS experience high passive discharge losses [10], comparatively high initial investment costs [14], and ongoing efforts to understand long-term behavior of rotor materials and failure [15][16]. In an effort to understand and improve flywheel rotor performance and safe operating limits, analytical models have been developed that consider material selection, rotor construction, and operating conditions.

This entry focuses on the design and analysis of the flywheel rotor itself. It will begin by highlighting some FESS applications and performance, followed by the design and manufacturing approach commonly used for flywheel rotors. Analytical modeling approaches for typical flywheel rotors will be discussed, including the effects of variable angular velocity, viscoelastic stress relaxation, and acceleration. Finally, rotor failure criteria will be discussed.

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