Flywheel energy storage small scale

There are two types of FESS rotors that can be taken into account for a high specific energy density: a flat disk rotor out of isotropic material (shape 1) and a cylindrical design with fiber reinforced plastics with fibers oriented in circumferential direction (orthotropic) (shape 2).

The equation to determine the energy content Ekin of a flywheel for a solid disk is

where m represents the mass of the flywheel, r the radius and o the angular velocity.

For isotropic materials, the energy density is limited by the maximum radial strength in the rotor and directly influences the energy density (energy-to-mass-ratio Em that can be written as:

Thin rings, constructed out of orthotropic materials like fiber composites, show two specific properties in comparison to disk-shaped isotropic materials:The maximum stress occurs in circumferential direction, which is in the fiber direction of the composite materials. Since carbon fibers show an enormous strength in the fiber direction, they are an optimal material to take the circumferential stress. Due to the slender ring thickness, radial stress that normally limits the flywheel performance and that would be taken mostly by the resin is negligible.

The momentum of inertia grows differently (see eq. [4]) in comparison to the mass (see eq. [5]) concerning the radii ratio ri/ra

Energy density depending on radii ratio ri/ra

If CNTs can be produced in length of cm instead of mm they would be suitable for FESS and could increase energy density of a FESS up to 2,900 W h/kg since they reach a yield strength of around 30 GPa (Yu 2000). For further calculations of shape 2, a radii ratio ri/ra of 0.9 was set. That allows us to use a simple equation for calculating the limiting circumferential stress for thin rims (Feldhusen 2001):

For thin rims, with a radii ratio ri/ra of 0.9, the shape factor decreases to K=0.45 and thus the energy density is calculated according to

To see how downscaling affects the energy content, the rotational velocity and the losses due to gas and motor friction, two concepts with the following dimensions relations are considered:

The CFRP-ring and the Laval-disk-with-rim shapes can be seen in Figure 3 where the Laval-disk-with-rim is assumed to be a disk with the same momentum of inertia and volume to allow the use of a less complex air loss estimation. Whenever disk shape is mentioned in the following, they imply the properties of the

Laval-disk-with-rim.

Schematic shape 1: ring (left), shape 2: Laval-disk-with-rim (top right) and a solid disk (bottom right) used for the simplified air loss estimation

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Web: https://www.kary.com.pl/contact-us/
Email: energystorage2000@gmail.com
WhatsApp: 8613816583346