Analytical Model and Finite Element Model

The analytical radial and hoop stress distributions in a free rotating thin rim as shown in Fig. 1 can be calculated with eqs. (3) and (4).

$$\sigma_r = \frac{1}{2} \rho \omega^2 R^2 (r/R)^2 - r^2 \rho \omega^2 R^2 (r/R)^2$$

(3)

$$\sigma_\theta = \frac{1}{2} \rho \omega^2 R^2 (r/R)^2 - r^2 \rho \omega^2 R^2 (r/R)^2$$

(4)

The static structural model of the free rotating ring under centrifugal force is considered as a 2D plane stress finite element model. Taking advantage of symmetry, a section of the 2D ring, as shown in Fig. 3, is modeled to reduce mesh count. Symmetric boundary constraints are imposed at the lateral faces. Quadratic quadrilateral elements are used in the simulation of 2D plane stress solids.

FEA simulation of a steel ring was simulated in ANSYS 19.1. The ring has outer radius of 0.17 m and inner radius of 0.09 m and a thickness of 0.3 m. This model was rotated with rotational velocity of 10000 rpm. The material properties of steel is listed in Table 1. The FEA stress and hoop stress distributions in the ring are shown in the contour plots in Figs. 4 and 5. The maximum hoop stress is at the inner surface and maximum radial stress is inside the ring. Hoop stress is found to be much higher than the radial stress. The FEA results are found to match the analytical results as shown in Fig. 6.

Flywheel Energy Storage System

Figure 1 shows a high speed flywheel energy storage system for wind power energy storage. A flywheel energy storage system mainly consists of a flywheel rotor, magnetic bearings, a motor/generator, a vacuum chamber, and power conversion system. Flywheel energy storage systems (FESS) are electromechanical systems that store energy in flywheels and electric machines.

$$E = \frac{1}{2} I \omega^2 = \frac{1}{2} \pi \rho (R^2 - r^2) \omega^2$$

(1)

\(\rho\) and \(\omega\) are the density and angular velocity of the flywheel.

$$E_{\text{loss}} = \frac{1}{2} I \omega^2 = \frac{1}{2} \pi \rho (R^2 - r^2) \omega^2$$

(2)

The maximum allowable angular velocity, \(\omega_{\text{MAX}}\), is under the mechanical strength of the rotor material and the rotor geometry shown in eq. (2). The flywheel rotor is considered as a thin rim of inner and outer diameters \(R\) and \(r\) and thickness \(h\). Eq. (2) also shows that a material of high hoop strength, \(\sigma_r\), and low density, \(\rho\), is desirable for achieving a high angular velocity. Thus, low density, high strength fiber reinforced polymer composite materials with filament wound in circumferential direction are often used in high speed flywheel rotors. The design of flywheel rotor needs to consider many factors, such as the stored energy, mass, cost, materials, cross sectional geometry, thickness, operational speed, hub design, etc.