Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 29-30, 2015

Effect of the Shrink Fit and Mechanical Tolerance on Reactor Coolant Pump Flywheel Integrity Evaluation

Donghak Kim *
KHNP Central Research Institute, 1312-70 Yuseongdae-ro Yuseong-gu Daejeon, 305-343 Korea
Corresponding author: donghak.kim@khnp.co.kr

1. Introduction

Reactor coolant pump (RCP) flywheel should satisfy the RCP flywheel integrity criteria of the US NRC standard review plan (SRP) 5.4.1.1[1] and regulatory guide (RG) 1.14[2]. Shrink-fit and rotational stresses should be calculated to evaluate the integrity. In this paper the effects of the shrink fit and mechanical tolerance on the RCP flywheel integrity evaluation are studied.

2. Acceptance Criteria and Methodology

2.1 Acceptance Criteria

The acceptance criteria considered in this paper are the following:

- The total stress at standstill and normal operating speed does not exceed one-third of the ultimate tensile strength.
- The total stress at design over-speed (125% of normal operating speed) does not exceed two-thirds of the minimum yield strength.
- The total stress at joint release speed (equal to or greater than 150% of normal operating speed) shall not exceed the lower of one-half of the minimum specified ultimate strength or two-thirds of the minimum specified yield strength.
- The normal speed should be less than one-half of the lowest critical speeds (The critical speed for ductile fracture, non-ductile fracture and excessive deformation).

2.2 Method to evaluate the stress

The flywheel of APR1400 is constructed by shrink fitting three parts which are the shaft, the hub and outer wheel as shown in Fig. 1. The stresses in the flywheel due to the shrink fit and the rotation of the flywheel should be calculated and superposed.

The radial displacement and radial and stress of the inner radius for the cylindrical shell under uniform internal radial pressure is determined from eq. (1)~(3), respectively.[3]

$$\Delta b = (Pb/E)\left[\left(a^2+b^2\right)/\left(a^2-b^2\right)+\nu\right] \quad (1)$$

$$Sr = -Pb^2\left(a^2-r^2\right)\left[r^2\left(a^2-b^2\right)\right] \quad (2)$$

$$St = Pb^2\left(a^2+r^2\right)\left[r^2\left(a^2-b^2\right)\right] \quad (3)$$

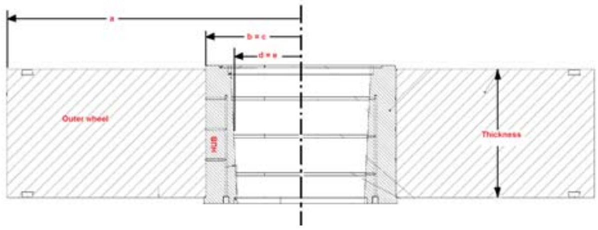


Fig. 1 RCP flywheel sketch

Where Δb = radial displacement of wheel, Sr = radial stress, St = tangential stress, a = outside radius of wheel, b = inside radius of wheel, r = distance from center of wheel, P = contact pressure between outer wheel and hub, E = Young's modulus and ν = Poisson ratio. And the radial displacement and radial and tangential stress of the inner radius for the cylindrical shell under uniform outer radial pressure is determined from eq. (4)~(6), respectively.

$$\Delta c = -(Pc/E)\left[\left(c^2+d^2\right)/\left(c^2-d^2\right)-\nu\right] \quad (4)$$

$$Sr = -Pc^2\left(r^2-d^2\right)\left[r^2\left(c^2-d^2\right)\right] \quad (5)$$

$$St = -Pc^2\left(d^2+r^2\right)\left[r^2\left(c^2-d^2\right)\right] \quad (6)$$

Where Δc = radial displacement of hub, c = outside radius of hub, b = inside radius of hub.

The contact pressure can be determined by equaling the shrink fit and the mechanical tolerance to the difference between the radial displacement of the inner radius for the outer wheel and the radial displacement of the outer radius for the hub due to the contact pressure between the outer wheel and the hub. The stresses may be calculated from eq. (2), (3), (5) and (6) by inserting the contact pressure. Similarly, the stresses can be calculated due to the shrink fit between the hub and the shaft. The radial and tangential stresses due to the shrink fit between the outer wheel and the hub and that between the hub and the shaft are superposed to calculate total radial and tangential stresses due to the total shrink fit.

Eq. (7) and (8) shows the radial and tangential stresses due to rotation.[3] The total stresses is determined by superposing the stresses due to the shrink fit and the rotation.

$$Sr = (1/8)(3+\nu)(\rho/g)\omega^2\left[a^2+d^2-a^2d^2/r^2-r^2\right] \quad (7)$$

$$St = (1/8)(\rho/g)\omega^2\left[(3+\nu)\left(a^2+d^2+a^2d^2/r^2\right)-(1+3\nu)r^2\right] \quad (8)$$

Where ρ = density, g = gravity and ω = angular velocity.

2.3 Method to calculate the critical speed

The joint release speed shall be equal to or greater than 150% of the normal operation speed. The joint release speed is determined by increasing the speed until either the contact pressure between the hub and the shaft is negligible, or the contact pressure between the hub and the outer wheel is negligible.

The critical speed for ductile fracture can be conservatively determined as the speed at which the maximum stress reached 0.7 times the ultimate stress.[4]

To determine the critical speed for non-ductile fracture, the stress intensity factor can be the calculated from the stresses computed section 2.2. The highest tensile stress is located on the inner radius of the outer wheel so that the stress distribution from this point toward the outer direction of the outer will can be represented by the forth order and the stress intensity factor due to this stress is calculated.[4] The critical speed for the non-ductile fracture is the rotation speed to reach the minimum stress intensity factor of 165 MPa $m^{1/2}$ which is the minimum requirement value for RCP flywheel[1]. The initial crack size is assumed as 0.5 inch.

The critical speed for excessive deformation can be conservatively estimated by determining the speed at which the maximum stress reached the yield stress.

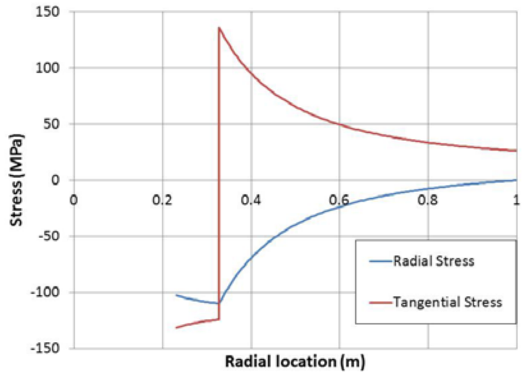
3. Effect of the shrink fit and mechanical tolerance

The shrink fit should be larger than the radial displacement due to the joint release speed and the shrink fit makes the stress at the standstill condition. The stresses at various speeds can be determined by superposing the stresses due to the rotation on these due to the shrink fit as shown in Fig. 2. The stress at the interface between the hub and the outer wheel shows the highest value. The stress due to the rotation is increased in proportion to the rotation speed.

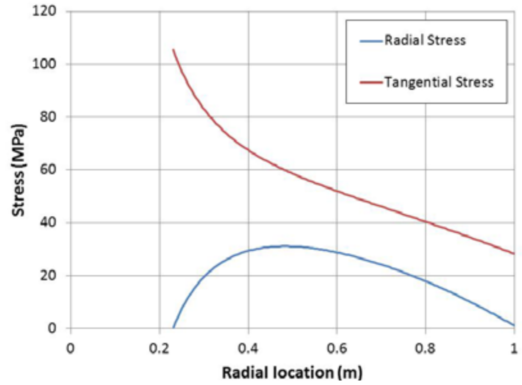
To minimize the stresses of the flywheel, the shrink fit can be determined by the joint release speed. The shrink fit is increased in proportion to the square of the joint release speed, and the contact pressure and the stresses due to the shrink fit are proportional to the shrink fit. Therefore, the shrink fit should be determined by the joint release speed and the stresses in the flywheel will be increased by the shrink fit.

If the stresses at the various speeds are not satisfied for the acceptance criteria, the material and/or the geometry of the flywheel should be changed.

The mechanical tolerance is determined from the manufacturing skill. The effect of the mechanical tolerance on the stresses can be considered by adding it to the shrink fit for the radial displacement. If the mechanical tolerance is considered, the stresses due to the shrink fit will be large. Therefore, the effect of the mechanical tolerance should be considered for the stress evaluation. And the effect of the mechanical tolerance should be not considered to determine the joint release speed. To decrease the stresses of the flywheel, the flywheel should be manufactured with the lower mechanical tolerance.



(a) stresses due to the shrink fit



(b) Stresses due to the rotation

Fig. 2 Stresses due to the shrink fit and rotation.

4. Conclusions

The shrink fit should be determined by the joint release speed and the stresses in the flywheel will be increased by the shrink fit. The stress at the interface between the hub and the outer wheel shows the highest value. The effect of the mechanical tolerance should be considered for the stress evaluation. And the effect of the mechanical tolerance should be not considered to determine the joint release speed.

REFERENCES

[1] US Nuclear Regulatory Commission Standard Review Plan, NUREG-0800, Section 5.4.1.1, Rev. 3, "Pump Flywheel Integrity (PWR)," May 2010.

[2] US Nuclear Regulatory Commission Regulatory Guide 1.14, Rev. 1, "Reactor Coolant Pump Flywheel Integrity," August 1975

[3] Young, Warren C. and Richard G. Budynas, "Roark's Formulas for Stress and Strain," Seventh Edition, McGraw-Hill Companies, Inc., New York, NY, 2002.

[4] API 579-1/ASME FFS-1, "Fitness-For-Service," Annex C, "Compendium of Stress Intensity Factor Solutions," June 5, 2007.