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STRESS ANALYSIS AND LIFE ASSESSMENT OF ROTOR AND RETAINING RING OF GENERATOR FOR FOSSIL POWER PLANT

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Key Words : Generator, Rotor, Retaining Ring, shrink-fit, End Winding, FEM(finite element analysis), SCC(stress corrosion cracking), SCF(stress concentration factor), LEFM(linear elastic fracture mechanics)

ABSTRACT

In addition to the higher centrifugal forces during normal operation in 3600 rpm, a generator rotor body is subjected to the contact pressures from shrink-fit between generator rotor and retaining ring. To obtain the structural reliability and life assessment of the generator, the finite element models were developed and structural analyses were carried out. The stress distributions and the critical locations of the rotor body were identified. Further, the fatigue life is performed to estimate the remaining life of generator. The critical crack size and probability of failure are also evaluated based on the analysis results. The critical sizes of a crack of generator are predicted using linear elastic fracture mechanics. These results will be applied to the development of a larger 1000MW capacity generator.

INTRODUCTION

In rapid technology advancement of the fossil power plant, it is inevitable that the output of a given turbine generator frame size will be increased from time to time. This has required redesign of the generator to keep pace with the increased rating. For turbine generators, increased rating presents challenges for designer. The designers to ensure that the new design can be satisfied the performance capabilities and electrical rating requirements, while maintaining mechanical, thermal and magnetic limits. These challenges come out largely as a result of increasing stresses, vibrational instability, fatigue and stress corrosion crack. To obtain the structural reliability and life assessment of the new generator, stress analyses, fatigue life assessment, and critical crack evaluation are required and the finite element analysis for the generator rotor assembly is used for this purpose.

Increased rating of the generator capacity can be achieved by either increasing length or diameter of generator rotor body. Increasing the length of the rotor diameter should ensure the dynamic stability. On the other hand, increasing rotor diameter should satisfy the strength limit of current rotor material.

This paper presents both stress analysis and life assessment results of the new 1000MW generator rotor assembly. The baseline design of the 800MW generator rotor was also evaluated for verifying the reliability of the analysis results. Two load cases, the contact pressures from shrink-fit between rotor and retaining ring and the centrifugal forces during normal operation in 3600 rpm, were considered.

To obtain the structural reliability and life assessment of the generator, the finite element models were developed and structural analyses were carried out. The stress distributions and the critical locations of the rotor body were identified. Further, the fatigue life is performed to estimate the remaining life of generator. The critical crack size and probability of failure are also evaluated based on the analysis results

THE STRUCTURE OF ROTOR AND RETAINING RING

Structure of rotor

Generator rotor is classified with 2 Pole and 4 Pole. 2 Pole is applied at fossil power plant and 4 Pole is applied at nuclear power plant. The pole geometry, number of slot, diameter and length influence the electrical capacity of generator. The generator structure is represented at Figure 1.

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Structure of retaining ring

Retaining ring is used for sustaining the end-winding of copper bar, which is extruded from the rotor, at the end part of rotor. Retaining ring is shrunk-on the rotor.

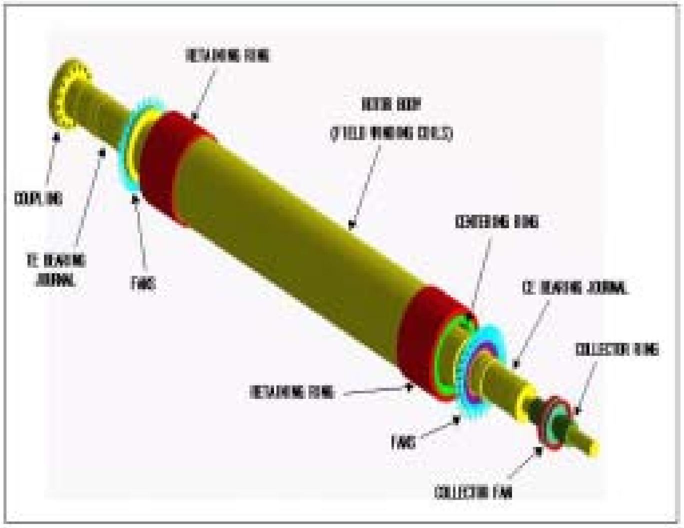

Figure 1: Generator structure.

Material properties of rotor and retaining ring

Generator rotor is used as the forged steel. Generally, the rotor material properties are specified in ASTM 470, Class 4. Retaining ring is manufactured from 18Mn-5Cr steel and 18Mn-18Cr steel. Due to the stress corrosion cracking 18Mn18Cr steel is currently used

LOADS OF GENERATOR AND RETAINING RING

Rotor loads

The generator rotor is under the centrifugal forces of self weight, copper bar and wedge in 3600 rpm operation. At standstill there is shrink-fit pressure.

Retaining ring loads

Retaining ring is influenced by the tangential stress and axial stress during operation and at standstill. There are two causes of tangential stresses during operation. The tangential stress duo to centrifugal force by self weight is 75% and the tangential stress by copper winding is 25%. If end windings are not uniformly distributed or the geometry of retaining ring changed to oval shape, the bending stress occurred. Generally, Retaining ring is designed under 70% of tensile strength in case that retaining ring operates at 20% overspeed. Load distributions are displayed at the Figure 2.

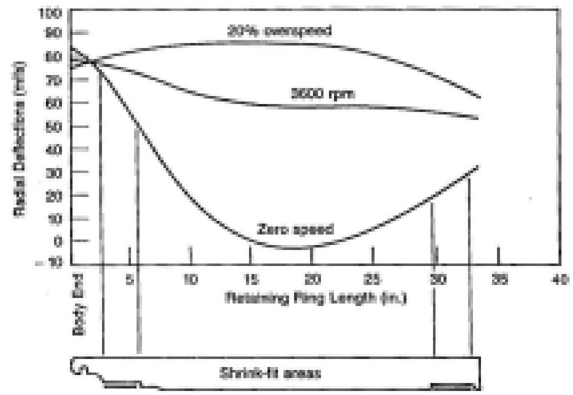

Figure 2: Load distribution of retaining ring.

FEM MODEL

In order to analyze the stress distribution of generator and retaining ring. 2D, 3D and 3D Full-model is created for the generator rotor. Retaining ring is included in 3D model.

The generator geometry of 2D cross-section and FEM Model are displayed at Figure 3. The copper winding, which supplies the current into generator rotor, is sustained by wedge and rotor tooth. The geometry and FEM model of rotor tooth are represented at Figure 4. The geometry and FEM model of end part of generator are displayed at Figure 5. The FEM full-model for generator is displayed at Figure 6.

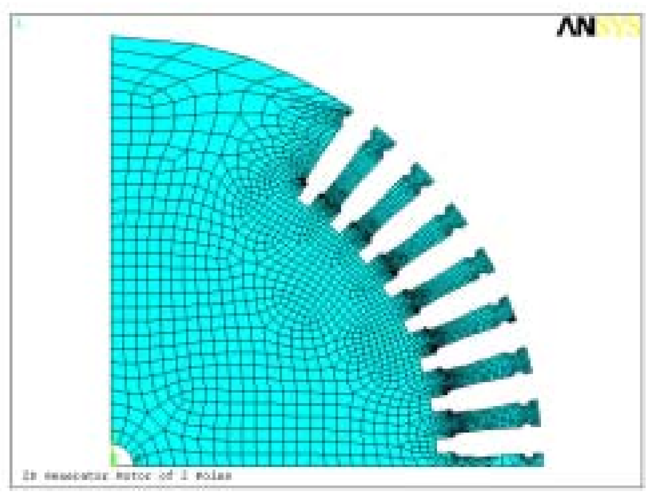

Figure 3: 2D FEM model of rotor.

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Figure 4: FEM model of rotor tooth.

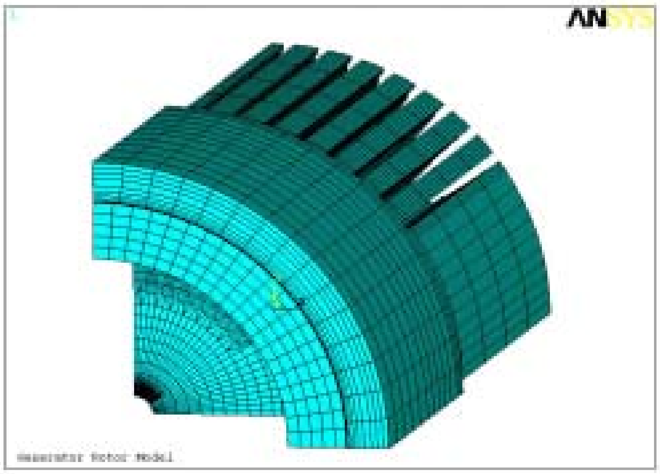

Figure 5: FEM model of rotor and retaining ring.

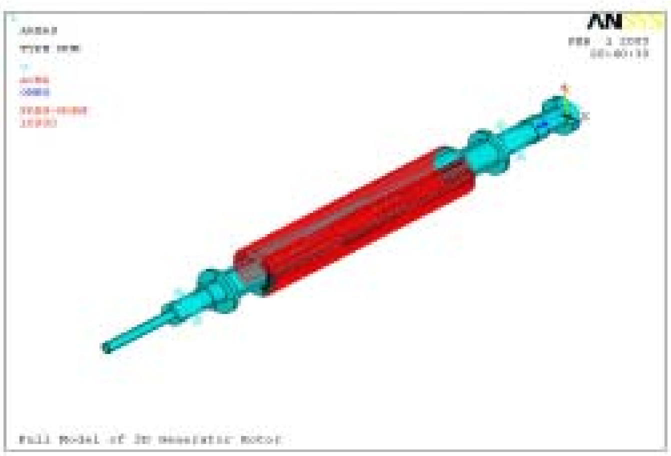

Figure 6: Full-model of rotor.

ANALYSIS RESULTS

2D stress analysis of generator rotor

The geometry type of generator rotor is decided by the electrical capacity of generator. Therefore, design variables are used as diameter, number of slot, pole angle and so on. Figure 7 represents the stress analysis results in case that diameter is 46.6 inches, the number of slot is 8 and rotation speeds are 1000, 3000, 3600 and 4320 rpm

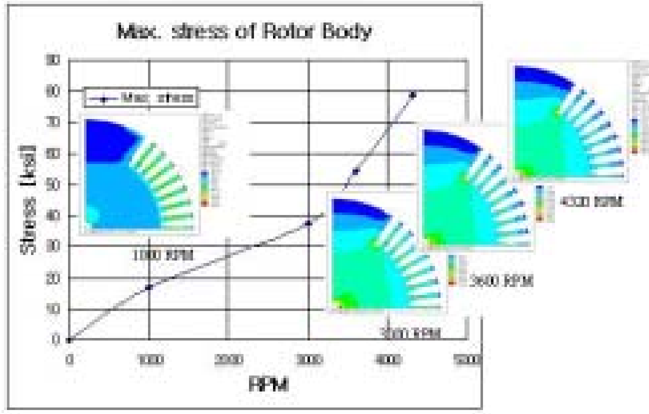

Figure 7: 2D Stress analysis result of rotor.

Figure 8 represents the stress analysis results in case that the number of slot is 8 and diameters of rotor are 41.94, 46.6 and 56.6 inches.

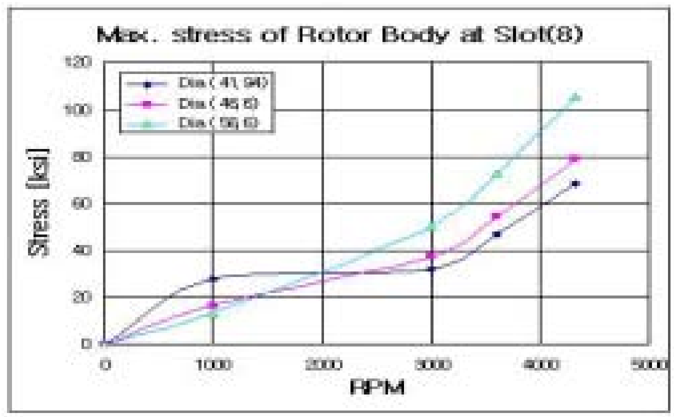

Figure 8: 2D Stress analysis of 8 slot rotor.

Figure 9 represents the stress analysis results in case that the diameter is 46.6 inches and the numbers of slot 6, 8 and 9.

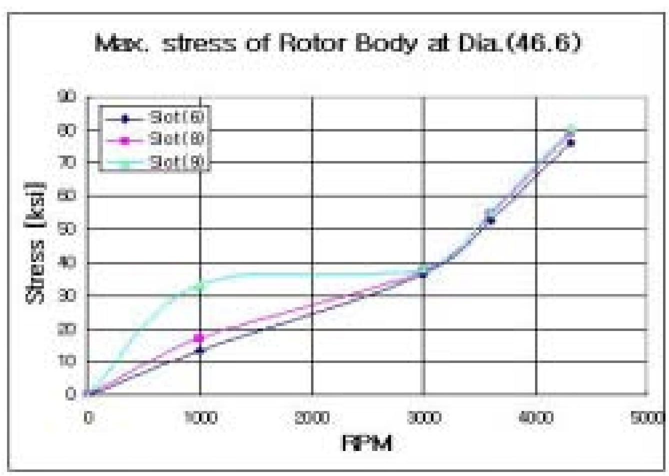

Figure 9: 2D Stress analysis of rotor (46.6 in).

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2D stress analysis of generator slot

The stress analysis results of rotor tooth, which the diameter is 46.564 inches and fillet radii are 0.05, 0.1 and 0.2 inches, are displayed at Figure 10 and Figure 11. The centrifugal force is applied by self-weight of tooth on 3600 rpm and the additional force due to copper bar replaced with the pressure in 10,000psi.

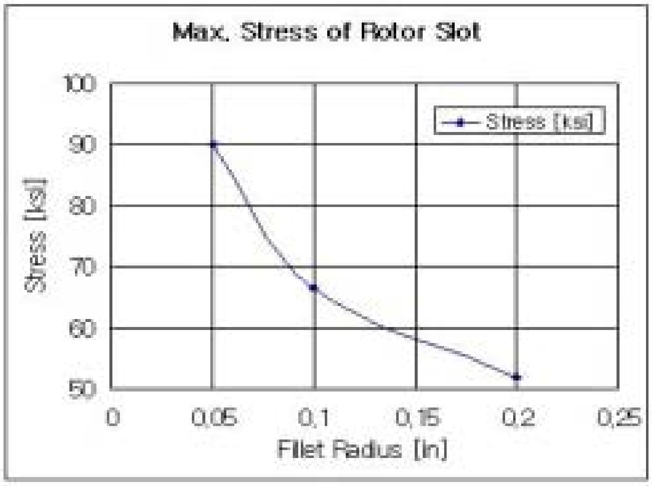

Figure 10: Tooth stress analysis of rotor.

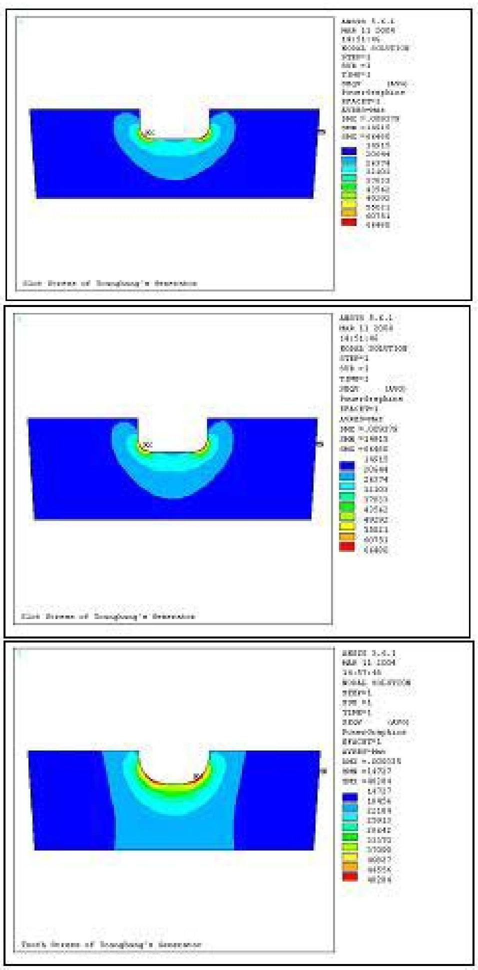

Figure 11: Stress analysis of sub-slot.

3D stress analysis of generator and retaining ring

The generator for analysis model applies at a large fossil power plant of 400MW. Outer diameter is 41.25in, Total length is 454.5 in and the length of part which copper bars wind is 198 in. The outer diameter and length of retaining ring are 44.95in and 27.456in. The analysis conditions of 3D FEM is following like table 1. Calculated results are Von Mises, Radial and Circumferential stresses.

Table 1: 3D Stress analysis conditions

	rotor+rr	rr+cr	unit
Shrink-fit	120	75	[mils]
Contact stiffness	0.5	0.5	
Penetration tolerance	0.5	0.5	

3D stress analysis results for 8 slot rotor are represented from Figure 10 to Figure 12.

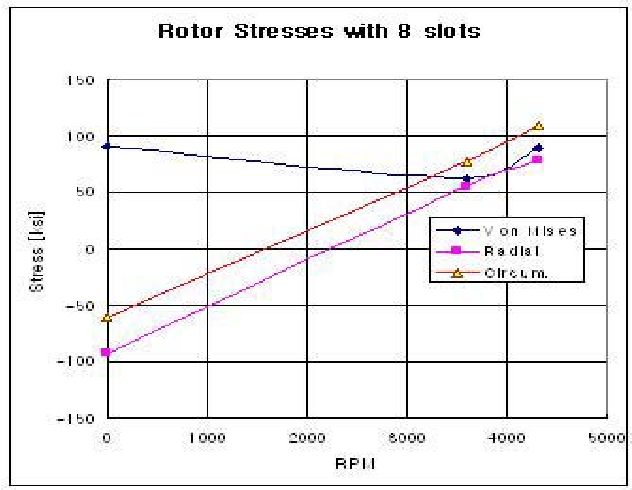

Figure 10: 3D Stress analysis of 8 slot rotor.

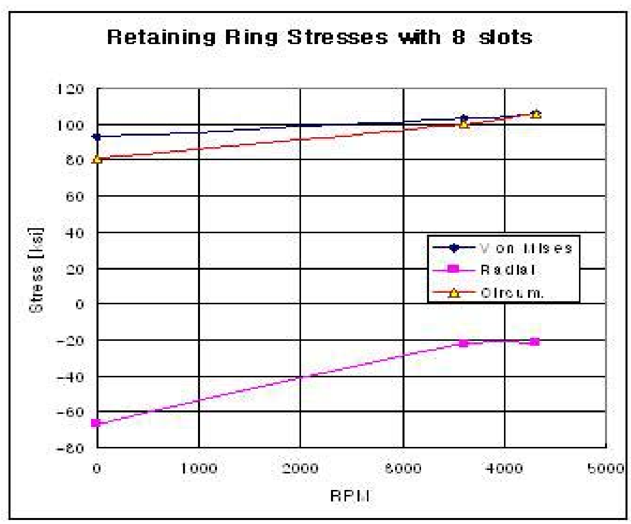

Figure 11: 3D Stress analysis of 8 slot retaining ring.

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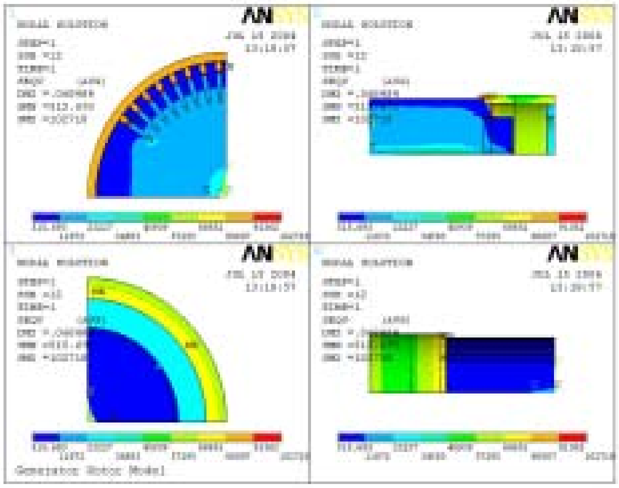

Figure 12: 3D Stress analysis of 8 slot rotor in 3600 rpm.

3D stress analysis results for 10 slot rotor are represented from Figure 13 to Figure 15.

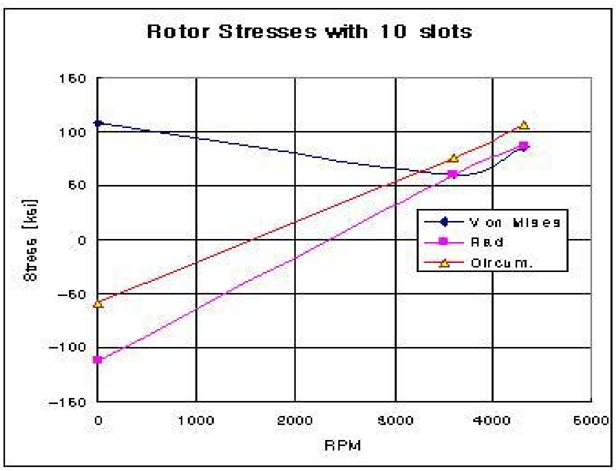

Figure 13: 3D Stress analysis of 10 slot rotor.

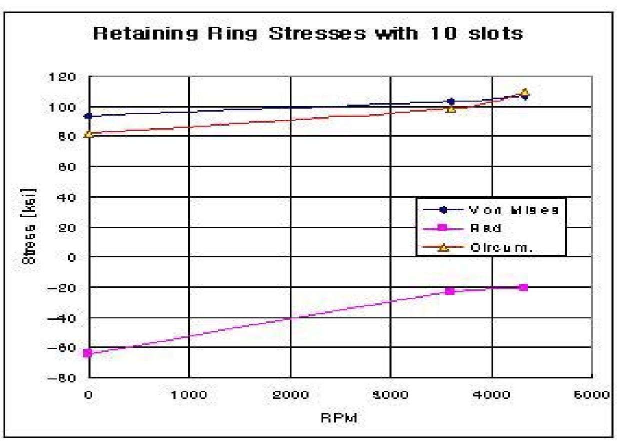

Figure 14: 3D Stress analysis of 10 slot retaining ring.

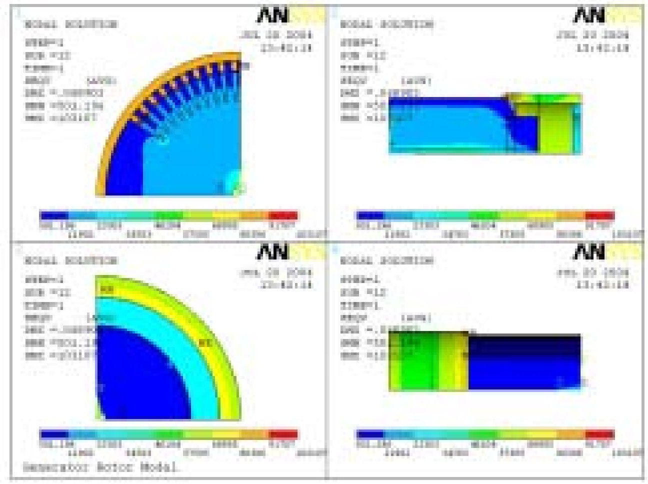

Figure 15: 3D Stress analysis of 10 slot rotor in 3600 rpm.

Figure16 represents the deflection for 8 slot rotor. The deflection is 0.0275 in. It is within the design limit of 0.03 in.

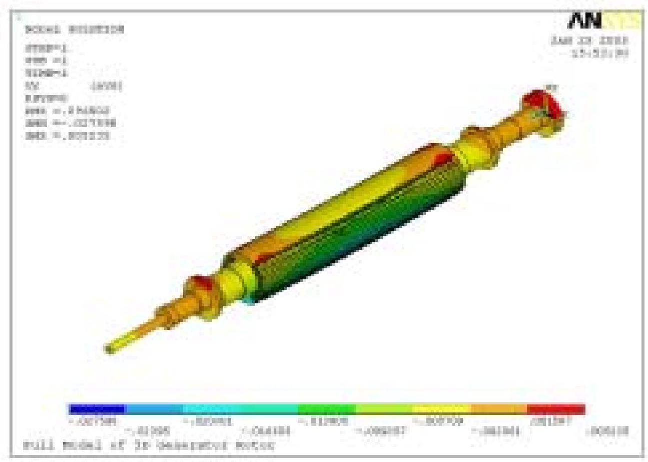

Figure 16: 3D Full-model deflection of 8 slot rotor.

FATIGUE LIFE OF GENERATOR ROTOR

The fatigue life is evaluated by fatigue life curves of generator materials, which is displayed at Figure 17, for the start-stop and operation mode of power plant. Generally, the design life of generator components is on the base of 40,000 cycles. The Figure 18 represents the strain results that rotor and retaining ring of 8 slot generator operate as 3600 rpm.

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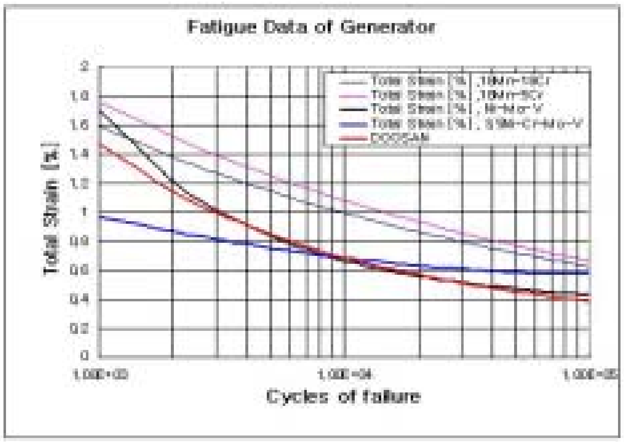

Figure 17: Fatigue life curves of generator materials.

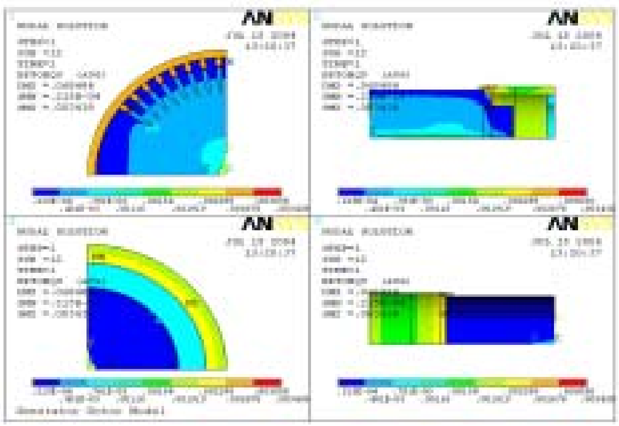

Figure 18: 3D Strain analysis of 8 slot rotor in 3600 rpm.

The analysis results show that both 8 slot and 10 slot are above 40000 cycles. Therefore, fatigue lives are satisfied. But in these analyses, non-uniform loads of copper winding, stress concentration effects and residual stress by shrink-fit are not considered.

CRACK ANALYSIS OF RETAINING RING

Critical size of a crack is evaluated from linear elastic fracture mechanics theory. Crack geometry is represented at Figure 19. For the conservative evaluation, Crack of retaining ring is assumed as a simple through crack on the internal surface of retaining ring.

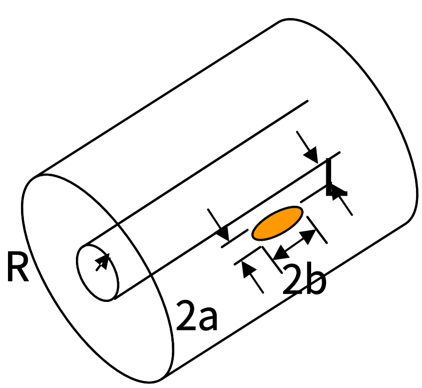

Figure 19: Crack geometry of retaining ring.

Crack growth rate of 18Mn18Cr steel represents at Figure 20.

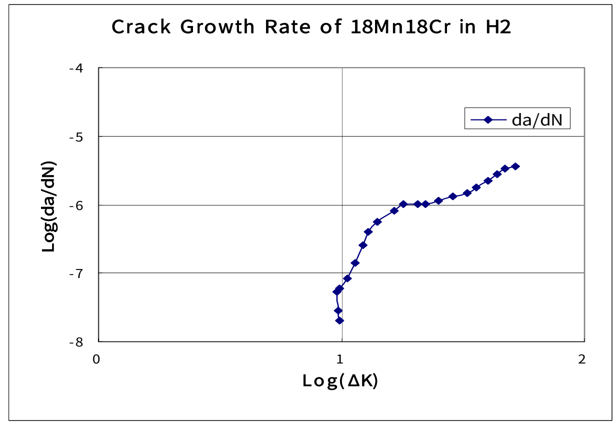

Figure 20: Crack growth rate of 18Mn18Cr.

Stress intensity factor (SIF) is obtained from LEFM. The SIF of a through crack is the following:

$$K = M\sigma\sqrt{\pi a} \qquad (1)$$

Where K is stress intensity factor, M is geometry factor, σ is the nominal stress and a is half length of a crack.
The crack growth rate of retaining ring is the following:

$$\left(\frac{da}{dN}\right) = C(\Delta K_I)^n \qquad (2)$$

Where C is 2.82E-10 and n is 2.51.

If the retaining ring has a through crack of 1 inch, the critical crack length is 3.8 inches. When the start-stop operation reaches 20000 cycles, the final crack length is 1.13 inches. The crack growth is represented at the Figure 21.

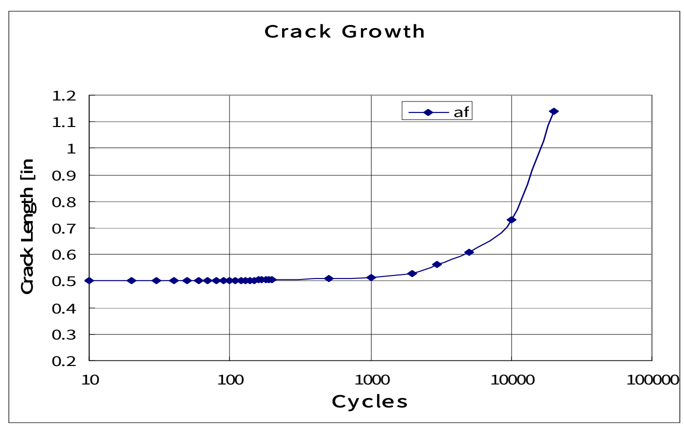

Figure 21: Crack growth in retaining ring.

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CONCLUSION

In this paper, 2D and 3D FEM analysis are performed for the generator rotor and retaining ring and the fatigue life and crack analysis are evaluated. The stress results reach the design limit of generator material in case of 120% overspeed operation. The increase of fillet radius of sub-slot part of generator tooth reduces the stress concentration highly. And also the fatigue life satisfies the 40,000 cycles of design limit. From the LEFM theory, crack growth are calculated under the critical size of a crack

But the shrink-fit results between rotor and retaining ring are analyzed in spite of the effect of residual stress due to thermal heating and cooling. The non-uniform load distribution of copper winding causes the oval shape of retaining ring and vibrates irregularly.

By carrying out this investigation, three major goals have been achieved:

1) To reduce the stress concentration of sub-slot part of generator tooth, Fillet radius is over 0.2 inches.
2) From 3D and Full-model analysis, the stress results are under the design limit and the fatigue life satisfies the 40,000 cycles.

From LEFM analysis, a through crack is under the critical size (3.8 inches).

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