Effect of Ovality on Maximum External Pressure of Helically Coiled Steam Generator Tubes with a Rectangular Wear

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1. Introduction

Recently, there is on-going effort that is developing advanced integral reactor which contains the main components, i.e., steam generator, reactor coolant pump and pressurizer, in the reactor vessel. Especially, helically coiled tubes are adopted to improve the thermal efficiency of the integral reactor's steam generator. In this steam generator, the primary coolant with relatively higher pressure flows down along the outside of tubes while the secondary coolant with relatively lower pressure flows through the inside of tubes, which means external pressure acts on the steam generator tube and it should be considered to ensure the safety of steam generator.

A structural integrity of steam generator tubes of nuclear power plants is one of crucial parameters for safe operation of nuclear power plants. Thus, many studies have been made to provide engineering methods to assess integrity of defective tubes of commercial nuclear power plants considering its operating environments and defect characteristics [1, 2]. As described above, the geometric and operating conditions of steam generator tubes in integral reactor are significantly different from those of commercial reactor. Therefore, the structural integrity assessment of defective tubes of integral reactor taking into account its own operating conditions and geometric characteristics, i.e., external pressure and helically coiled shape, should be made to demonstrate compliance with the current design criteria [3]. Also, ovality is very specific characteristics of the helically coiled tube because it is occurred during the coiling processes. The wear, occurring from FIV (Flow Induced Vibration) and so on, is main degradation of steam generator tube.

In the present study, maximum external pressure of helically coiled steam generator tube with wear is predicted based on the detailed 3-dimensional finite element analysis. As for shape of wear defect, the rectangular shape is considered. In particular, the effect of ovality on the maximum external pressure of helically coiled tubes with rectangular shaped wear is investigated.

2. Geometry and Finite Element Analysis

In the present paper, helically coiled steam generator tube with rectangular shaped wear is considered. The ratio of the outer diameter (D_o) to the thickness (t) is 6.7.

Table I: Summary of geometries considered in the present work

Defect depth (d/t)	Defect length (l, mm)	Wrap angle (θ, deg.)	Ovality (W)
0.1, 0.3, 0.5, 0.7, 0.9	5, 15, 30	45, 90, 180	0.025, 0.05, 0.08

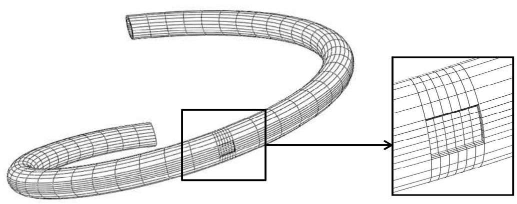

Fig. 1. Typical FE meshes employed in the present work

The shape of the rectangular shaped wear is characterized by the depth, length and wrap angle along the circumference of tube. For loading condition, external pressure is considered. As mentioned above, during coiling process of steam generator tube, the ovality could be inherently generated in the tube, which is defined as follows [4].

$$W = \frac{D_{o,\max} - D_{o,\min}}{D_o} \quad (1)$$

where, $D_{o,max}$ and $D_{o,min}$ denote the maximum and minimum outer diameter, respectively, and W is ovality tolerance.

Table 1 summarizes geometries considered in the present work.

Fig. 1 depicts the typical FE mesh employed in the present work. The general-purpose FE program, ABAQUS [5] was used. Material was assumed to be elastic-perfectly plastic, and reduced integration 20-nodes brick elements (C3D20R in ABAQUS element library) were used to avoid problem associated with incompressibility. The wear defect is assumed to be located in the extrados of helically coiled tube.

As for the loading condition, external pressure was applied as distributed load to the outer surface of tube. In addition, due to the convergence problem in elastic-perfectly plastic calculations for calculating maximum pressure, the modified RIKS option within ABAQUS was invoked, from which values of the maximum external pressure of tube with rectangular shaped wear

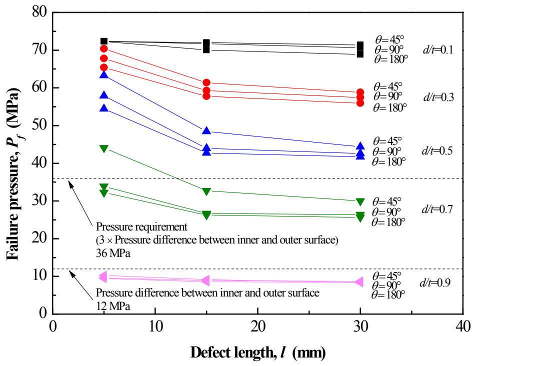

Fig. 2. Variation of maximum external pressure according to defect depth, defect length and wrap angle.

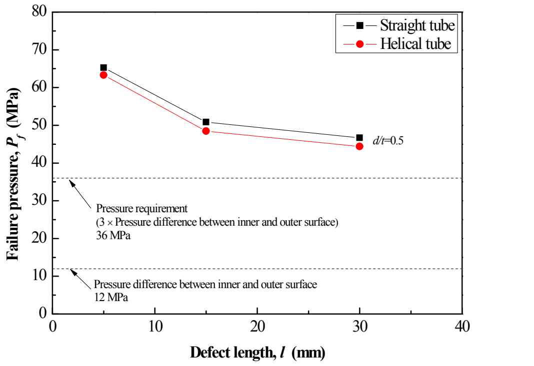

Fig. 3. Comparison of the maximum external pressures from straight tube with those from helical tube

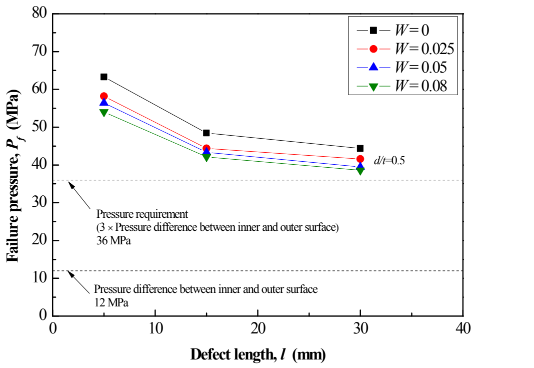

Fig. 4. Effect of ovality on maximum external pressure

can be easily calculated by using the RIKS factor provided by FE analysis. In terms of boundary conditions, both ends of FE model were fully constrained. As a material, the titanium alloy was employed and the properties at the high temperature (350℃) were used.

3. Results

Fig. 2 shows variations of maximum external pressure of helically coiled tube with rectangular shaped wear. The allowable pressure in accordance with the current condition monitoring and operational assessment guideline is also given in Fig. 2.

As shown in Fig. 2, it is revealed that the maximum external pressure of helically coiled tube with rectangular shaped wear is highly affected by the depth of wear. On the other hand, the effect of wrap angle on maximum external pressure is negligible for the case of d/t=0.1 and 0.9. Furthermore, when the wear length is long, the wrap angle of rectangular wear has little or no effect on the maximum external pressure.

As described above, one of the governing criteria for a degraded steam generator tube is the normal operating differential pressure requirement. When considering margin of three against the normal operating differential pressure [3], wear depths within ~70% of thickness of tube seem to maintain the structural integrity of tube in the operating condition.

Fig. 3 compares the FE values of maximum external pressure from helically coiled tube with those from straight tube. In this analysis, the values of wear depth (d/t) and wrap angle are fixed to be 0.5 and 45°, respectively. As shown in Fig. 3, the maximum external pressures based on the helically coiled tube are slightly lower than those based on the straight tube.

Fig. 4 shows the effect of tube ovality on maximum external pressure of helically coiled tube with rectangular shaped wear. As the values of ovality increase to W=0.08, the maximum external pressure decrease by 16 % for the case considered in the present work.

4. Conclusion

In the present work, the maximum external pressure of helically coiled steam generator tube with rectangular shaped wear is investigated via detailed 3-D FE analyses. In order to cover a practical range of geometries for defective tube, the variables affecting the maximum external pressure were systematically varied.

In particular, the effect of tube ovality on the maximum external pressure is evaluated. It is expected that the present results can be used as a technical backgrounds for establishing a practical structural integrity assessment guideline of helically coiled steam generator tubes of integral reactor.

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