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Dynamic Characteristics of Steam Generator Tubes with Defect due to Wear

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1. Introduction

Steam generator tubes are subject to flow-induced vibration due to various mechanisms such as vortex shedding, random turbulence and fluid-elastic instability during operation [1]. Hence wears or cracks can be formed on the surface of tubes, especially at the contact region with anti-vibration bars or tube support plates. These defects may affect the dynamic characteristics of tubes, and therefore, the vibrational behavior of the tube due to flow-induced loads can be varied. Change in the vibrational response of a tube may result in different wear characteristics from the design condition, which must be checked for both safety and economic point of view. This paper deals with the study on the effect of wears or cracks on the dynamic characteristics of steam generator tubes using finite element analysis.

2. Finite Element Model of Steam Generator Tube

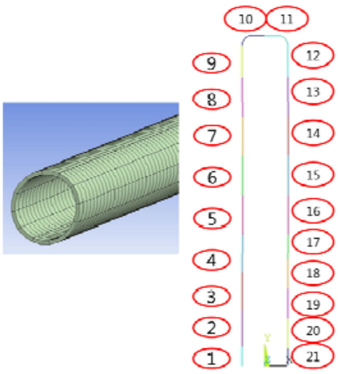

Fig. 1. Finite element model of steam generator tube (Row number 41 of OPR-1000)

Fig. 1 shows the finite element(FE) model of row # 41 tube of OPR-1000 steam generator. It is composed of 21 spans. Each span has different density due to the different added mass effect. Total height of the tube and width are 332.875 and 46 inches, respectively. The outer diameter is 0.75 inch and thickness is 0.042 inch.

As the boundary conditions of the FE model, the tube is supported by the tube support plates at the elevation between spans. Bottom surface of the two lowest spans, which are span 1 and 21, are clamped to simulate the connection between the tube and the tube sheet tube. Constraint to vertical direction is applied to the uppermost span 10 and 11. Along the circumferential and radial directions 15 and 1 elements are formed, respectively. The number of total nodes and elements of the FE model are 355,216 and 53,501, respectively.

3. Modeling of Tube with Defects

In order to observe the effect of defects due to wear on the dynamic characteristics, various wears were assumed. First, 0.375 inch diameter hole was assumed to exist at the middle area of the curved area between spans 9 and 10, and also between spans 11 and 12. Two different cases were considered: a hole is formed on one side, and two holes are formed on two opposite sides. Fig. 2 shows the FE model including a penetration on one side.

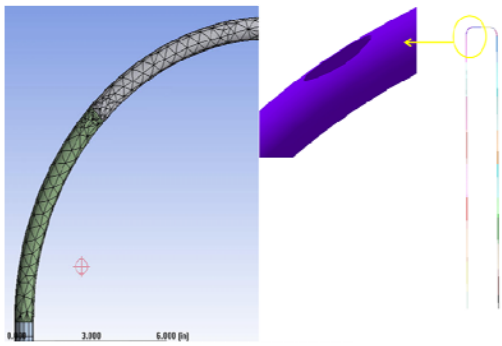

Fig. 2. Finite element model of the tube having wear near the contact location with the diagonal strip

As the second case the defect due to wear was approximated by decreasing young's modulus to half. This approach was applied to one of the spans from span 8 to 13.

As the third case, cracks were supposed. In more detail, an inner crack in the left side was assumed. Then as the next case, an outer crack in the left side was assumed. For the third and fourth cases inner and outer cracks on both sides were assumed. All cracks were assumed to be as big as half of the diameter of the tube.

4. Analysis Results: Change of Dynamic Characteristics of Steam Generator Tube

Fig. 3 compares the variation of natural frequencies due to the penetration holes on one or both sides. In general, the natural frequencies of the tube having holes decrease maximum about 7% compared to the normal intact tube. For higher mode, *e.g.*, 8th mode, the defective tube has a slightly higher natural frequency. For the calculation of flow-induced vibration (FIV) responses lower modes are more influential, therefore, this variation should be considered in the FIV analysis.

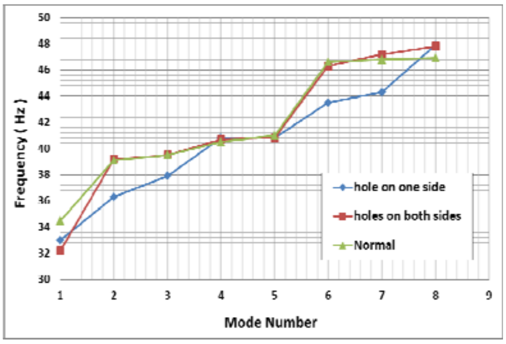

Fig. 3. Variation of natural frequencies of the tube having penetration holes at curved span

Fig. 4 shows the variation of natural frequencies when half young's modulus is applied for different spans. This also shows the similar trend in the change of dynamic characteristics in Fig. 3, and for the 1st mode the variation is about 8% decrease, therefore, the re-evaluation of the FIV response calculation is necessary.

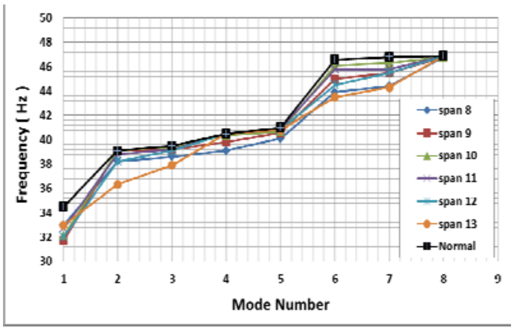

Fig. 4. Variation of natural frequencies of the tube having reduced elastic modulus for spans 8 through 13

Fig. 5 presents the variation of natural frequencies of the tubes with cracks at the spans 8 and 13. The cracks were assumed to exist at inner or outer surfaces on either or both sides. Fig. 5 tells the effect of crack on the natural frequencies is very small, and this seems a contradiction to one's expectation. More detailed analysis for different location of the cracks needs to be performed.

On the other hand, mode shapes were revealed not to be very sensitive to the defects. For example, Figs. 6 and 7 compares two mode shapes sets for normal tube and cracked tube, which look basically the same. More detailed analysis using quantitative measures to compare these mode shapes is to be performed.

5. Conclusions

In this paper the effect of defects on the surface due to wear on the variation of dynamic characteristics of

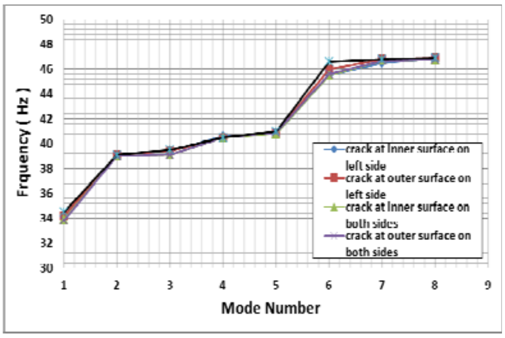

Fig 5. Variation of natural frequencies of the tube having cracks

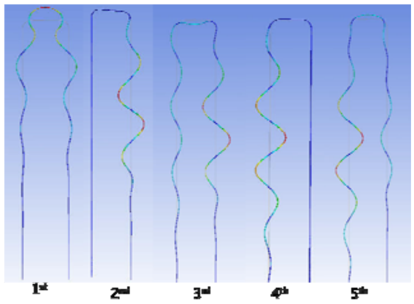

Fig. 6. Mode shapes of intact tube

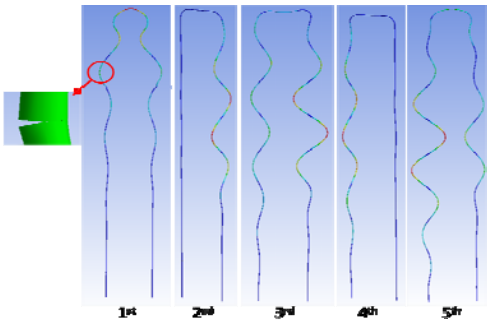

Fig. 7. Mode shapes of tube having outer crack on one side

steam generator tubes was studied using the finite element analysis. The changes of natural frequencies and mode shapes can directly affect the flow-induced vibration response characteristics, therefore, they must be evaluated appropriately. The results in this study can be a good basis to estimate the FIV characteristics of the steam generator tubes having defects such as wear or crack.

Acknowledgement

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References

[1] Huinam Rhee, et al, "Development and application of an efficient method for performing modal analysis of steam generator tubes in nuclear power plants", Nuclear Engineering and Design, 240(10), pp. 3669-3676, 2010.