# Investigation of vibration wear of the steam generator tube bundles for OPR1000 nuclear power plant

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## 1. Introduction

Both nuclear and thermal power plants are types of steam power plants. These power plants generate electricity by utilizing thermal energy, which is produced by burning fuels such as coal, gas, or nuclear fuel. This thermal energy is converted into mechanical energy with the help of steam, which acts as a medium for transferring thermal energy to mechanical energy. Therefore, steam generators are critical components in power plants that utilize thermal resources. In particular, nuclear power plants have two primary and secondary systems to ensure nuclear safety [1]. Heat is transferred from the primary to the secondary system, generating steam. Thus, maintaining the integrity of steam generator tubes is essential for the safety and efficient operation of nuclear power plants [2].

As high-temperature steam passes through the tubes, it transfers thermal energy to the surrounding coolant. The flow inside and around the tubes induces vibrations, which can lead to wear or damage to the tubes. Therefore, investigating the vibrations of steam generator tubes is crucial for predicting and assessing wear. To address this, various experimental and numerical studies have been conducted. In this study, we investigated the key factors influencing wear in nuclear power plant steam generator tube bundles by using computational fluid dynamics (CFD) and finite element analysis (FEA).

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## 2. Materials and Methods

In this study, the results of computational fluid dynamics analysis performed on the steam generator were utilized to calculate the load applied to each steam generator heat pipe. The computational fluid dynamics analysis was performed using the commercial analysis code Siemens Simcenter STAR CCM+, and the flow analysis was performed under normal operating conditions, considering the steam generator of the OPR1000 reactor (Fig. 1).

Using the calculated flow rate, the PSD (power spectral density) values of the turbulent load for each heat pipe were calculated (Fig. 2). The calculated PSD loads were recalculated as time history loads, and these were applied as distributed loads on the upper part of the finite element model of each heat pipe developed using beam elements to analyze the behavior of the heat pipes. The heat pipes were developed using beam elements, but the added mass due to the heat pipe and the fluid inside and outside was considered. Accordingly, the density of the material was redefined and used. In addition, since the heat pipe vibrates in water, it is subject to structural damping and the surrounding fluid's damping. Therefore, the damping due to the flow was calculated and considered together. In this study, the dynamic behavior of the heat pipes was analyzed for a total of 10 seconds, and the finite element analysis was performed using the implicit finite element analysis code Abaqus/Standard.

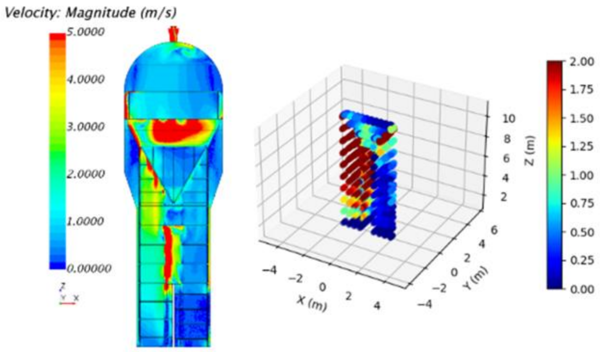


Fig. 1 Predicted fluid flow in the steam generator and distribution of the flow velocity.

*Upstream* *Interior*

$$V = 500\ mm/s$$
$$D = 17\ mm$$
$$L = 249\ mm$$
$$\rho = 1.0e-9\ ton/mm^3$$

Upstream: $C_R(f) = 0.108 \cdot 10^{-0.0159f}$ (if f > 40); $C_R(f) = 0.025\ (otherwise)$

Interior: $C_R(f) = 0.054 \cdot 10^{-0.0159f}$ (if f > 40); $C_R(f) = 0.0125\ (otherwise)$

$$G(f) = \left[C_R(f) \cdot \frac{1}{2}\rho V^2 D\right]^2 \quad \textit{Turbulent force per unit length}$$

Fig. 2 Calculation of the power spectral density of random excitation force on the tube

## 3. Results

Changes in the stress on the tube bundles were investigated via finite element analysis (Fig. 3). The impact load and frequency caused by the contact between the support and the steam generator tube were also predicted. The most significant impact load and vibration frequency were predicted in the tubes of column 73 and row 84, which can be considered the relatively inner tube. Also, approximately five impacts were expected during the analysis time of 10 seconds (Fig. 4 and 5).

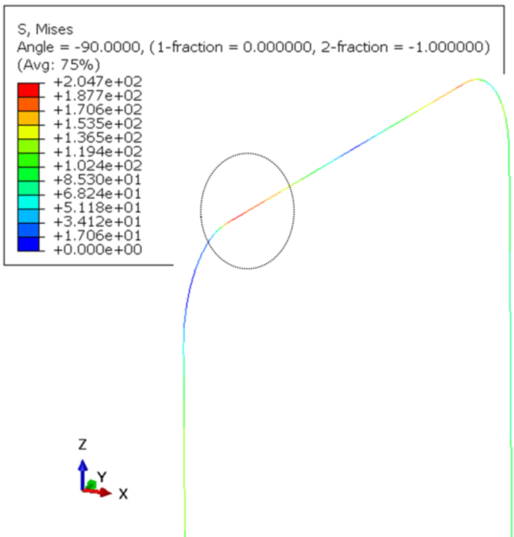


Fig. 3 Von-Mises stress distribution on the steam generator tube at column 73 and row 84.

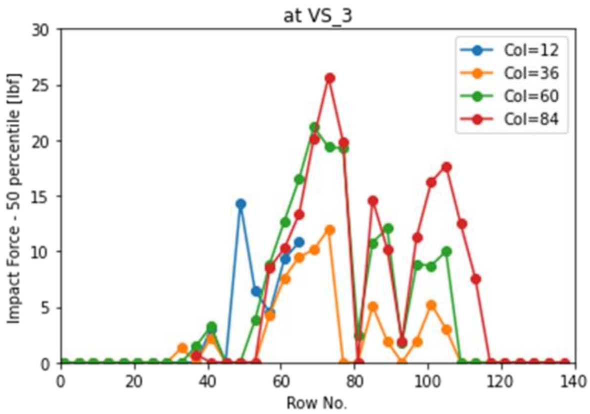


Fig. 4 Predicted contact force between steam generator tubes and the third (middle) vertical strip

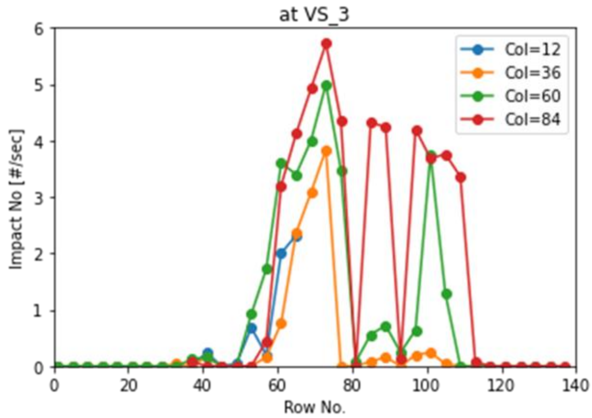


Fig. 5 Predicted the number of impact of steam generator tubes on the third (middle) vertical strip

## 4. Discussion and Conclusion

This study analyzed the dynamic behaviors of the steam generator tube bundles using nonlinear contact analysis. In previous studies, contact was simplified as pin restraint and studied. However, because contact is one of the major factors influencing tube wear, we believe that a nonlinear dynamic analysis method that considers contact should be utilized.

In this study, we analyzed the factors influencing steam generator tube wear. For the accurate prediction and estimation of the steam generator's wear, it is necessary to derive the optimal equation among various wear equations by comparing them with experiments and actual cases. The results of this study can be used as a basis for other studies, and we hope that they help improve predictions of wear similar to those of steam generator tube bundles.

## Acknowledgement

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