Development of Automatic Helical type Steam Generator Design Program for Small Modular Reactor

Juae Oh [a], Seongmin Chang [a*]
[a]*School of Mechanical Engineering, Chungnam National University, Daejeon 34134*
[*]*Corresponding author: schang@cnu.co.kr*

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1. Introduction

In recent years, nuclear reactor have been developed in the form of integrated small modular reactors (SMR) in which major devices such as steam generators, pumps, and generators are included in a single vessel. In order to reduce the size of these devices, the shape of the heat transfer tube is changing from a U-shape to a helical shape in order to reduce the size of the steam generator. However, the three-dimensional design of helical heat transfer tube is difficult, and design changes often occur in the development of new reactors. Therefore, this paper aims to develop an effective automatic design program for helical heat transfer tubes to simplify the design changes of complex three-dimensional designs. The developed program is configured to pre-test the contact (convergence) between the heat transfer tubes by inputting the dimensions of the design factors of the heat tubes, and to automatically run the three-dimensional design. In addition, it is planned to perform effective analysis and design not only for three-dimensional design, but also in integration with various reduction techniques such as fluid-structure interaction (FSI) analysis in the future [1-5].

2. Methods and Results

The developed design automation code was developed using the MALAB program, and the configuration of the heat transfer tube model is defined as a helical section and a transient section. The headers connecting the heat transfer tube to the steam generator vessel are located at the top and bottom, respectively, as shown below.

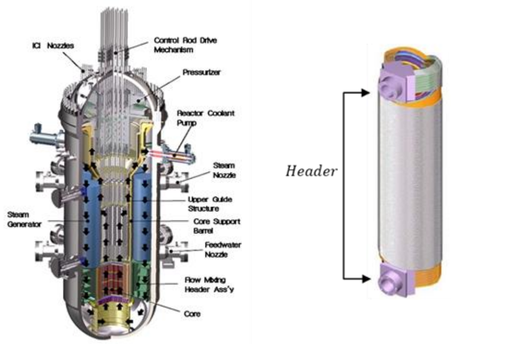

Fig 1. Internal geometry of small modular reactor and position of helical steam generator header [6, 7].

The coordinate planes (R-θ and Rθ-z) applied to the heat transfer tube design are defined as follows [Fig 2].

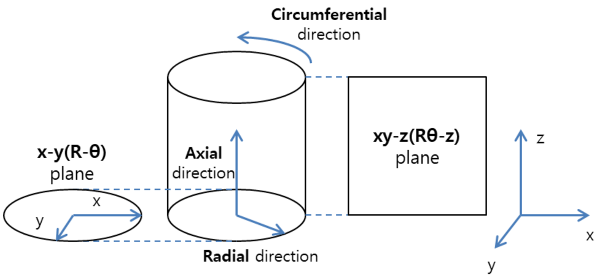

Fig 2. Definition of heat transfer tube coordinate plane.

2.1 Helical section

To design the helical section, design variables such as the number of heat transfer pipes, diameter and height of the helical section, and number of turns are entered in MATLAB in the form of a vector (matrix). As this design variable matrix is entered, the height pitch is automatically calculated in consideration of the height and number of turns, and three-dimensional coordinates are generated to form the helical section of the heat transfer tube. At this time, the heat transfer tube can be designed in multiple layers.

2.2 Design of transient section

2.2.1 x-y (R-θ) plane transient section

Before designing a three-dimensional transient, we first design a transient in the x-y (R-θ) plane. The design method for the top and bottom transients is the same, so this section will be based on the top transient. Extract the coordinates of the top of the helical and the coordinates of the header, and generate a vector of each from the center of the vessel. Use these vectors to automatically design a curve that is tangent to the helical curve to generate two-dimensional R-θ transient section coordinates [Fig 3].

$$\alpha = cos^{-1}\left(\frac{\overrightarrow{VecT} \cdot \overrightarrow{VecTH}}{\|\overrightarrow{VecT}\|\|\overrightarrow{VecTH}\|}\right)$$

$$\theta = 180 - 2\alpha\,, \qquad R = \frac{\|\overrightarrow{VecTH}\|}{2cos\alpha}$$

$$CenP = Tube + R * \frac{\overrightarrow{VecT}}{\|\overrightarrow{VecT}\|}$$

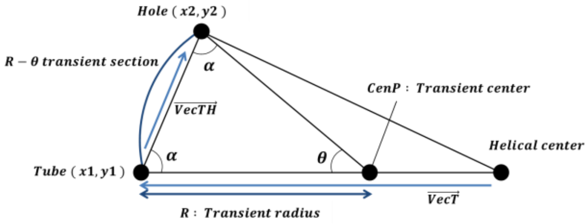

Fig 3. Calculation two-dimensional R-θ transient coordinates.

2.2.2 xy-z (Rθ-z) plane transient section

As with the transient in the x-y (R-θ) plane, the design method for the top and bottom transients is the same, so this section is based on the top transient. For the Rθ-z transient in the height direction, the minimum curvature is applied in consideration of the in-service inspection when manufacturing the actual heat pipe. Since the heat transfer tube must be connected vertically to the header, there may be insufficient distance to apply only the curvature when considering the header coordinate and the top coordinate of the helical, so the Rθ-z transient section is calculated as the sum of the straight section and the curvature section. In this case, the straight section generates a vector considering the pitch and angle of the helical section. The combination of this helical straight line vector and the vector perpendicular to the header finally produces the Rθ-z transient curvature coordinates [Fig 4].

$CenP$: *Transient center*

K : *Rθ − z transient radius(minimum radius)*

$Theta$: *Transient angle*

$x\ direc$: *Rθ axial direction vector*

$\overrightarrow{VecT}$: *Tube vector*

$Tube1$: *Helical final point*

$Tube2$: *Helical initial point*

$TubeNew$: *Tube vector point tangent to radius K*

r : *Rθ transient radius*

α : *Rθ transient angle*

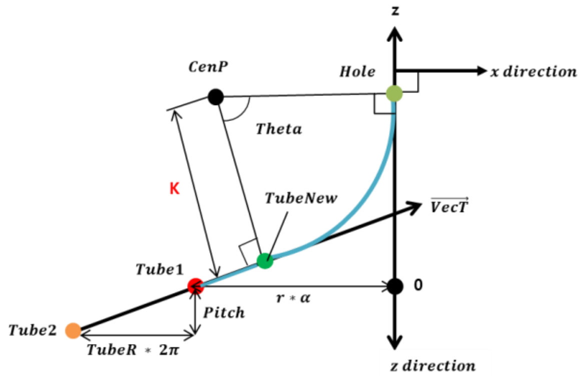

Fig 4. Calculation two-dimensional Rθ-z transient coordinates.

2.2.3 Three-Dimensional mapping

Perform three-dimensional mapping based on the previously calculated two-dimensional R-θ and Rθ-z transient section coordinate values. For the R-θ transient, the coordinate placement is calculated as a constant ratio, and for the Rθ-z transient, the coordinate placement ratio is different between the straight and curved sections, so the R-θ transient coordinate placement ratio is rearranged according to the Rθ-z transient coordinate placement ratio, and then organized into three-dimensional coordinates. Finally, the three-dimensional transient section curvature coordinate values can be obtained.

2.3 Contact (Convergence) test

The helical section and the transient section are coordinated with the values calculated by points and lines, and interference may occur in the three-dimensional aspect considering the diameter of the heat transfer tube in actual production. Therefore, the distance between the coordinates is calculated and compared with the diameter of the heat transfer tube, a contact test is performed, and if no interference occurs, the design of the helical heat transfer tube is finally completed [Fig 5,6].

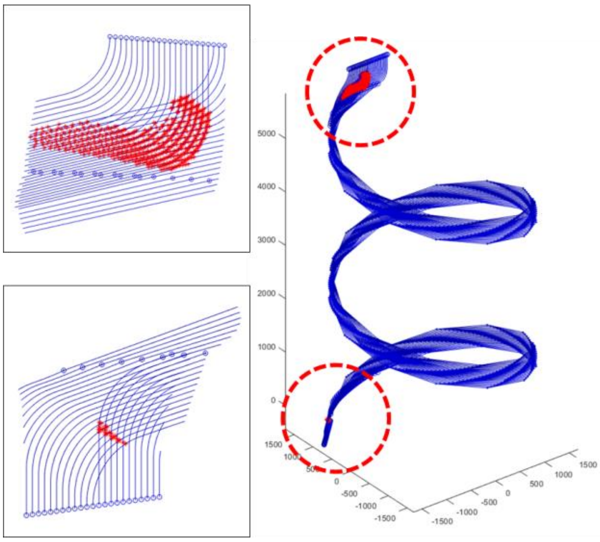

Fig 5. Indicate contact (convergence) occurrence point.

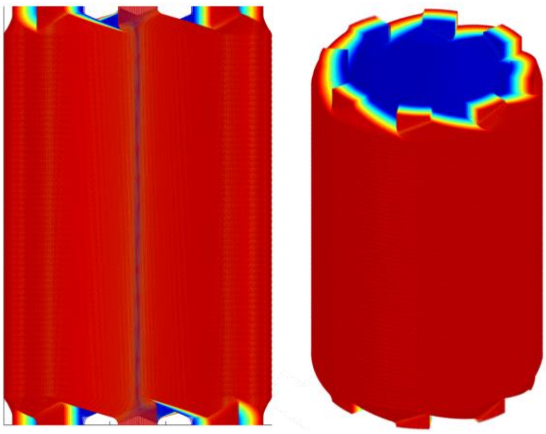

Fig 6. Final three-dimensional model of helical heat transfer tube.

3. Conclusions

When designing helical heat transfer tubes for steam generators, the design of the transient section, the part where the heat transfer tube is connected to the header, is a key technology. Through the development of this program, it is possible not only to design the transient section in three dimensions, which is the core technology, but also to automatically change the transient section design according to the shape of the header hole arrangement, such as rectangular or arched, and to extract the coordinate values of the heat transfer tube separately and use them not only for simple structural analysis but also for Fluid-structure interaction (FSI) analysis.

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