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Design Optimization of Upper Plenum of PBMR Using 3-D RANS Analysis

Sang-Moon Lee and Kwang-Yong Kim*
Department of Mechanical Engineering, INHA Univ., Korea
**Corresponding author: kykim@inha.ac.kr*

1. Introduction

Pebble-bed modular reactor (PBMR) as a high temperature gas cooled reactor (HTGR) is one of the renewed reactor designs of Generation IV. In cooling system of PBMR, Helium gas as a coolant enters the reactor core at a temperature of about 540°C and at a pressure of about 7 MPa, cools the pebble in the core and then leaves the reactor through lower plenum at a temperature of about 900°C under normal operating conditions. Kim et al. [1] obtained an optimum shape of inlet plenum of PBMR with Reynolds-averaged Navier-Stokes (RANS) analysis and Kriging modeling. Kim et al. [2] performed flow and heat-transfer analysis of a very high temperature reactor (VHTR), and suggested a relation between height of upper plenum and flow distribution in the upper plenum.

In this work, shape optimization of upper plenum of a PBMR type gas cooled nuclear reactor has been performed by using three-dimensional Reynolds-Averaged Navier-Stokes (RANS) analysis and Kriging modeling technique [3]. The design objectives are to maximize flow uniformity in the reactor core.

2. Flow Analysis and Optimization Methods

A commercial code ANSYS CFX 11.0 [4] is used for the analysis in PBMR. The computational domain is shown in Fig. 1. In this work, Shear Stress Transport (SST) model [5] with automatic wall treatment is used for accurate prediction of turbulent flows.

For the first step of the optimization procedure, the objective function and design variables are selected. The design space is then decided for improved system performance. Design points are selected through Latin-hypercube sampling [6]. At these design points, the objective function is calculated using RANS analysis. Finally, the Kriging model is constructed, and then optimal points are searched by the optimal point search algorithm.

The objective function (F) is defined as uniformity of a velocity distribution in reactor core inlet as follows:

$$F = \frac{V_{\max} - V_{\min}}{V_{avg}} \tag{1}$$

where V_{avg} is an average velocity at the inlet of the reactor core.

Three design variables viz., the ratio of thickness of slot to diameter of rising channels, ratio of height of upper plenum to diameter of rising channels, and ratio of height of the slot at inlet to that at outlet, are selected for the optimization.

3. Results

The results of the optimization are shown in Table I. The objective function has been reduced by 24.8% in comparison with the reference shape. Prediction for the objective function at the optimum point by Kriging model shows 9.21% relative error compared to that calculated by RANS analysis at the same point.

Fig. 2 shows velocity distribution at the inlet of the reactor core. A normalized velocity V_i is used to compare velocity distribution of reference shape with optimum shape effectively. V_i is defined as follows.

$$V_i = \frac{V}{V_{avg}} \tag{2}$$

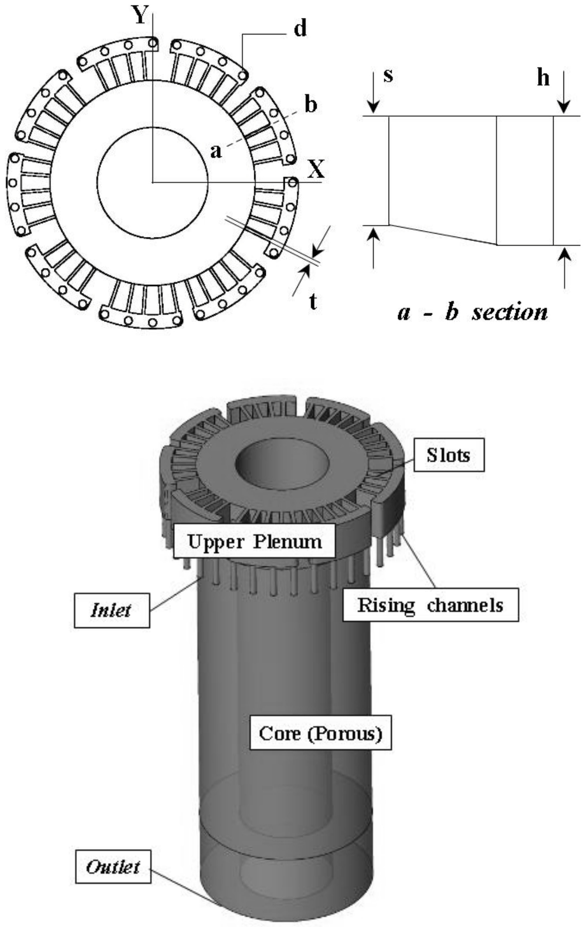
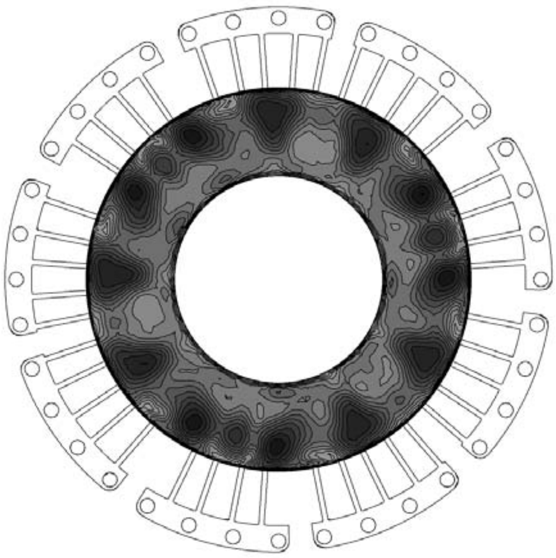
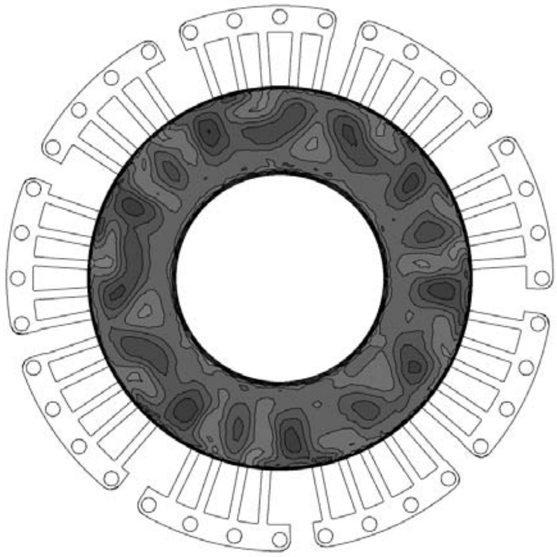


Fig. 1. Computational Domain and Upper Plenum Geometry



(a) Reference shape



(b) Optimum shape

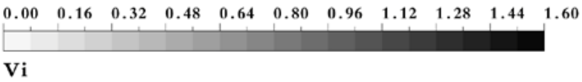


Fig. 2. Normalized velocity contours on the inlet of the core

Table I: Results of Optimization

	Reference	Optimum	
		RANS	Kriging
F	0.613	0.461	0.422

The optimized shape shows higher flow uniformity than the reference shape.

4. Conclusions

Shape optimization of the upper plenum has been performed to enhance the uniformity of flow distribution in the reactor core. The objective function at design points is calculated by RANS analysis and then Kriging model is constructed for prediction of an optimum objective function. As the results of the optimization, the uniformity of flow has been improved in comparison with the reference shape. Therefore, the optimization procedure presented in this work is proved to be efficient and also economic for the design of cooling passages of PBMR.

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