# Assessment of Pebble Bed Micro Model using Modified Circulator Model in MARS-GCR

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## 1. Introduction

The Pebble Bed Micro Model (PBMM) is a benchmark model of the Power Conversion Unit (PCU) to demonstrate the dynamic behavior of a three shafts power conversion system with nitrogen as a working fluid [1]. It is important for the safety analysis code to be able to accurately predict the behavior of the PCU. MARS-GCR code has been extended for application to the Gas Cooled Reactor (GCR) in the existing MARS code [2]. The developed MARS-GCR was applied as a safety analysis code of PBMM. In this study, circulator model of MARS-GCR code is modified and simulated in the PBMM.

## 2. Numerical Methods

### *2.1. Modified Circulator Model*

Among the components of the PBMM facility, the compressors are the most important machineries to model the whole Brayton cycle. In MARS-GCR, the circulator model was also added by extending the existing "PUMP" model. The circulator model requires user's input for the performance curves. The performance of the circulator model can be evaluated by computing the pressure ratio between inlet and outlet pressures and the efficiency given as a function of rotational speed of circulator and mass flow rates. The pressure ratio and efficiency are computed by linear interpolation of the circulator performance curve data [3].

The linear interpolation is quick and easy, however, it is not good precise and differentiable at the interval. The interpolation error, including polynomial interpolation and spline interpolation, is proportional to the square of the distance between the data points.

The spline method uses low-degree polynomials in the each interval, and chooses the polynomial pieces such that they fit smoothly together. The cubic spline interpolation for modification of interpolation method of circulator model is used. The cubic spline interpolation can be expressed as

$$S(x)=\begin{cases} s_1(x) & \text{if } x_1 \le x < x_2 \\ s_2(x) & \text{if } x_2 \le x < x_3 \\ \quad M & \\ s_{n-1}(x) & \text{if } x_{n-1} \le x < x_n \end{cases} \qquad (1)$$

where, $x_i$ is data point and $s_i(x)$ is a third degree polynomial by

$$s_i = a_i(x-x_i)^3 + b_i(x-x_i)^2 + c_i(x-x_i) + d_i \qquad (2)$$

for i=1,2,…,n-1.

In above, cubic spline properties are found by substituting into the following equations. a, b, c and d values correspond to the polynomial definition for each segment.

$$a_i = \frac{M_{i+1}-M_i}{6h} \qquad (3)$$

$$b_i = \frac{M_i}{2} \qquad (4)$$

$$c_i = \frac{y_{i+1}-y_i}{h} - \left(\frac{M_{i+1}-2M_i}{6}\right)h \qquad (5)$$

$$d_i = y_i \qquad (6)$$

where, $s_i''(x_i) = 2b_i = M_i$ , $h_i = x_i - x_{i-1}$, $s_i''(x_i)$ is second derivatives of n-1 and $h_i$ is distance between $x_i$ and $x_{i-1}$.

### *2.2. MARS-GCR model of PBMM*

The PBMM, which is better understanding of the mechanisms and processes in the dynamic behavior of PCU, is a model of the Brayton cycle with nitrogen as working fluid [4]. A nodalization of the PBMM power conversion cycle for the MARS-GCR code is shown in Fig.1.

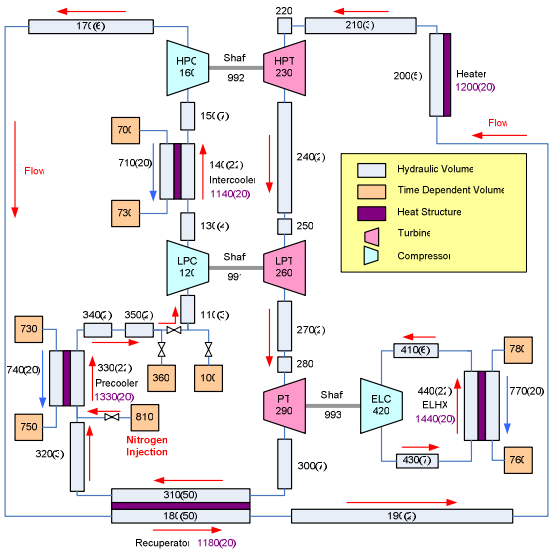


Fig. 1. Nodalization of MARS-GCR code

The steady state calculations of the PBMM are carried out by using the MARS-GCR code [5]. The pressure boundary at the inlet of the lower pressure compressor (LPC) is 94 kPa. Heater power is maintained as 650 °C for the heater outlet temperature. The boundary conditions of the secondary sides are tabulated in Table 1.

Table 1. Boundary conditions in 94 kPa

| | |
|---|---|
| Suction pressure of LPC | 94 kPa |
| Heater outlet temperature | 644.6 °C |
| Cooling water flow rate | |
| Pre-Cooler | 2.05 kg/s |
| Inter-Cooler | 1.63 kg/s |
| External Load Cooler | 1.20 kg/s |
| Cooling water temperature | 14.2 °C |
| Cooling water pressure | 350 kPa |

## 3. Results and Discussions

The Figures 2 and 3 show the temperature and pressure in the case of 94 kPa. The calculated temperatures are close to the experimental values. The maximum deviation temperature is 7.5 % and lower values than existing MARS-GCR. The average deviation temperature between existing MARS-GCR and modified MARS-GCR is similar to 3.55 % and 3.37 %, respectively. Also the maximum deviation pressure is 8.2 %. The average deviation pressure of the existing MARS-GCR and modified MARS-GCR is 3.11 % and 4.46 %, respectively.

In these results, it can be concluded that modified circulator model with cubic spline interpolation of MARS-GCR are generally well enough for the safety analysis of the GCRs.

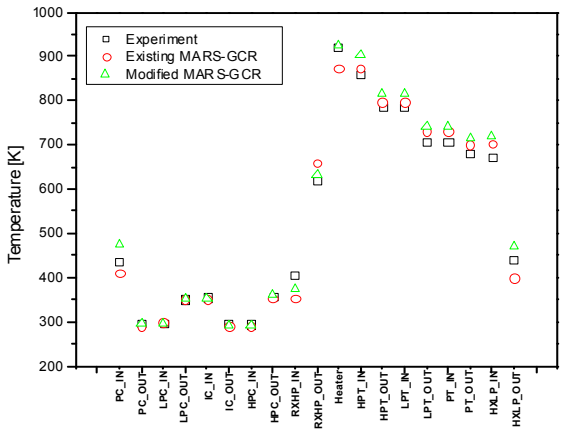


Fig. 2. The temperature distribution

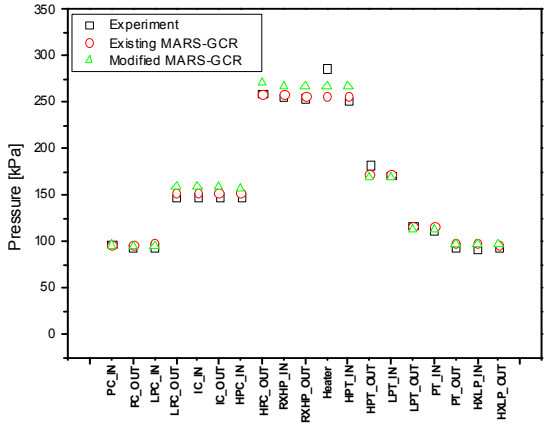


Fig. 3. The pressure distribution

## 4. Conclusions

MARS-GCR code by modified circulator model is implemented to simulate the three shafts power conversion system of the PBMM by using nitrogen as a working fluid. The results of the steady state were compared with the experimental results to show good agreement with each other. In conclusion, the closed loop problem of PBMM was well predicted. The improvement of interpolation method of circulator model using cubic spline interpolation can simulate a little more accurate prediction than the existing circulator model.

In future, transient problems using cubic spline interpolation will be performed. Further improvements are required for more accurate behavior of the modified circulator model in MARS-GCR.

## ACKNOWLEDGEMENT

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