The effect of turbomachinery performance degradation on the load-following performance of S-CO_2 direct-cycle Micro Modular Reactor (KAIST-MMR).

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1. Introduction

The Supercritical CO_2 (S-CO_2) power cycle is considered to be one of the promising next generation power cycles. A S-CO_2 power cycle gains benefits such as a small footprint and high efficiency by utilizing the unique properties near the critical point. Nuclear engineering is one of the first areas to exploit advantages of S-CO_2 power systems [1]. In particular, in the nuclear power field, not only indirect cycles, but also S-CO_2 direct-cycle reactors are being studied. The Sandia National Laboratory (SNL) research team has developed a 200MW_{th} scale SC-GFR concept [2], and the Massachusetts Institute of Technology (MIT) research team has also conducted a concept study on the 2400MW_{th} scale S-CO_2 direct-cycle Gas-cooled Fast Reactor (GFR) by Pope et al., [3]. Korea Advanced Institute of Science and Technology (KAIST) research team has developed a concept of KAIST-Micro Modular Reactor (KAIST-MMR), a 10MWe scale S-CO_2 cooled direct-cycle GFR that can be transported via truck [4].

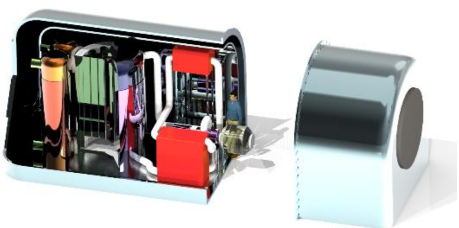

Figure 1. Concept art of KAIST-MMR

Although S-CO_2 is reported as a powerful cleaning agent [5-6], the performance of a power system operating with S-CO_2 will also inevitably degrade over time. Previous researchers have shown that turbomachinery deterioration could be a major subject regarding the system performance degradation [7]. Nevertheless, no quantitative evaluation has yet been made so far.

In this study, an impact of performance degradation of S-CO_2 turbomachinery during a load-following scenario is analyzed quantitatively. Health Parameter concept is used to simulate turbomachinery degradation. In order to quantify the impact, the KAIST-MMR is selected as the target system. A transient analysis platform is built using a nuclear system safety analysis code and the Deep Neural Network (DNN) based S-CO_2 turbomachinery off-design performance model [8] based on the GAMMA+ code [9]. In the course of load-following operation, the effect of performance degradation of the turbomachinery on the control is evaluated, and analysis is performed from the viewpoint of reactor safety.

2. Methodology

2.1. KAIST-MMR

KAIST-MMR is a reactor concept developed by KAIST, and it is a 10MWe class S-CO_2 direct-cycle GFR shown in Figure 2. It utilizes a S-CO_2 simple recuperated cycle. The controllers covered in this study are turbine bypass controller and inventory controller. In this study, the controllers which are designed in the absence of degradation are evaluated whether the controllers will still work well when the system is degraded.

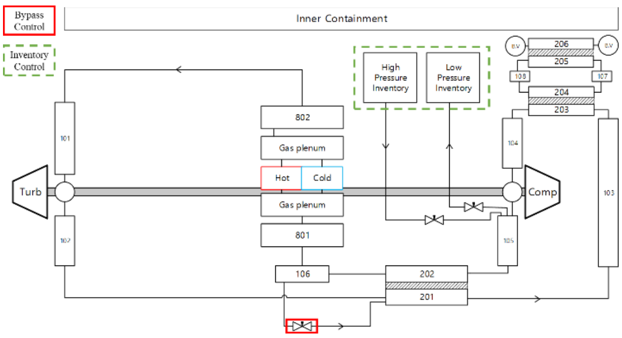

Figure 2. The locations of each controllers of KAIST-MMR, Red box: Bypass control, Green box: Inventory control

2.2. Turbomachinery Degradation Model

In this study, the degradation of turbomachinery performance is simulated using the concept of health parameter developed for performance degradation of a gas turbine system or an aviation turbine [10-11]. DI means health parameter of the turbine and EI means health parameter of the compressor. m_T and m_C is mass flow rate of the turbine or compressor, and η is isentropic efficiency. The models are shown below:

For Turbines:

$$\frac{\Delta m_T}{m_T} = 1 + 0.5DI \quad \frac{\Delta \eta_T}{\eta_T} = 1 - DI$$

For Compressor:

$$\frac{\Delta m_C}{m_C} = 1 - 0.5FI \quad \frac{\Delta \eta_C}{\eta_C} = 1 - FI$$

3. Result and Discussion

The scenario for load following operation was selected from the report published by International Atomic

Energy Agency (IAEA) [12]. The scenario used is to reach 20% relative electric output (REO) at full-power operation, then hold for 5 minutes and then return to full power operation as shown in Figure 3.

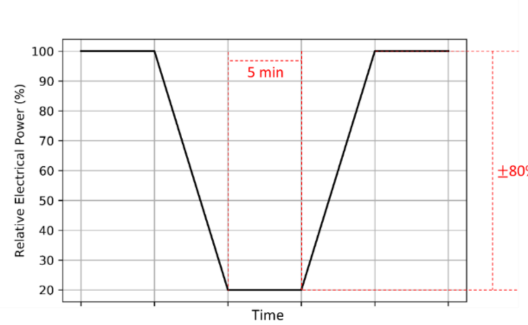

Figure 3. Scenarios selected for load following capability evaluation

At the ramp rates of 10-30 REO%/min, the turbine over-speeds due to degradation of turbomachinery performances are predicted as shown in Figures 4. The turbine over-speed values are higher in the ramp-up scenario.

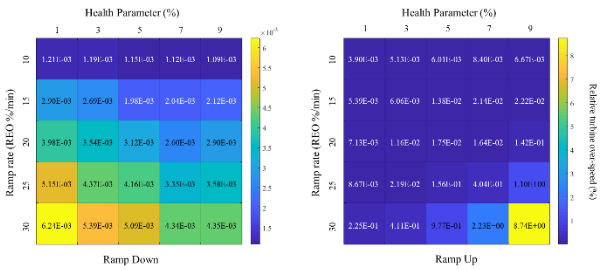

Figure 4. The chart of maximum turbine over-speed of KAIST-MMR during the load following scenario.

PCT and FCT are shown in Figure 5 at 30% REO / min and 9% DI and FI, where the turbine over-speed was the largest within the analyzed range.

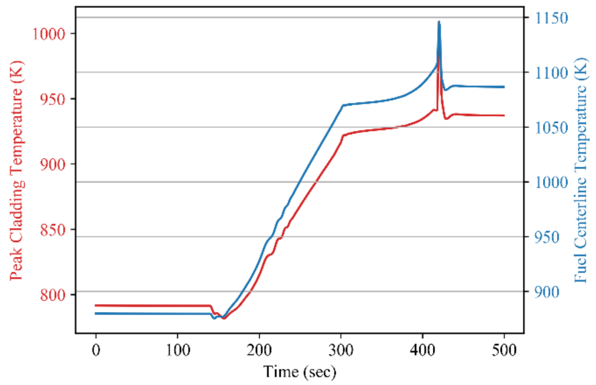

Figure 5. Peak Cladding Temperature and Fuel Centerline Temperature during 30% REO/min ramp-up scenario with 9% HP of turbomachinery degradation

The results show that PCT and FCT peaks occur at the end of the ramp-up scenario. However, numbers are still below the design limit. (1450K)

These results show that turbomachinery degradation in the load-following scenario affects the dynamic response. However, PID control failures in the analyzed range were not observed. Also, it was confirmed that peaks of FCT and PCT may occur in the ramp-up process from the core point of view, but it is not expected to cause safety problems.

ACKNOWLEDGEMENT

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