A Linear Load Follow Analysis of a Trans-critical CO_2 Rankine Cycle for Nuclear Marine Application

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1. Introduction

In the previous study, the KAIST-MMR was redesigned for the marine application by coupling with the trans-critical CO_2 Rankine cycle instead of the Brayton cycle [1-2]. To model and analyze the CO_2 two-phase flow close to the critical point, a system analysis code adopting the HEM (Homogeneous Equilibrium Model) was developed namely the KAIST-STA. In the last study, the behavior of the KAIST-MMR was analyzed for the load reduction operation with the developed code [1].

As an extension to the study, the authors performed a linear load change analysis of the system. This load follow scenario becomes important when the engine load should be changed within a short amount of time. In this study, the linear load change operation of 100-50-75% loads was analyzed occurring within 300 sec. The analysis shows the marine type KAIST-MMR can be controlled under the scenario, however it is found that KAIST-MMR needs additional controls for increasing the system load more than 75% load from lower load without decrease of the turbine speed from the designed RPM within short time.

2. The analysis of the linear load follow operation

Using the KAIST-STA code, the redesigned KAIST-MMR system was modeled as shown in Fig. 1. It shows the comparison result between the design parameters and calculation values at the steady-state within ±1% temperature and pressure. It proves the modeling and calculation of the code was properly carried out even if the system experiences the CO_2 phase change in the pre-cooler.

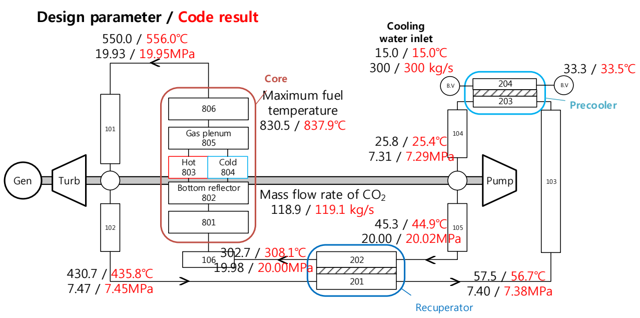

Fig. 1. Nodalization diagram of the marine KAIST-MMR with design parameters and code results.

In this study, the load change operation from 100-50-75% loads was analyzed as shown in Fig. 2. Similar to the linear load change operation, the designed controllers adjust the valve opening fractions of the core bypass valve and inventory control valves to maintain the turbine rotational speed and set the optimum CO_2 mass in the system according to the load as shown in Fig. 3. The mass flow rates for the turbine and pump are adjusted as the result of the core bypass valve position control as shown in Fig. 4.

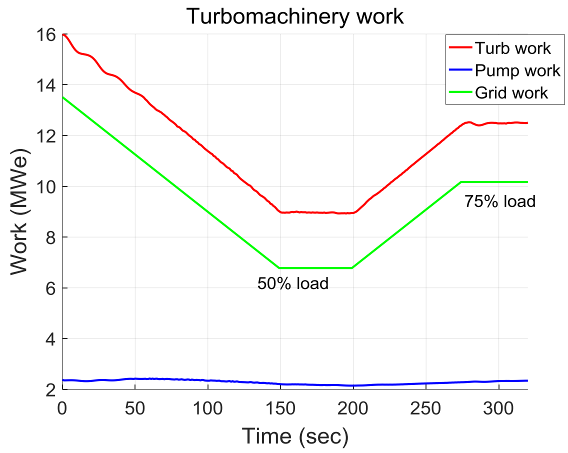

Fig. 2. Variation of load and turbomachinery works during the part load operation.

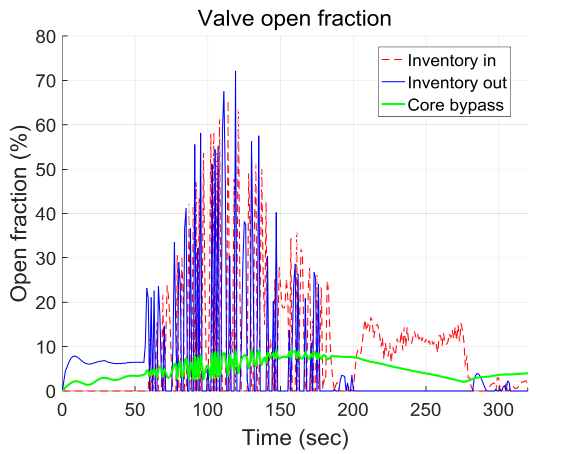

Fig. 3. Open fraction variations of control valves during the part load operation.

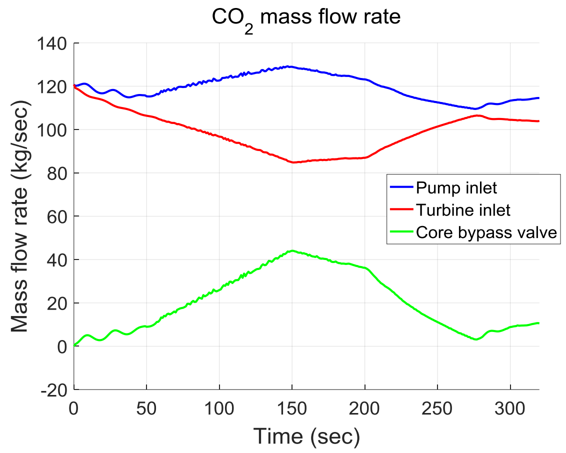

Fig. 4. Variations of CO_2 mass flow rate during the part load operation.

Figs. 5 and 6 separately represent the variations of turbomachinery rotational speed and cycle efficiency during the linear part load operation. Fig. 7 shows the change of reactor core power. It represents that the core power is adjusted by the reactivity of the core during the transient. In this study, the code applied the point kinetics model for the core modeling.

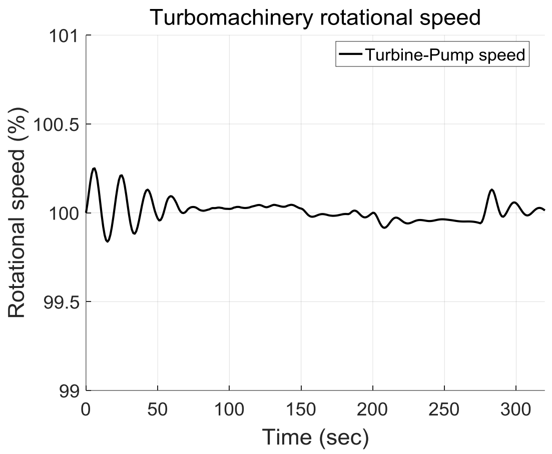

Fig. 5. Variation of turbomachinery rotational speed during the part load operation.

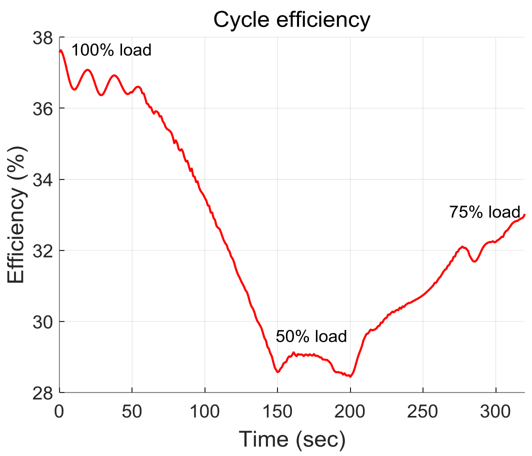

Fig. 6. Variation of cycle efficiency during the part load operation

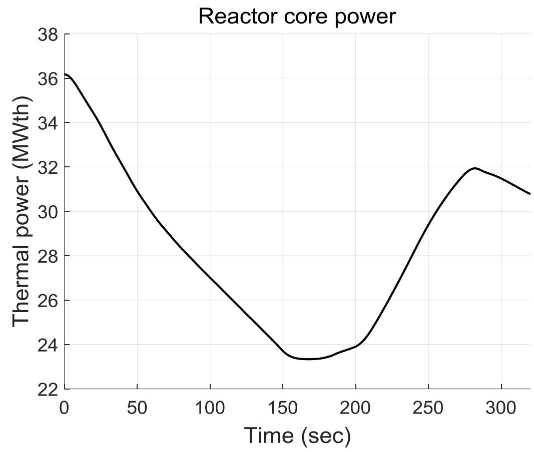

Fig. 7. Variation of reactor core power during the part load operation.

Figs. 3 and 4 show that the open fraction of the core bypass valve increases during the load decreasing situation, but on the contrary it decreases when the load demand falls off. It is close to zero when the load reaches to 75% load. It means that KAIST-MMR requires additional controls for increasing the system load more than 75% load from lower load without decrease of the turbine speed from the designed RPM. This control can be adjustments of the core reactivity, the total amount of CO_2 mass in the system, and others.

3. Conclusions

In this study, the marine type KAIST-MMR was modeled and a linear load change analysis was carried out with the KAIST-STA code for 100-50-75% load change scenario. The reactor power of the system is adjusted automatically in accordance with the variation of the power demand due to its strong negative feedback coefficient of temperature in the core. The results show that the system is able to be automatically controlled through the core bypass control and the inventory control without any direct control action due to the core characteristics. However, it is found that KAIST-MMR needs additional controls for increasing the system load more than 75% load from lower load without decrease of the turbomachinery rotational speed. Other operating scenarios will be analyzed for KAIST-MMR to further improve the maneuverability.

REFERENCES

[1] S. J. Bae, B. Oh, J. I. Lee, Design and Transient Analysis of a Trans-critical CO2 Rankine Cycle for Nuclear Marine Application, Korean Nuclear Society Spring Meeting, May 17-18, (2018)

[2] B. S. Oh, Safety analysis and development of control logic of KAIST Micro Modular Reactor with GAMMA+ code, KAIST master's thesis (2017)