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Control logic development of KAIST Micro Modular Reactor for marine propulsion

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1. Introduction

The newly released IMO regulation for reducing CO_2 emission forces the diesel engine on the container ship to be replaced. To comply with the regulation, the alternative engine should reduce or remove CO_2 emission. Since the ship has limited space, the alternative engine should also be compact enough to be stored in the ship. To satisfy the requirements above, a concept of fully modularized fast reactor with supercritical CO_2 (S-CO_2) cooled direct Brayton cycle, namely Micro Modular Reactor (MMR), can be used. The conceptual diagram of MMR in ship process is shown in fig 1.

In this paper, the feasibility of using MMR is first checked. From the trends of the diesel engine's application for various container ship sizes, the MMR size and weight are small enough to the diesel engine with 10MW power output. [1]

The propulsion system of the ship should be modulated to follow the desired speed under various situations. In order to meet this requirement, an automatic controller for MMR should be developed further.

In this paper, the MMR propulsion with a control logic will be simulated and evaluated.

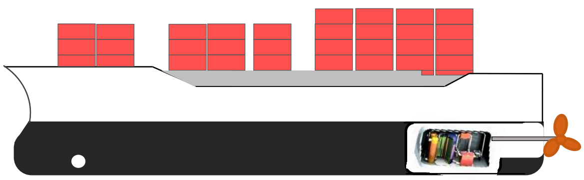

Figure 1. The concpet figure of the MMR storered in container ship

2. Methods and Results

2.1 Feasibility of MMR for marine propulsion

The genset diesel engine which has the same power with MMR (10MWe) is usually used for a small container ship with 1000 TEU (Twenty-foot Equivalent Unit, unit for describing the capacity of the 20-foot-long container) capacity. The 1000 TEU container ship is considered for the application of the MMR in this paper [1].

The diesel engine with power output of 10MW, the Wärtsilä 9L46F's dimensions are 11m in length and 5m in height. Its weight is 140 tons. Hyundai 20H32/40V's are 13m in length and 4.8m in height. Its weight is 153.5 tons [2], [3]. The MMR has compact dimensions as shown in Fig 2.1 and its weight is approximately 150 tons. Thus, MMR can replace the diesel engine of current container ship without significant design change of the ship's hull. Furthermore, the MMR does not require refueling for 20 years. Therefore, the fuel storage area can be additional used in the ship.

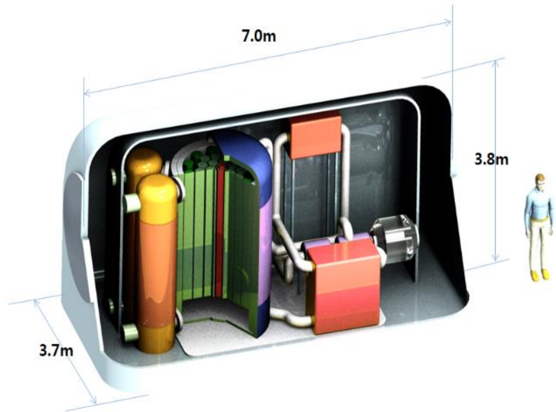

Figure 2.1 Configuration of MMR [6]

2.2 MMR turbine bypass control method

The turbine of the propulsion system should follow the desired turbine speed(RPM) so that the ship can successfully navigate through any circumstances. A desired power profile of running ship is referred from [4]. At first, the ship is at full speed. Then, due to change in environment such as wind and wave conditions, the desired turbine speed is reduced and kept at that level for safety. After a while, the desired speed recovers back to the full power speed when the environment becomes better.

The effective control methods for the MMR are decided from [5], which are turbine bypass, inventory and throttling controls. However, the control logic was tested for the land based power generation situation only. To test the same logic if it can meet the ship propulsion engine condition, the developed MMR simulation code was modified. For the sake of simplicity and fast response of turbine RPM change, the turbine bypass controller is first chosen for the test. The turbine bypass valve creates a flow detour pass of turbine and the valve is regulated by the PID controller.

The MMR with a turbine bypass controller is simulated with the General Analyzer for Multi-component and Multi-dimensional Transient Application (GAMMA+ code) code. With the GAMMA+ code, the MMR under the marine propulsion condition is simulated. The results are shown in the Figs 2.2 ~ 2.7.

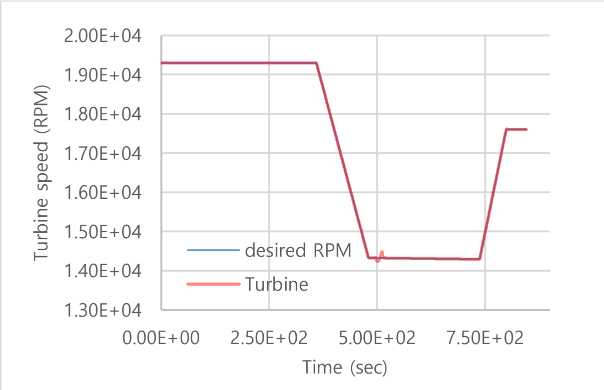

Figure 2.2 Turbine speed during ship running simulation

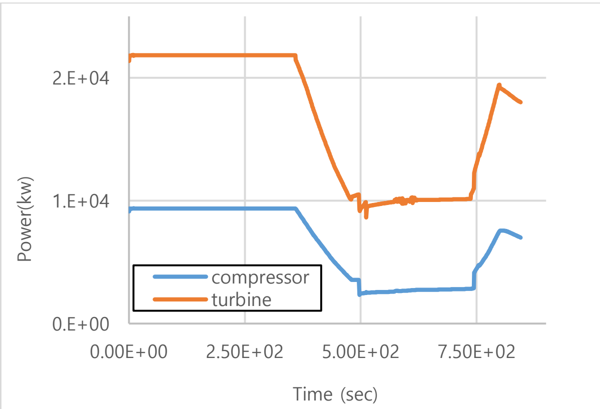

Figure 2.3 Turbomachinery work during ship running simulation

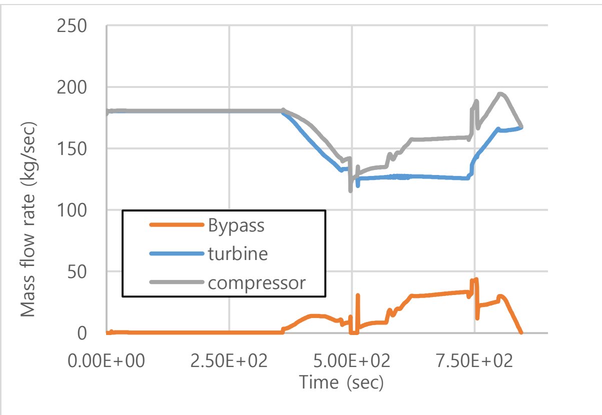

Figure 2.4 Mass flow rate during ship running simulation

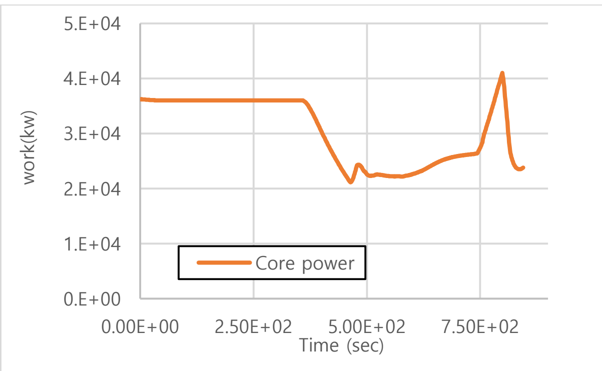

Figure 2.5 MMR core power during ship running simulation

Since the S-CO_2 properties abruptly change near the critical point, the state of the S-CO_2 should be kept in supercritical region for safety and efficiency during operation. The minimum temperature of the CO_2 in the cycle during the whole operation is 42℃ and the minimum pressure is 7.98MPa. The change in the compressor inlet condition is also monitored for the simulated conditions. These are described in figs 2.6 and 2.7. CO_2 is in the supercritical region but the temperature is lower than the steady state.

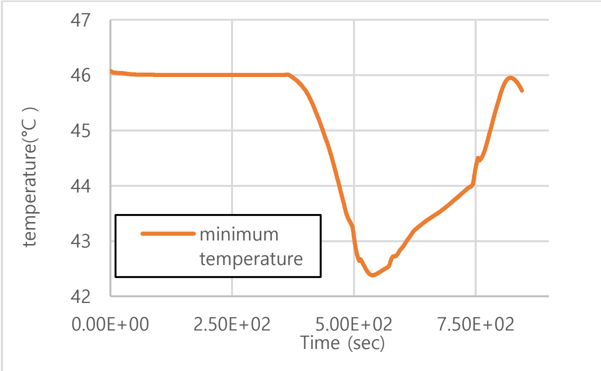

Figure 2.6 MMR minimum temperature during ship running simulation

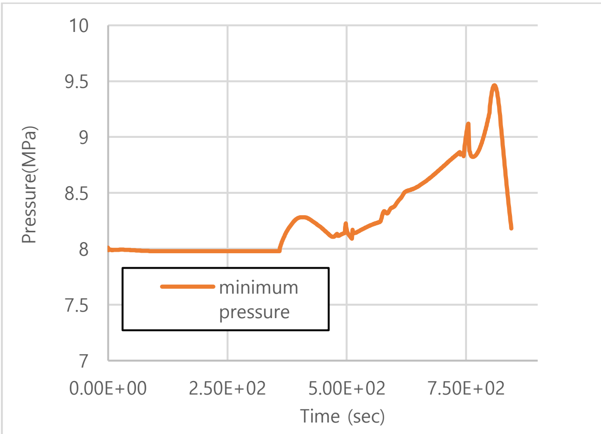

Figure 2.7 MMR minimum pressure during ship running simulation

3. Conclusions and Future Works

From the results, the turbine RPM follows the desired values under the ship running condition. This is due to the initial success of turbine bypass flow control as well as success in the core power control. However, the controller is not fully optimized yet and it will be optimized in the future by utilizing the Ziegler-Nichols tuning method. Furthermore, the original land base MMR is designed with the air-cooling option, but for the marine propulsion the system has to be redesigned for the sea water cooling condition. This is also left as the future work.

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