Effects of Inventory Control on the Performance of HTR-10GT

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INTRODUCTION

Closed Brayton cycle is one of the promising energy conversion methods for the fourth generation advanced nuclear energy system [1]. Helium turbine system coupled with the high temperature gas-cooled reactor (HTGR) can not only achieve inherent safety, but also high power generation efficiency. Unlike the conventional gas turbine system based on open Brayton cycle, there are three fundamental methods to regulate the closed Brayton cycle, reactivity control, and inventory control and bypass valve control [2]. Previous studies indicated that inventory control was the effective method to keep the cycle performance in off-design conditions as high as rated conditions [2-4]. Its rate of regulation was not as fast as the rate by bypass valve control [5]. But these results were obtained in quite ideal conditions. In this paper, the effects of helium storage system on performance of closed Brayton cycle during the inventory control were investigated by using HTR-10GT as example. The results will be helpful to understand and develop the helium turbine system coupled with HTGR.

THE MODELS OF HTR-10GT

HTR-10GT was taken as example to explore the features of inventory control. The 10MW High Temperature Gas Cooled Test Reactor (HTR-10) was developed by Institute of Nuclear and New Energy Technology (INET) [6]. Second phase of HTR-10, known as HTR-10GT, planed to increase the core outlet temperature to 750°C and use a helium gas turbine instead of the steam turbine [3, 4]. The schematic diagram of HTR-10GT was shown in Fig.1.

The components of HTR-10GT could be divided into several categories, heat exchangers, turbo-compressors, valves, etc. As the internal volumes of compressors and turbines were relatively small and inventory control processes were quite slow, quasi-steady-state models were used to calculate the cycle. Flow channels inside heat exchangers were modeled as single phase 1-demensional flow dominated by mass, momentum and energy conservations and discretized in control volume method, considering thermal inertia and thermal resistance of metal wall. The reactor was simulated by point-kinetics and 1-D flow model. Compressor performance maps were used to estimate the status under off-design conditions. WASSELL method was introduced to correct compressor efficiency, pressure ratio, mass flow and surge-pressure ratio, which were influenced by Reynolds number. For 6 stages helium turbine, Flügel Formula was used to estimate its performance at off-design conditions. Valve's model was based on the IEC 534/ISA S.75 standard for compressible fluid.

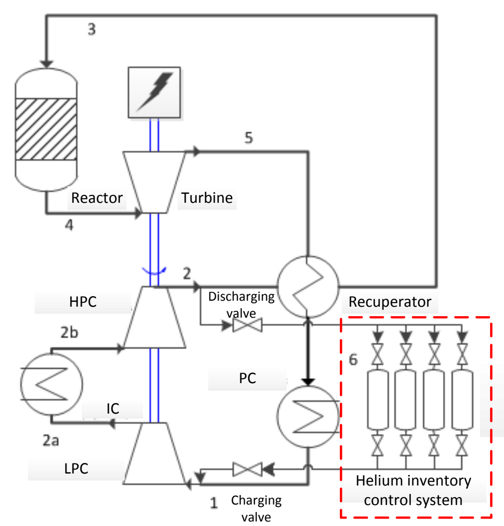

Fig.1 Schematic diagram of HTR-10GT

RESULTS AND DISCUSSIONS

The volume of helium storage tank was the function of temperature, power regulating range and stage numbers, as shown in Fig.2.

The temperature of tank had effects on the charging/ discharging processes. The isothermal boundary of helium storage tanks needed smaller volume, while the adiabatic boundary of tanks needed larger volume. The range of inventory control also influenced the total volume of tanks. Because the charging and discharging of helium were driven by the pressure difference between the cycle and helium storage tanks, the wide inventory control range needed the large volume of tanks. And the stage number determined the pressure difference between cycle and tank, the more stage number of tank is, the less volume of tanks needed. For example, it was impossible to adjust the power from 30% to 100% with only one tank.

Fig. 3 presented the effects of inventory control on cycle. The stage number of tanks is four. At 0-1000s, the cycle discharged helium from cycle to tanks. At 3000-4000s, it began to charge helium to the cycle. The cycle power and flow rate changed during the processes of inventory control. The output power of cycle was proportional to the helium mass flow rate.

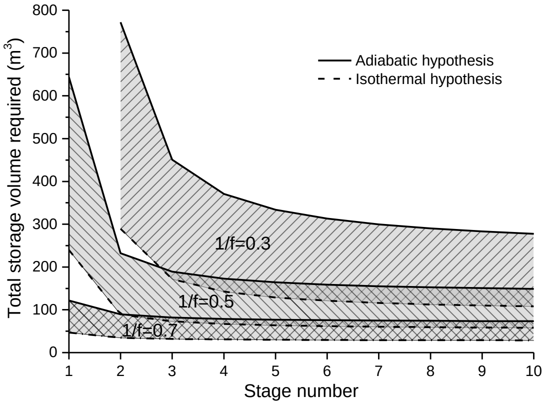

Fig.2 Effects of temperature, power regulating range and stage number on the volume of tanks

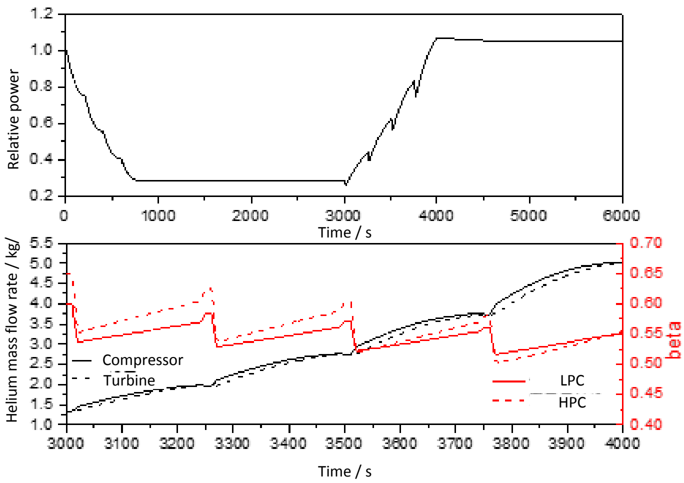

Fig.3 The instability of charging process

it was found that there were power fluctuations as valves opening in charging process (3000-4000s). There was no such phenomena during discharging process (0-1000s). The power depression could be explained by the unbalance of mass flow rate in compressors and turbine. In charging process, the helium was injected into the inlet of compressor. So the mass flow rate of compressors was larger than that of turbine. It would cause the power consumption by compressors increasing suddenly, and the fluctuations of output power. The larger the volume of high pressure was, the higher amplitude of power depression was. It might have impact on the rotor of turbo-compressors and generator and cause the instability of cycle. Measurements should be taken to mitigate the effects of helium charging.

CONCULSIONS

Effects of inventory control on closed Brayton cycle were investigated in this paper, taking HTR-10GT as example.

1. Temperature of helium storage tanks had effects on the inventory control. High temperature needed more storage volume.
2. The stage number of tanks influenced the tank's volume and the range of power regulation.
3. During the helium injecting process, there existed sudden power fluctuations. Measurements should be taken to mitigate its effects on the cycle.

The results will be helpful to develop the control methods for helium turbine system coupled with HTGR.

ACKNOWLEDGEMENTS

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