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Experiment Status of Supercritical CO_2 Turbo Alternator Compressor (TAC) Supported with Ceramic Ball Bearing

Seong Kuk Cho[a], Seongmin Son[a], Yongju Jeong[a], Jeong Ik Lee [a*]
[a]*Dept. Nuclear & Quantum Eng., KAIST, 373-1, Guseong-dong, Yuseong-gu, Daejeon, 305-701, Republic of Korea*
[*]*Corresponding author: jeongiklee@kaist.ac.kr*

1. Introduction

The necessity of the next generation nuclear reactors has been constantly brought up because of global warming, the issues of spent nuclear fuel, and enhanced safety. A supercritical CO_2 (S-CO_2) Brayton cycle is the promising power technology for the next generation nuclear reactors due to high thermal efficiency at moderate turbine inlet temperature (450~750 °C), compact cycle configuration, and the alleviation of turbine blade erosion in comparison with the steam Rankine cycle [1]. Because of these advantages, it has been considered as a future power system for various heat sources (i.e. fossil fuel, waster heat, solar thermal and fuel cells) as well as nuclear.

The desire to minimize water consumption led to the power plant integrated with a dry cooling system. Furthermore, dry cooling system is sometimes preferred for a power plant using supercritical CO_2 power cycle. However, this will result in a higher compressor inlet temperature (CIT). Thus, as shown in Fig. 1, the S-CO_2 Brayton cycle with the dry cooling system inevitably faces substantial deterioration of the cycle efficiency due to losing the benefit of reduced compression work when the dry cooling is necessary. Previously it was identified that a way to improve the aerodynamic performance of the S-CO_2 compressor is to increase backsweep angle [2].

This research summarizes the performance test results to collect fundamental test data for the high performance S-CO_2 compressor and further works.

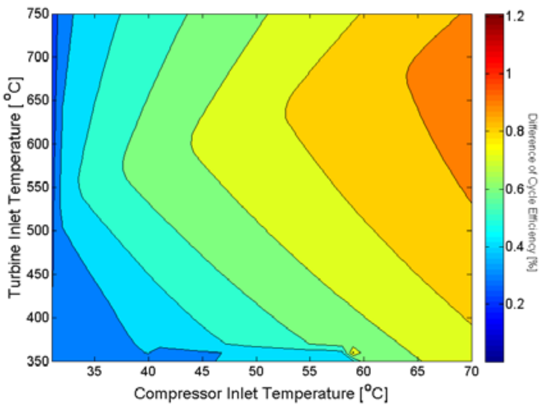

Fig. 1. Performance of S-CO_2 Brayton cycle relative to CIT and TIT variations (S-CO_2 recuperation Brayton cycle)

2. Status of Performance Test

2.1 Description of S-CO_2 TAC test facility

The test facility consists of two control valves, a Turbo-Alternator-Compressor (TAC) and a pre-cooler. Each control valve is located at the turbine outlet and the compressor outlet, respectively, because it varies the flow resistance to control each performance. The thermodynamic cycle is completed through a pre-cooler, which transfers generated heat from the loop to cooling water. Fig. 2 and Fig. 3 show the schematic diagrams of the test facility and the S-CO_2 TAC. The cooling flow path is detoured to avoid bearing failure.

The inlet conditions of compressor near the critical point (T_c = 304.13 K, P_c = 7377 kPa) were selected because of the fact that it has the highest safety margin of centrifugal stress. The S-CO_2 compressors have been mainly designed for extreme operating conditions. DN number, which the product of the average diameter of the bearing (millimeters), D, and the rotational speed (rpm), N, is a representative parameter that shows how challenging it is. The DN numbers used in the existing integral test loops are in the range of 3 to 4 million over the range of generally used gas bearings or magnetic bearings.

In this study, the TAC supported with ball bearings, which the DN is about 1.6 million, was adopted in order to improve the operability. The high specific speed was selected considering manufacturing tolerance. Finally, the design conditions were selected to have pressure ratio, 1.3, mass flow rate, 3kg/s, and specific speed, 0.65. Table I summarizes specifications of TAC.

Through commissioning, it was confirmed that fine particles in piping damage impeller blades in the compressor. The reason is that blade height and tip clearance at trailing edge are very small, which are 2.2mm and 0.1mm, respectively. The damaged impeller degrades the performance of the compressor (e.g. efficiency, pressure ratio and mass flow rate). The fine particles occurred due to carbon bearing of the pre-installed pump and erosion of the pipe surface. Therefore, as a solution to this problem, the pump was isolated and a conical shape strainer with low pressure drop was installed. However, the installation of the strainer was only possible after the compressor inlet conditions measurement, shown in Figure 2.

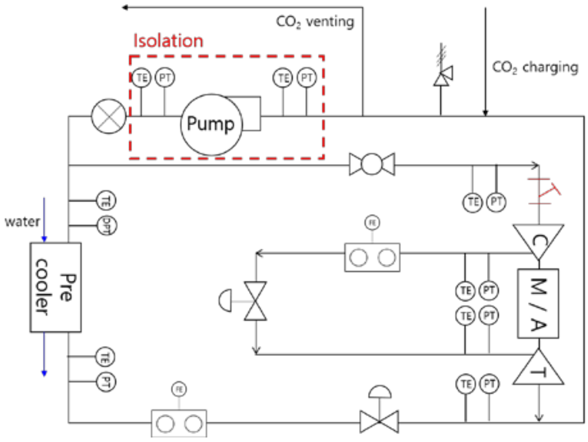

Fig. 2. P&ID of S-CO_2 TAC experiment facility

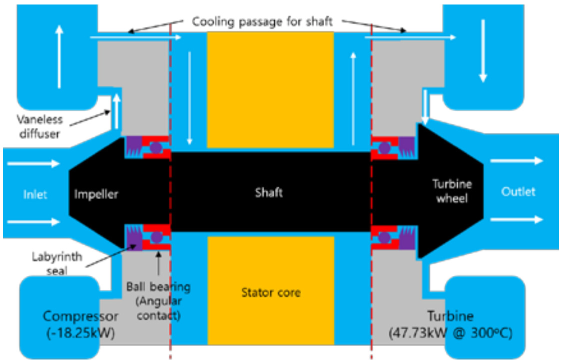

Fig. 3. Schematic diagram for flow path of S-CO_2 TAC

Table I: Specification of S-CO_2 TAC

	Centrifugal Compressor
Specific speed	0.65
Pressure ratio	1.29
Inlet temperature	31.4 ºC
Inlet pressure	7.60 MPa
Isentropic Efficiency	56 %
Mass flow rate	3 kg/s
Design speed	40,000 rpm
Impeller type	Unshrouded impeller (Semi closed)
DN factor	1,560,000
Bearing type	Agular contact ball bearing (Ceramic & 15 º)

2.2 Status of test

Figs. 4 and 5 show comparison of prediction results from an in-house code KAIST-TMD and test results. The main performance indicators of compressor are mass flow rate, pressure ratio and efficiency. The mass flow rate reached at about 85% of the mass flow rate compared to the design point. However, the pressure ratio and efficiency were substantially below the predicted performance. This is the result of uncertainties in measuring the inlet pressure used for pressure ratio and efficiency, and uncertainties in the power consumption of the compressor used for efficiency estimation.

Currently, there is a problem that the pressure transmitter at the inlet measures at the upstream of the filter, so that differential pressure caused by the filter is not quantified. To solve this issue, the test will be conducted to confirm the differential pressure form the filter. Once the filter pressure drop is subtracted from the current pressure measurement, the pressure ratio will automatically increase. Moreover, the reason for the lower than expected efficiency is that power from the inverter to the motor is used rather than the actual consumed power of the compressor. This will be fixed by directly measuring power of the compressor using power meter.

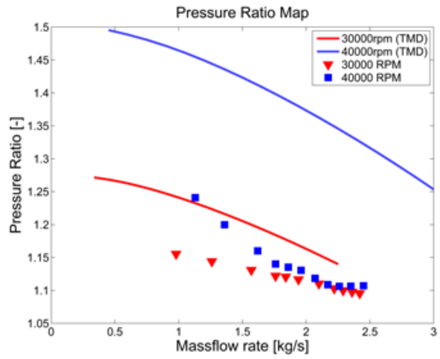

Fig. 4. Schematic diagram for flow path of S-CO_2 TAC

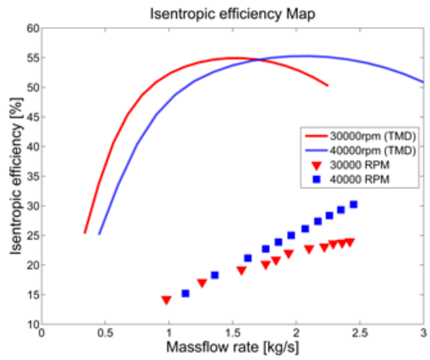

Fig. 5. Schematic diagram for flow path of S-CO_2 TAC

3. Summary and further works

This study summarizes the status of performance test results. Even though the mass flow rate reached at about 85% compared to the design point, the mass flow rate and pressure ratio were substantially below the expected performance caused by the measurement issues.

As further works, to resolve these issues, measurements of pressure ratio considering the differential pressure of the installed filter and power measurements using the power meter will be conducted.

ACKNOWLEDGEMENT

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