Summary of Performance Test Plan for a Supercritical CO_2 Turbo Alternator Compressor (TAC) with High Backsweep Angle Design

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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 (450~650 ^oC), 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. The previous proposed the way to improve the aerodynamic performance of the S-CO_2 compressor is to increase backsweep angle [2].

This study summarizes the performance test plan to confirm the effect of high backsweep angle design and to collect fundamental test data for the S-CO_2 Brayton cycle.

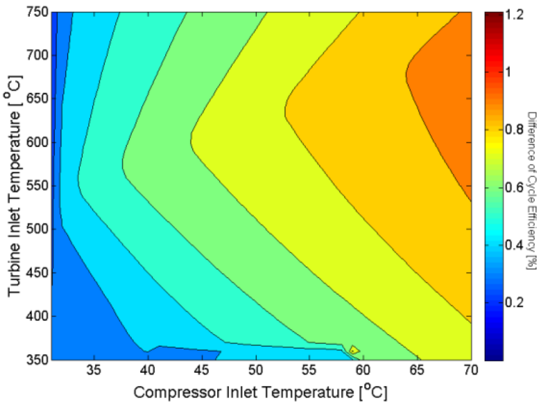

Fig. 1. Performance of S-CO_2 Brayton cycle relative to CIT and TIT variations (S-CO_2 recuperation Brayton cycle)

2. Progress of Performance Test

2.1 Description of S-CO_2 TAC test facility

The test facility consists of two control valves, a TAC and a pre-cooler. Each control valve is located at the turbine outlet and the compressor outlet, respectively, since it varies the flow resistance to control each performance. The thermodynamic cycle is completed through a pre-cooler, which transfers the heat into water. Fig. 2 and Fig. 3 show the schematic diagrams of the test facility and the S-CO_2 of 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 due to 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 one 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.

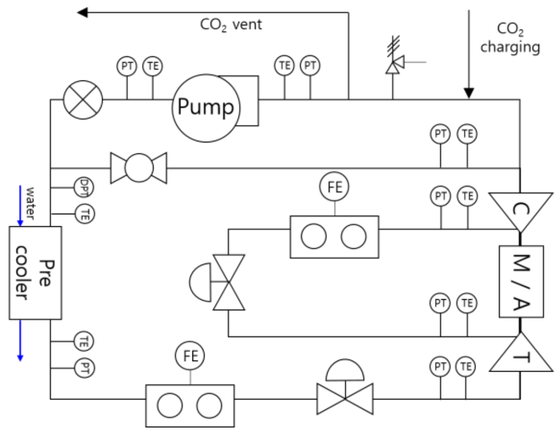

Fig. 2. P&ID of S-CO_2 TAC experiment facility

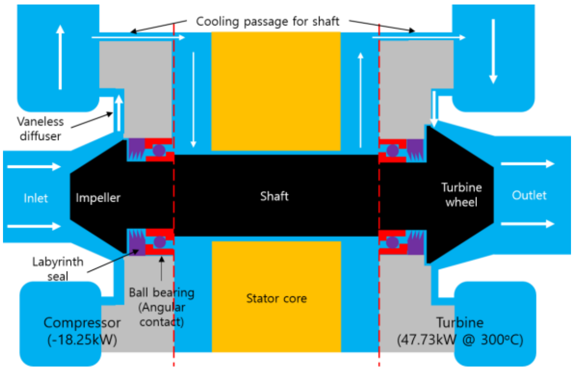

Fig. 3. Schematic diagram for flow path of S-CO_2 TAC

Table I: Specification of S-CO_2 TAC

	Centrifugal Compressor	Radial Inflow Turbine
Specific speed	0.65	0.48
Pressure ratio	1.29	1.22
Inlet temperature	31.4 °C	300 °C
Inlet pressure	7.60 MPa	9.66 MPa
Efficiency	56 %	76 %
Mass flow rate	3 kg/s	
Design speed	40,000 rpm	
Impeller type	Unshrouded impeller	
DN factor	1,560,000	
Bearing type	Agular contact ball bearing	
Backward angle at rotor exit [°]	-50 /-70	

2.2 Selection of test conditions

The test conditions were chosen considering the predicted measurement uncertainty and compressibility factor [2]. From the previous study, 1D calculation results did not showed there was no change in the S-CO_2 compressor performance with respect to change in the compressibility factor. Thus, case 2 and case 3 are chosen not only to collect low uncertainty data but also to confirm this prediction. The density decreases from cases 1 to 3. Table II summarizes the test matrix.

Table II: Selected operating conditions for compressor test

Case #	Case 1	Case 2	Case 3
Inlet pressure [MPa]	7.6	7.6	7.6
Inlet temperature [°C]	32	37	47
Density [kg/m^3]	578	263	208
Compressibility factor [-]	0.23	0.49	0.60
Relative error of efficiency [%]	77	20	13
Relative error of pressure ratio [-]	0.3	0.3	0.3

2.3 Progress of TAC test

As shown in Fig. 4, the test was conducted up to 32,000rpm, which is 80% of the design speed, under 2 MPa and 28 °C. The previous compressors were free from the axial thrust force because those were adopted as double suction type. However, the TAC should be tested by checking the axial thrust force during operation because of the difference in pressure on the left and right sides. Therefore, the test will be carried out by checking its balance using two control valves from the low pressure condition.

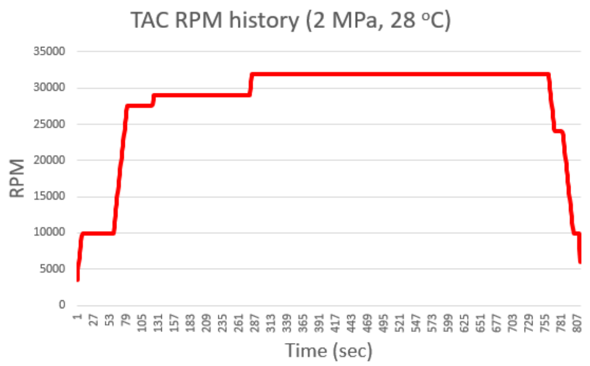

Fig. 4. RPM history of S-CO_2 TAC (2 MPa, 28 °C)

3. Summary and further works

This study summarizes the performance test plan to confirm the effect of high backsweep angle design and to collect fundamental test data for the S-CO_2 Brayton cycle. The facilities were constructed and the test conditions were adopted from the predicted measurement uncertainty and the compressibility factor.

Before the compressor performance test, the load test will be carried out from the low pressure conditions that require less axial thrust force.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government (Ministry of Science and ICT) (NRF-2019R1F1A1059915)

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