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Design of S-CO_2 TAC Test Rig for High Back sweep Angle Impeller Validation

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1. Introduction

The necessity of the next generation nuclear reactors has been constantly brought up because of the global warming, the spent fuel reprocessing, 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.

While designing a turbomachinery, the complexity of analysis and practical machinability have to be considered, which leads to fixing the design parameters from experience of each vendor. However, an S-CO_2 Brayton cycle is not yet mature power generation technology. The previous study proposed that an S-CO_2 compressor has higher isentropic efficiency as the back sweep angle increases using one dimensional mean stream-line method [2]. This paper will cover a design of TAC (Turbine-Alternator-Compressor) test rig to confirm the effect of high back sweep angle on S-CO_2 radial compressor.

2. Experiment Facility Plan

A turbomachinery in-house code, namely KAIST-TMD, is utilized to estimate a compressor design specification and select design parameters [3]. Because most constraints of the S-CO_2 TAC test rig are strongly coupled with an S-CO_2 compressor, the compressor design has been considered first.

2.1 Selection of Design Parameters

The test rig consists of two control valves, a TAC and a pre-cooler. Each control valve is located at the compressor outlet and the turbine outlet because it varies the flow resistance to control each performance. The working fluid completes a cycle through a pre-cooler to transfer the heat into water. Fig.1 and Table I represent the schematic diagram of test rig and operation conditions, respectively.

The inlet conditions of compressor just away from the critical point (T_c = 304.13 K, P_c = 7377 kPa) were selected to avoid two phase issue inside the compressor. S-CO_2 compressors have been designed mainly extreme operation 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 existing integral test loops are in the range of 3 to 4 million over the range of generally used gas bearings.

In this study, the TAC with a DN number to less than one million was considered in order to improve the operability. As shown in Fig. 2, the DN number increases when the specific speed is higher. The low specific speed was selected rather than the conventional region to be high. However, if the specific speed is too low, it is impossible to product it. Therefore, the design conditions were selected to have pressure ratio, 1.3, mass flow rate, 3kg/s, and specific speed, 0.33, to have manufacturable blade height and DN number less than a million.

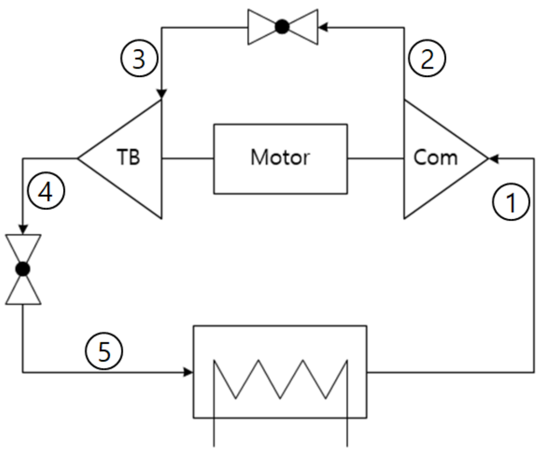

Fig. 1. Schematic diagram of S-CO_2 TAC test rig

Table I: Cycle operation conditions of S-CO_2 TAC test rig

	Temperature [K]	Pressure [MPa]
①	305	7.60
②	313	9.88
③	573	9.78
④	559	7.77
⑤	558	7.67

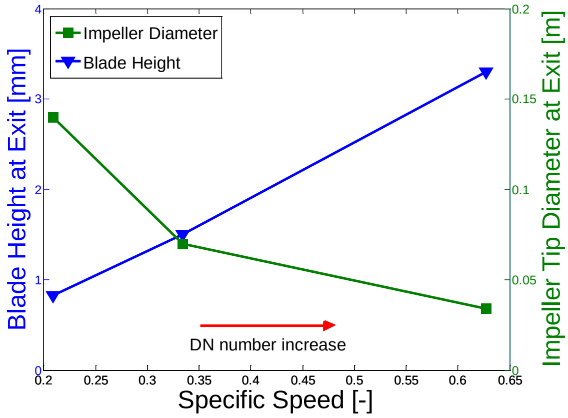

Fig. 2. Specific speed effect on radial compressor geometry

2.2 Back sweep Angle Effect

When the back sweep angle increases, the isentropic efficiency and the diameter of a compressor tends to increase. However, the back sweep angle is usually limited despite better aerodynamic performance because it leads to the structural issue. On the other hand, S-CO_2 compressor can has the higher back sweep angle when it operates near the critical point. The small compression work near the critical point can reach at its target outlet pressure as the lower tip speed. It means that S-CO_2 compressors can be more flexible from centrifugal stress when the back sweep angle increases.

In the previous study, the target outlet pressure was consistent with all cases and the diameter was a dependent variable of back sweep angle. Fig. 3 describes the radial compressor geometry and velocity triangles. The back sweep angle is beta2, blade angle at impeller exit. However, it does not match the test condition because identical stators of a compressor are utilized. In other words, the impeller diameter should be same when its back sweep angle increases.

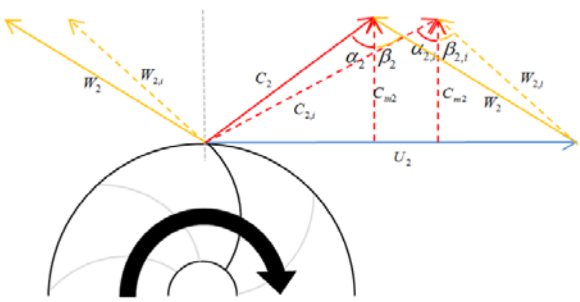

Fig. 3. Radial compressor geometry and velocity triangles

Considering the realistic constraint, the one dimensional analysis to estimate compressor performance was performed again. Fig. 4 represents its results. The effect on the pressure ratio is insignificant while the effect on efficiency is more remarkable in comparison with the results of the previous. Impellers with back sweep angle of -30 ^{o}, -50 ^{o} and -70 ^{o} will be made for future validation.

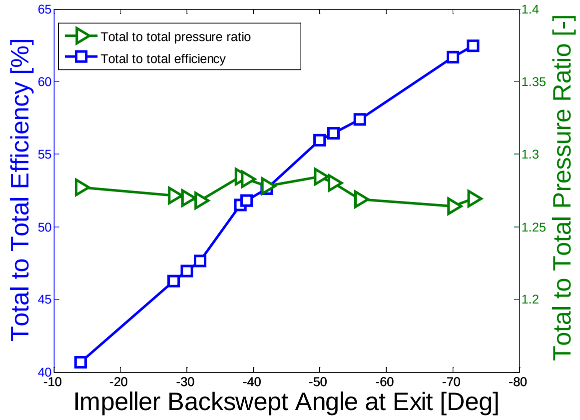

Fig. 4. Back sweep angle effect on radial compressor performance

3. Summary and further works

S-CO_2 phase change during compression, the bearing technology and blade height were considered to design cycle operation conditions of S-CO_2 TAC test rig. Its main feature compared to existing S-CO_2 compressors is to select the low DN number and the low specific speed for the ball bearing adoption instead of gas bearing or magnetic bearing. Also, impellers with back sweep angle of -30 ^{o}, -50 ^{o} and -70 ^{o} were selected for experimental validation.

The high pressure operating conditions causes large axial thrust force on turbomachinery. Thus, the turbine design that minimizes the axial thrust force based on the compressor design will be carried out.

ACKNOWLEDGEMENT

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