Supercritical CO_2 Compressor with Active Magnetic Bearing

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1. Introduction

The Supercritical CO_2 Brayton cycle power generation system has the potential as one of the future power conversion systems. The principal advantages of the sCO_2 Cycle are high efficiency at moderate temperature range, compact components size, simple cycle configuration, and compatibility with various heat sources[1]. The Supercritical CO_2 Brayton Cycle Integral Experiment Loop (SCIEL) has been installed in Korea Atomic Energy Research Institute (KAERI) to develop the base technologies for the sCO_2 cycle power generation system. The operation of the SCIEL has mainly focused on sCO_2 compressor development and establishing sCO_2 system control logic.

The installation of the SCIEL low compression loop was finished and research team succeeded in generating electric power on the supercritical state in last year. KAERI has also developed the sCO_2 Compressor supported with Active Magnetic Bearing to enhance the rotor rotation rate. In this paper, the current status of SCIEL and AMB sCO_2 Compressor are briefly discussed.

2. SCIEL and AMB sCO_2 Compressor

2.1 sCO_2 Brayton Cycle

The Gen-IV reactor system can achieve higher cycle efficiency than the Pressurized Water Reactor since the core outlet temperature is higher than that of the steam Rankine cycle. The development of sCO_2 Brayton cycle technology was started to combine experiences and advantages from the gas turbine technology and steam Rankine cycle technology to fully utilize Gen-IV reactor potential. The principal advantages of the sCO_2 cycle are high efficiency at moderate temperature in the range of 450~700^{o}C, compact component size, and simple cycle configuration.

Despite of these advantages, sCO_2 Brayton cycle has technical challenges on handling dramatic change in thermodynamic properties near the critical point, operation experience, system control logic development, and material data base. If its technologies mature enough for stable operation, high economic advantages can be expected from applying the sCO_2 Brayton cycle to the Gen-IV reactor[1].

KAERI has designed and constructed an integral loop named as Supercritical CO_2 Brayton Cycle Integral Experiment Loop (SCIEL).

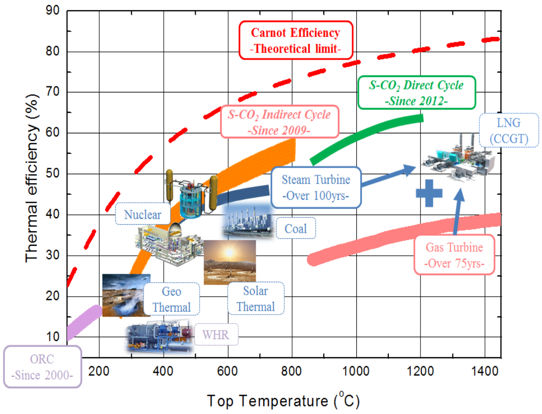

Fig. 1. Efficiency of Various Power Cycles

2.2 SCIEL Facility

To provide the fundamental data and develop key technologies about system operation for the plant grade sCO_2 Brayton cycle demonstration, KAERI developed 300kWe sCO_2 Test Loop SCIEL with KAIST and POSTECH. The main design parameters and layout are summarized in Table 1 and Fig. 2, respectively.

Table 1. The main design parameters of SCIEL

TIT	500℃	Cycle layout	Recuperated
COP	20MPa	Target CIT	33.2℃
CIP	7.78MPa	Recuperator effectiveness	85%
Turbine efficiency	85%	Heater / Pre-cooler ΔP	400kPa /200kPa
Compressor efficiency	65%	Recuperator HS / CS ΔP	300kPa /100kPa

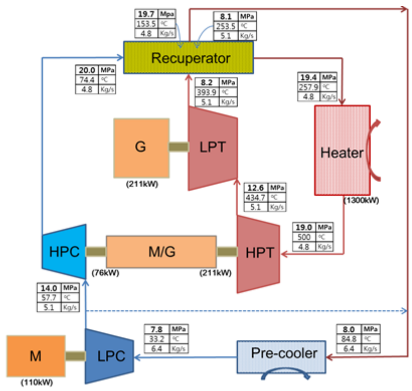

Fig. 2. The final cycle layout of SCIEL

As the design pressure ratio is set higher than the existing S-CO_2 integral system loops, such as Sandia National Lab (SNL), Bettis Atomic Power Lab (BAPL), the two-stage of compression and expansion process is considered. By utilizing the low pressure compressor (LPC) and the low pressure turbine (LPT), the loop test of simple Brayton cycle can be carried out. For the high pressure ratio operation, the high pressure compressor (HPC) and the high pressure turbine (HPT) will be added to simple Brayton cycle as Turbo-Alternator-Compressor (TAC) type. Thus, integral experiment loop adopts the stepwise upgrade plan in order to develop element technologies and conduct various experiments. As the compressor and turbine are not mechanically connected, they operate at different rotating speed.

Twin and shrouded impeller concept was newly introduced to control an axial thrust load in the compressor which is the key technology for stable operation of sCO_2 compressor operation. The concept of shrouded impeller can fundamentally resolve the axial thrust balancing issue by canceling out the pressure difference of the front and back surface of the compressor wheel. Also, the shrouded impeller has a benefit to reduce the clearance loss of impeller[2].

The electricity generation test of sCO_2 closed Brayton cycle was also conducted at compressor inlet condition, 7.5MPa and 32℃, and compressor shaft speed, 24,500RPM. The power generation was performed in the low turbine inlet temperature region since the compressor supporting force should be enhanced. Research team succeeded in generating electric power around 1.2kW on the supercritical state.

2.3 Active Magnetic Bearing

The current sCO_2 compressor of the SCIEL has gas foil bearings to support a rotor which drives impellers at both sides. In case of gas foil bearing, there is some instability at the clearance between rotor and bearing due to high Reynolds turbulent flow of the sCO_2 inherent high density property. Instead of gas foil bearing, Active Magnetic Bearing technology is adopted to control the supporting force of rotor. AMB controls rotor position with the electromagnetic force and gap sensor signal. The advantage of AMB is non-contact lubrication free, and low vibration. Thus, it is possible to operate high rotation rate.

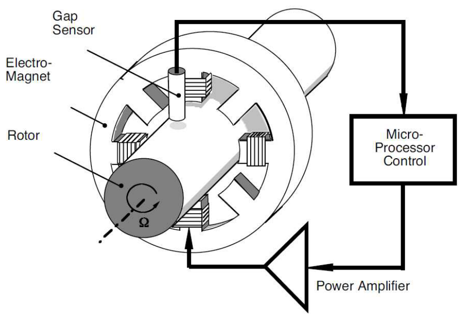

Fig. 3. Schematics of AMB rotor control

2.4 AMB sCO_2 Compressor

The objective of sCO_2 AMB turbomachinery development is to obtain the high rotation bearing technology in the supercritical fluid for the high temperature environment at around 300°C. Fig. 4 shows sCO_2 AMB compressor assembly, which includes gas foil trust bearing and AMB journal bearing. In case of trust bearing, its performance was already confirmed from the previous operation test. Thus, we only designed journal bearing by modification of previous sCO_2 compressor with gas foil bearings.

Table 2. Design Value of AMB sCO_2 Compressor

Rotation rate [RPM]	70,000	
Rotor mass [kg]	11	
Radial	Static load [N]	108
	Unbalance mass [g-mm]	3.75
	Omega square [(rad/s)^2]	53,734,512
	Dynamic load [N]	201.51
	Bearing load [N]	309.5

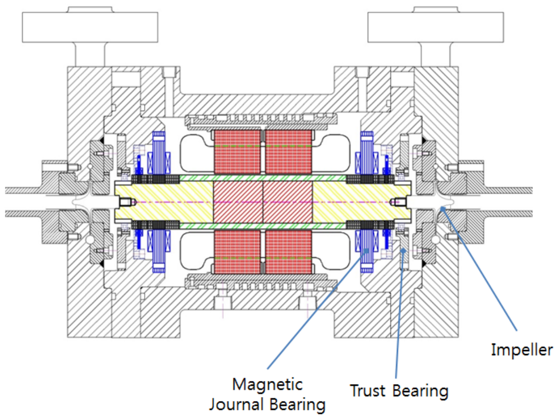

Fig. 4. Schematics of SCIEL AMB sCO_2 Compressor

3. Summary

For the stable operation of the sCO_2 integral test facility SCIEL, KAERI prepared Active Magnetic Bearing sCO_2 compressor for the 70,000RPM operation. Power generation test with AMB compressor will be finished within first half year of 2016 under supercritical state.

REFERENCES

[1] Dostal, V., et al., A Supercritical Carbon Dioxide Cycle for Next Generation Nuclear Reactors, MIT-ANP-TR-100, 2004.

[2] J. E. Cha, et al., "Current Status of the Supercritical CO_2 Brayton Cycle Integral Experiment Loop", The 7th China-Korea Workshop on Nuclear Reactor Thermal-Hydraulics, WORTH-7 Kunming, China Oct. 14~17, 2015.