Effect of Large Backswept Angle S-CO_2 Compressor to System Part Load Performance

NQe Department of Nuclear & Quantum Engineering
KAIST

Bong Seong Oh[a], Seong Kuk Cho[b], Jeong Ik Lee[a]*,

a. Dept. of Nuclear & Quantum Engineering, KAIST, 373-1, Guseong-dong, Yuseong-gu, Daejeon, 305-701, Republic of Korea

b. Environment & Energy Research Laboratory, Research Institute of Industrial Science & Technology, 67, Cheongam-ro, Nam-gu, Pohang-si, Gyeongsangbuk-do 37673, Repulic of Korea

Introduction

▣ KAIST-MMR has around 30% thermal cycle efficiency because the cycle layout is a simple recuperated cycle whose thermal efficiency is compromised with the compactness and the compressor inlet temperature of the system is selected for 60ºC because it was designed to cool by air for being independent on the regional environment

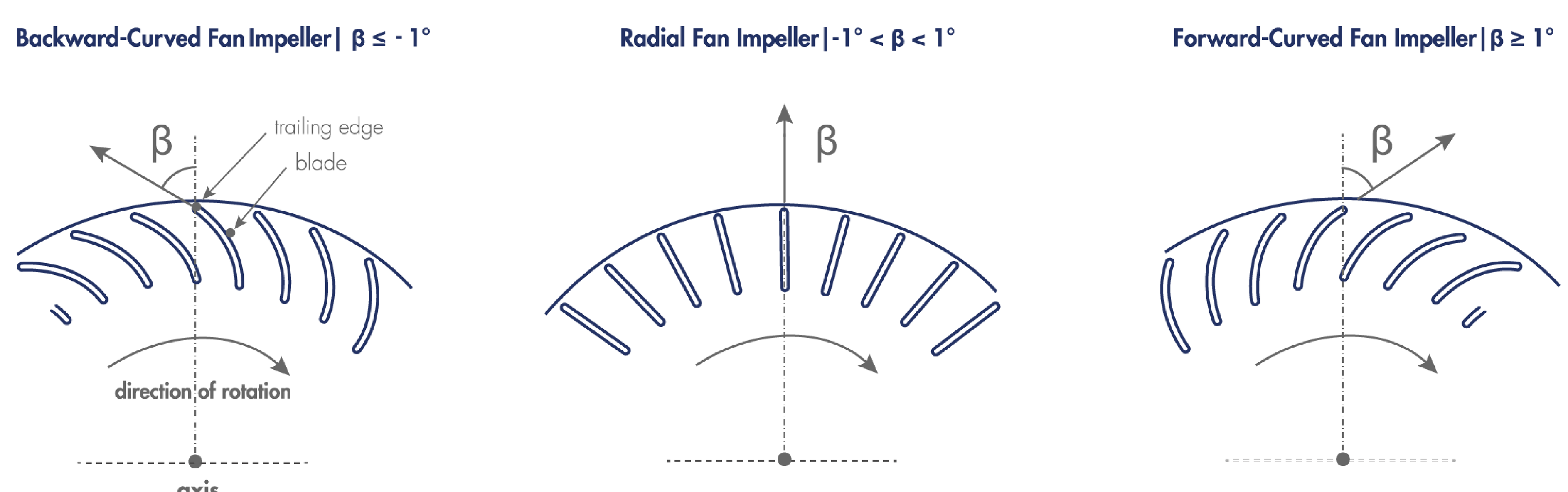
▣ To increase the thermal efficiency during the load following, a compressor with high efficiency and enough surge margin is required to enhance overall system performance

▣ Large backswept angle compressor was proposed as the compressor with high efficiency and enough surge margin but the study in terms of overall system has not been conducted

▣ In this study, the system performance of KAIST-MMR will assessed when -50º backswept and -70º backswept angle compressors are applied

▲ Conceptual diagram of KAIST-MMR

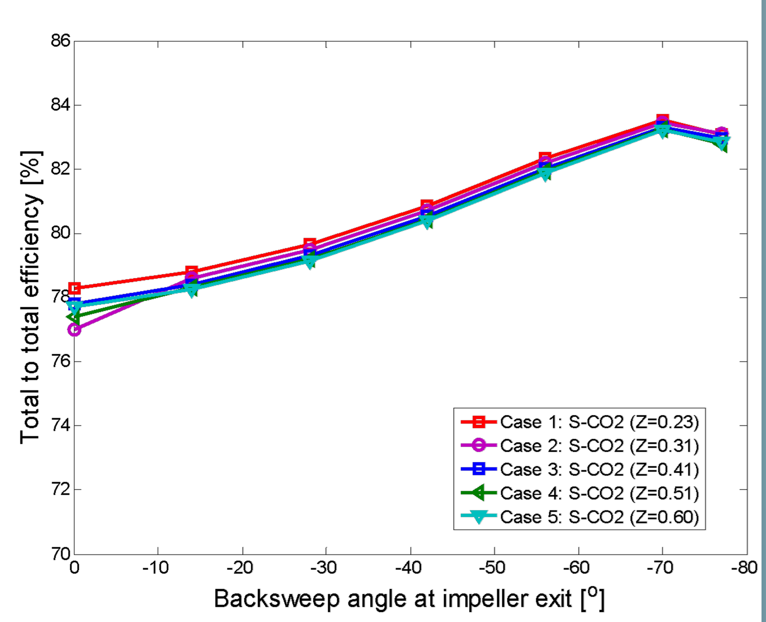
Large Backswept Angle Compressor



▲ The definition of backswept angle of centrifugal compressor

Effect of large backswept angle

- The S-CO_2 centrifugal compressor showed the best efficiency at -70º back swept angle, which is larger than the typical design value for the air centrifugal compressor, -50º
- The cases represents that the how CO_2 fluid has the characteristics of ideal gas as the Z is close to 1.0. This means that the S-CO_2 compressors have high efficiency when the backswept angle is larger regardless of the inlet conditions (i.e. how far from the critical point)



▲ Compressor efficiency with respect to backswept angles

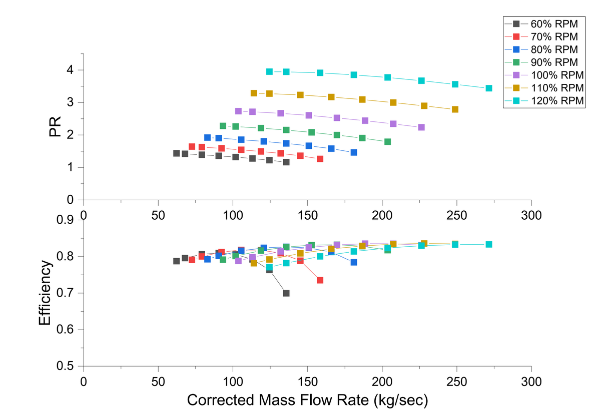
Conclusions

- The performance map of a large backswept angle compressor shows slightly higher efficiency at the design point and low surge mass flow rate
- Large backswept angle compressor has more sloped pressure ratio map so that integral gains of the major controllers are higher
- Large backswept angle compressor can adopt inventory control for the lower power load level because the compressor has lower surge mass flow rate
- It means that system with large backswept compressor has much higher part load efficiency at the low power load level
- Therefore, the large backswept angle compressor could be effectively utilized in the application of frequently changed power systems

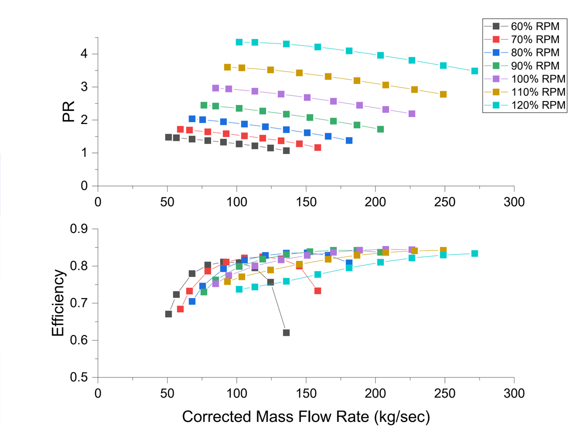
Part load simulation

50º and -70º compressors of KAIST-MMR

- -70º compressor's performance map has more slope in pressure ratio
- At the same rotational speed, -70º compressor has lower surge mass flow rate than -50º, i.e. enough surge margin for -70º compressor (Approximately, 20% low surge mass flow rate for -70º compressor)



▲ -50º compressor map



▲ -70º compressor map

Table. System performance when applying two compressors

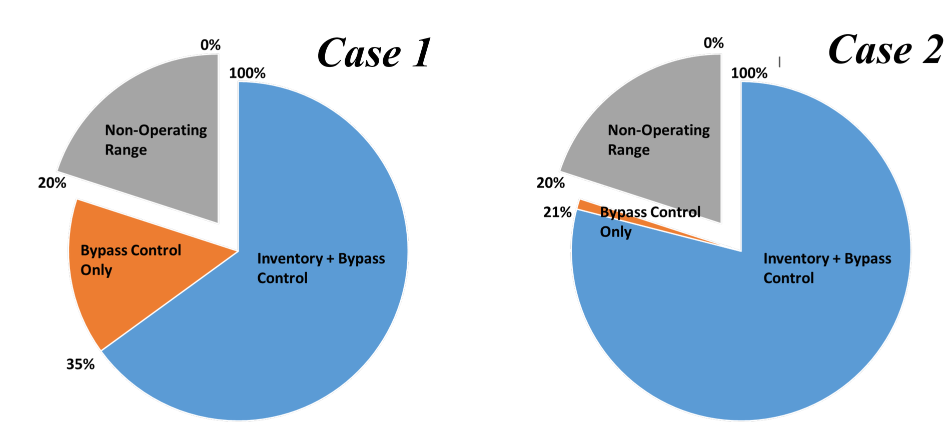
	Parameter	Case 1	Case 2
		-50º compressor	-70º compressor
Power	Core power	36.18 MW_{th}	
	Net Work	12.91 MW	12.98 MW
Efficiency	Compressor efficiency	83.5%	84.3 %
	Cycle efficiency	35.7 %	35.9 %

Controller design of two cases

- Compressor inlet temperature, turbine bypass, inventory controllers are optimized for two cases
- For two cases, CIT controller results show the very similar because the compressor power is almost identical for two compressor
- Since -70º compressor has more sloped pressure ratio performance, the large integral gain is obtained
- For control logic, case 2 has broad inventory control operation range because -70º compressor has enough surge margin so that it is possible to regulate system inventory to the 20% grid power demand
- However, for case 1, inventory control should be switched as bypass control because it has large surge mass flow rate

Table. Optimized Controller gains of Case1 and 2

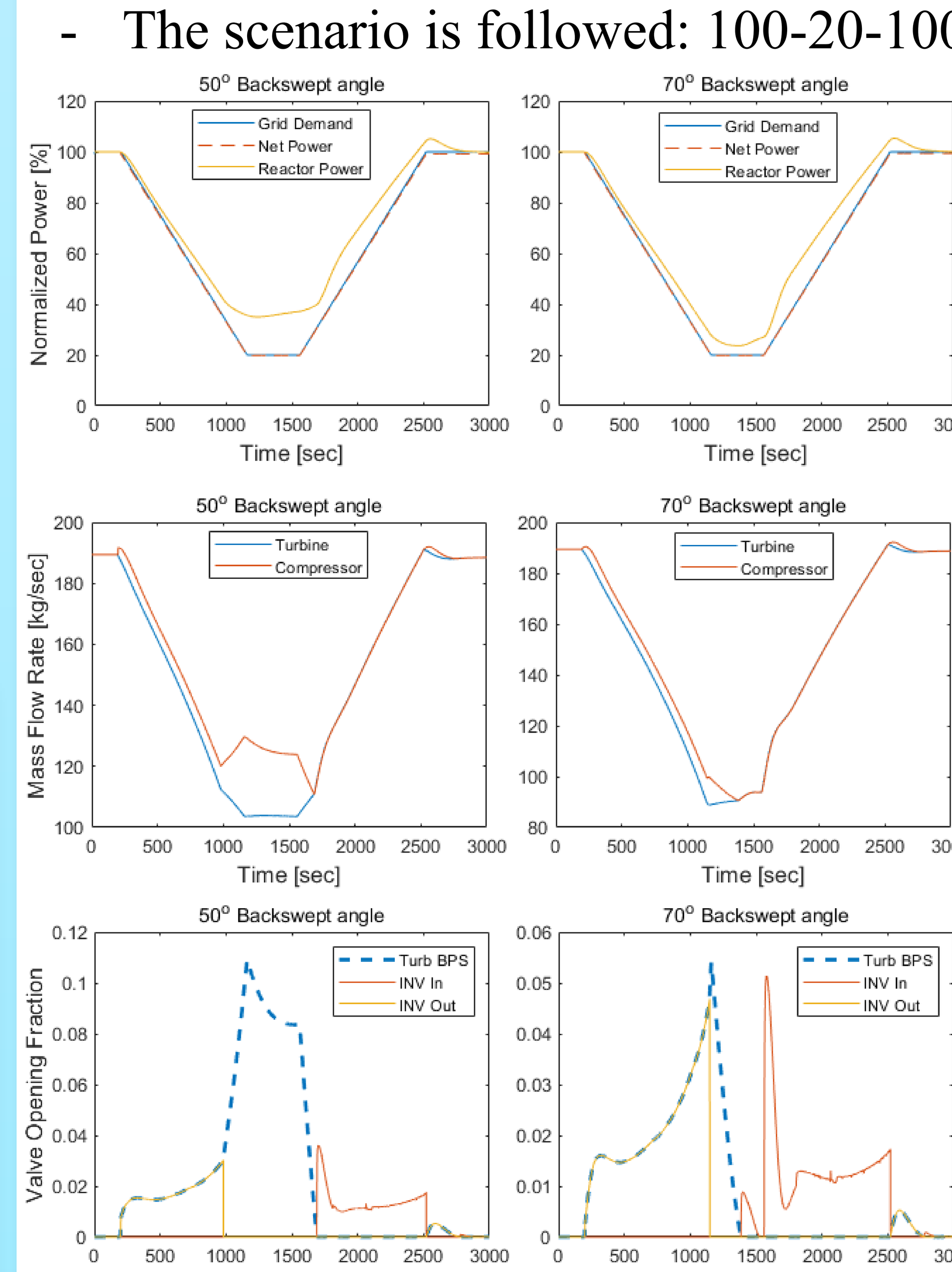
	Comp Inlet Temperature		Turbine Bypass Controller		Inventory Controller	
	-50º	-70º	-50º	-70º	-50º	-70º
K_{cr}	50.0	50.0	110.0	130	40.0	40.0
T_{cr}	53.0	57.0	9.0	4.0	16.0	2.0
K_p	20.0	20.0	44.0	52.0	16.0	16.0
T_I	42.4	45.6	7.2	3.2	12.8	1.6
P gain	20.0	20.0	44	52.0	16.0	16.0
I gain	0.47	0.44	6.1	16.25	1.25	10.0



▲ Control logic of Case 1 and 2

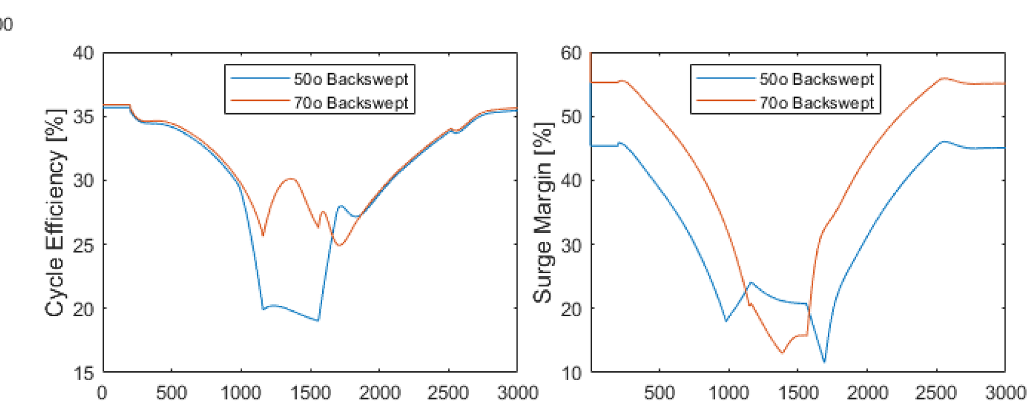
Part load results

- The scenario is followed: 100-20-100% with 5%/min rate



▲ System performance during 100-20-100% load

- System's net power is well fitted to the grid demand for both cases
- Due to the inventory control, system pressure can be reduced further for -70º compressor, reactor power can be decreased so that the off-design efficiency is much higher for -70º compressor while keeping 10% surge margin



▲ Part load efficiency (left) and surge margin (right) of MMR with -50º and -70º compressors