Start up Modeling of KAIST Micro Modular Reactor Compressor Using Beta line Method with GAMMA+

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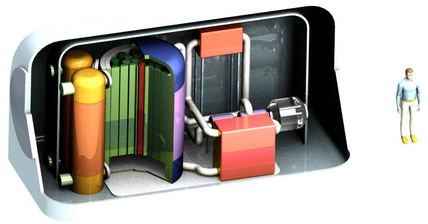
Introduction

- KAIST developed an sCO_2 cooled nuclear system, called KAIST Micro Modular Reactor (MMR), for supplying distributed power source by transports such as trailers, ships and trains.
- In this work, start up procedure of MMR compressor from zero rotational speed to nominal state is modeled before start up of whole system.



➢ Figure. Configuration of MMR

Methodology

Low speed extension method

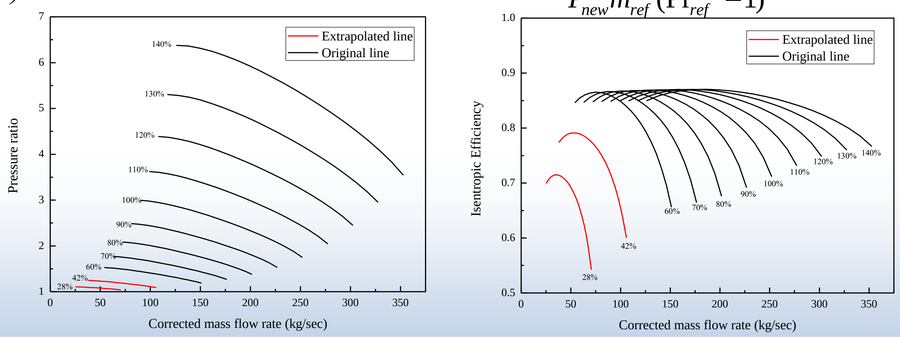
- The performance map of turbomachines rarely can be extended to the low speed region because of the unsteady nature of low speed conditions, so that physical and empirical extension method is needed.
- For this, the similarity laws of incompressible fluid are introduced because the pressure rise is small enough that the effects of compressibility can be negligible in the low speed region.

$$\frac{\dot{m}_{new}}{\dot{m}_{ref}} = \left(\frac{N_{new}}{N_{ref}}\right) \qquad \frac{W_{new}}{W_{ref}} = \left(\frac{N_{new}}{N_{ref}}\right)^2 \qquad \frac{P_{new}}{P_{ref}} = \left(\frac{N_{new}}{N_{ref}}\right)^{2.75}$$

- From above similarity laws, Agrawal and Yunis derived pressure ratio and isentropic efficiency of compressor map based on the ideal gas assumptions.

$$\mathrm{Pr}_{new} = \left(1 - \frac{W_{new}}{C_{p,in}T_{in}}\eta_{ref}\right)^{\frac{\gamma}{\gamma-1}}$$

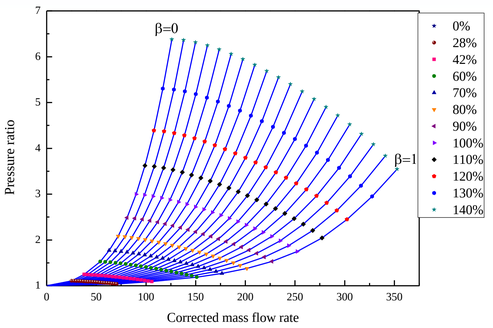
$$\eta_{new} = \frac{\dot{m}_{new}C_{p,in}T_{in}\left(\mathrm{Pr}_{new}^{\frac{\gamma-1}{\gamma}}-1\right)}{P_{new}} = \eta_{ref}\frac{P_{ref}\dot{m}_{new}\left(\mathrm{Pr}_{new}^{\frac{\gamma-1}{\gamma}}-1\right)}{P_{new}\dot{m}_{ref}\left(\mathrm{Pr}_{ref}^{\frac{\gamma-1}{\gamma}}-1\right)}$$



➢ Figure. Extrapolated compressor map

Application of beta line method

- Beta line method utilizes an auxiliary coordinate for the pressure ratio map as the following figure:
- the independent parameters to interpolate pressure ratio and isentropic efficiency become compressor speed and beta value.
- This means the interpolation of pressure ratio with respect to the corrected mass flow rate becomes non-sensitive to the shape of pressure ratio curve after BETA line is newly introduced.



Result

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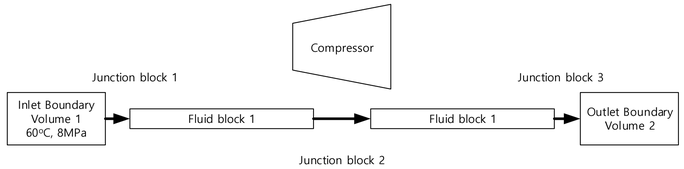


➢ Figure. MMR Compressor test section in GAMMA+ code, which is an system code for sCO_2 systems

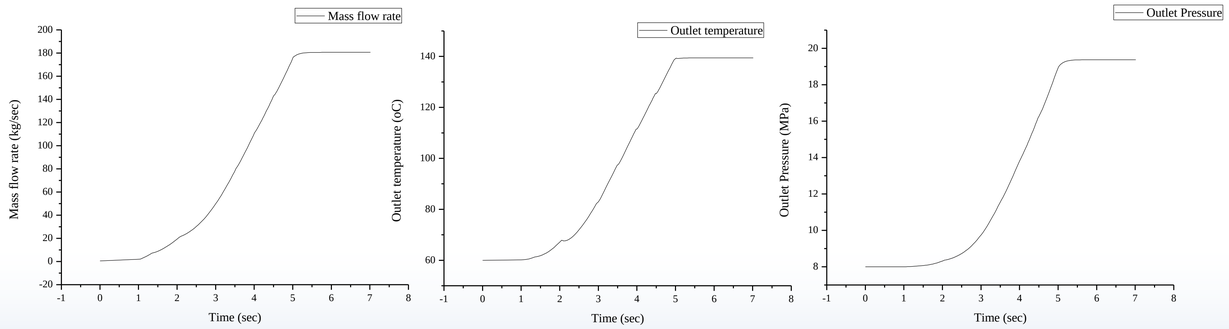
Boundary condition

1. Fixed compressor inlet (60°C, 8MPa) 2. Given compressor speed (20% increase/s)

➢ Table. On-design points of MMR compressor

Rotational speed	Mass flow rate	Outlet pressure	Outlet temperature
19,300 RPM	180 kg/sec	20 MPa	142.2 °C

- Compressor start up result.



➢ Figure. Mass flow rate (1), Compressor outlet temperature(2), outlet pressure (3) vs. time during startup