Process Control Strategy for ITER CS Operation (C-PREST)

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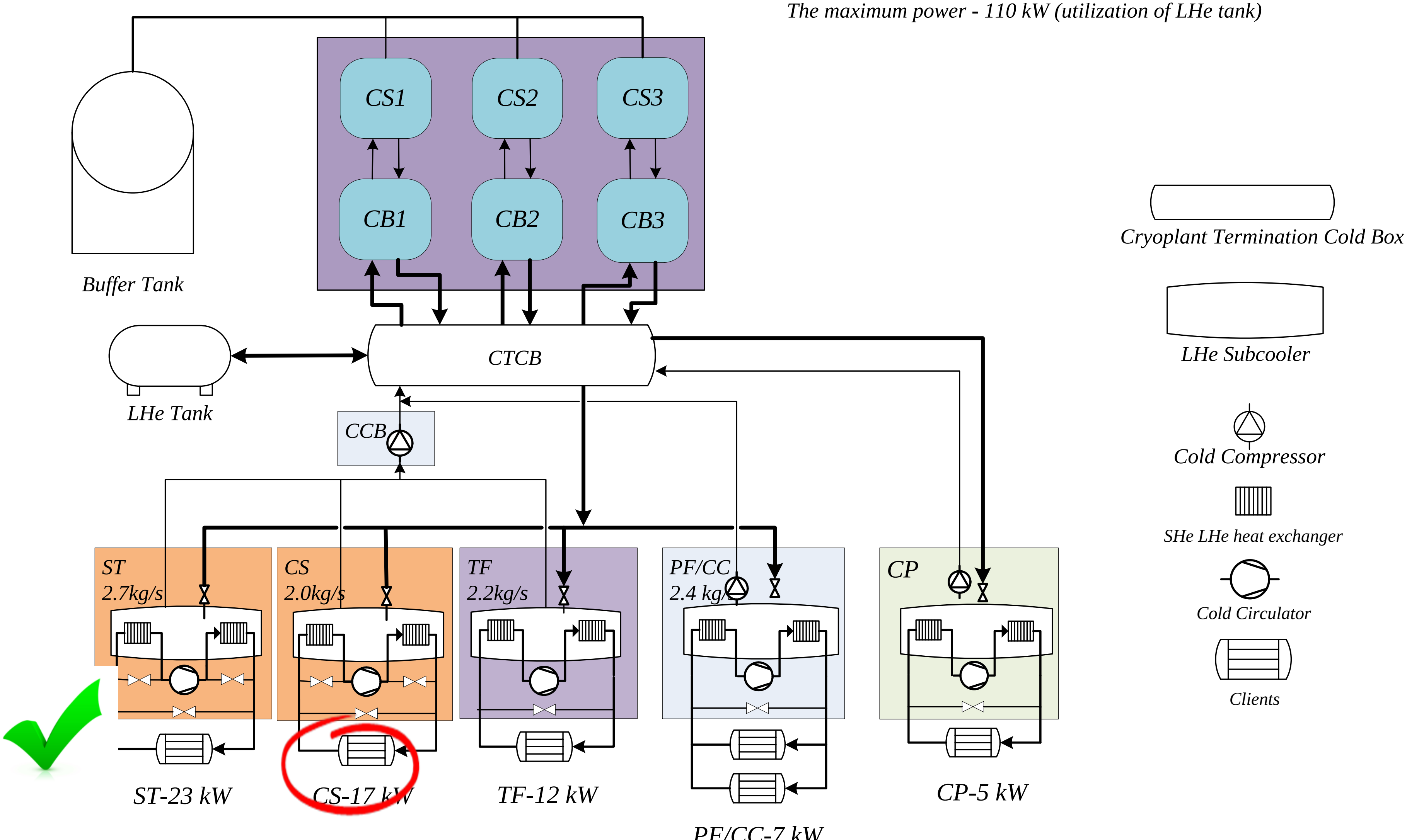
ITER Cryogenic System

Cryoplant 25kW x3 CBs

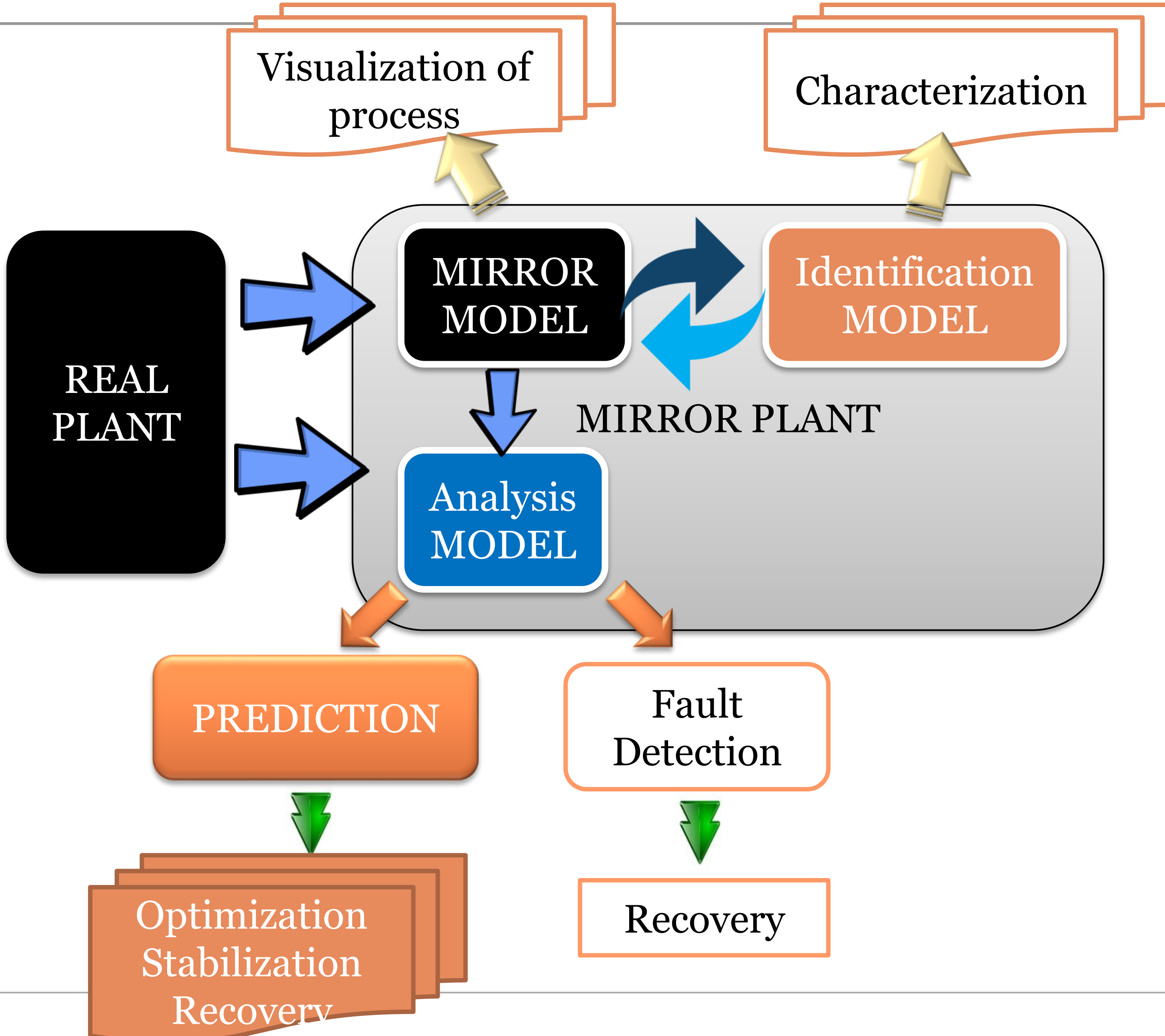
Nominal operation - 75 kW
The maximum power - 110 kW (utilization of LHe tank)



Design value for HX

Target for process simulator development

Mirror Plant



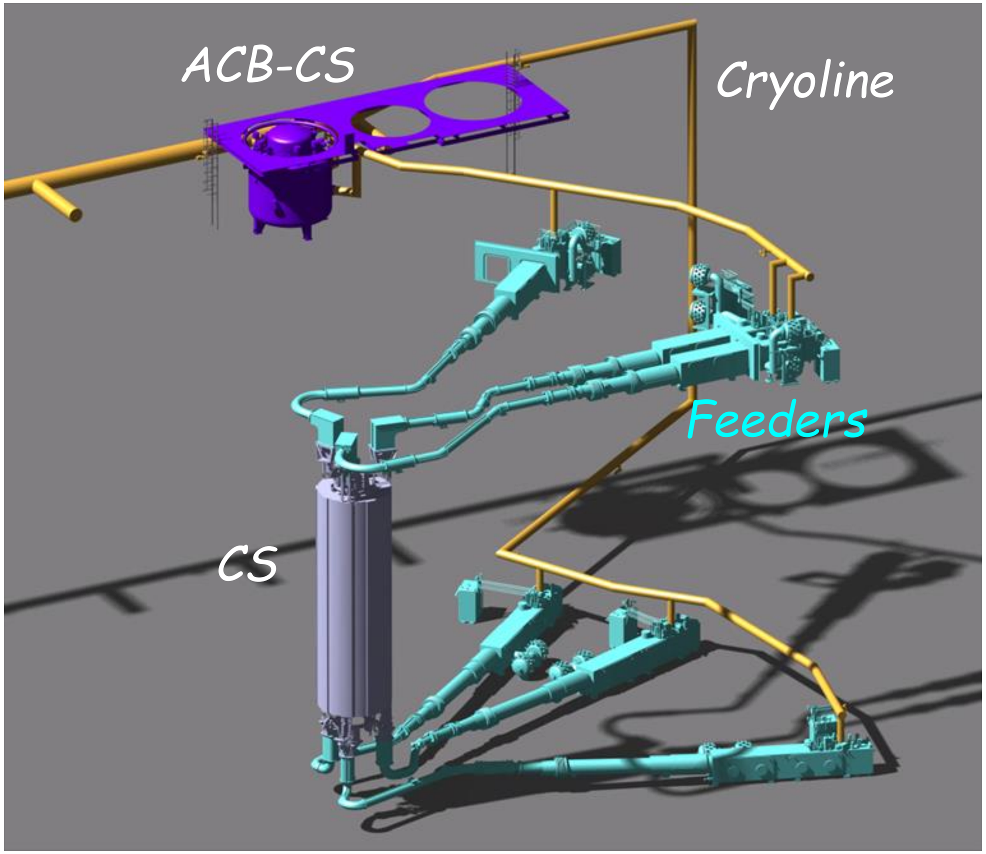
- reference "Yokogawa Technical Report English edition Vol.56 No.1 (2013)

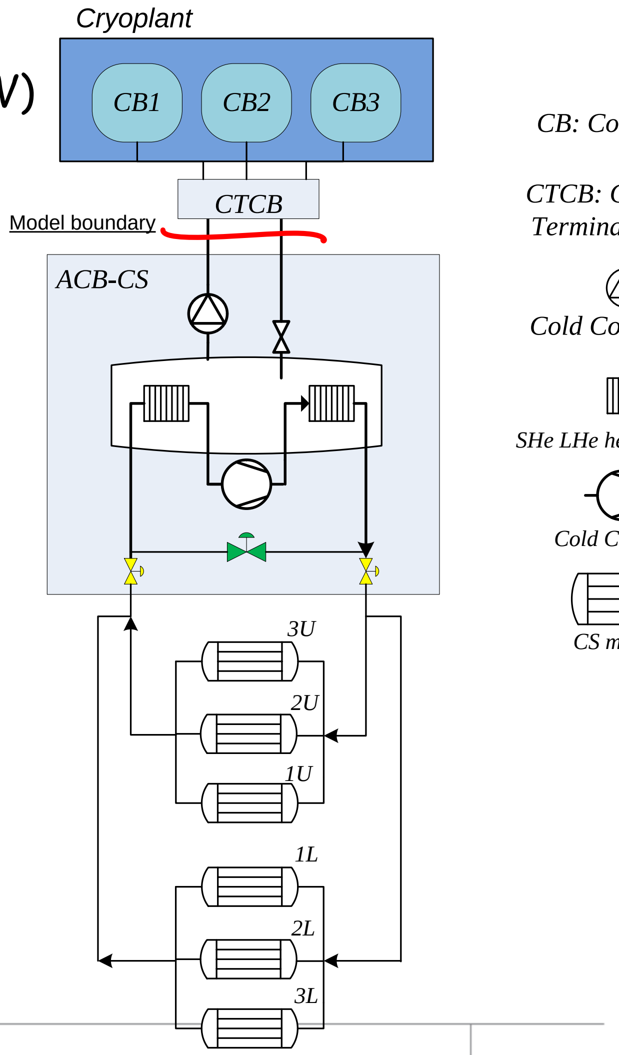
Outline

- Objective
- Simulation model
- Dynamic simulation
  - Nominal operation
    - Impact on cold circulator/compressor
      - Cold circulator
        - » feedback Anti-Surge-Control
      - Cold compressor
        - » feedback ASC
        - » Mitigation by Circulator speed
- Conclusion

Objective

- Identify potential risks during 15MA baseline operation
  - CS IM → Risk of surge for **circulator**
  - POS→ Wide operation range for **compressor** (5-16kW)

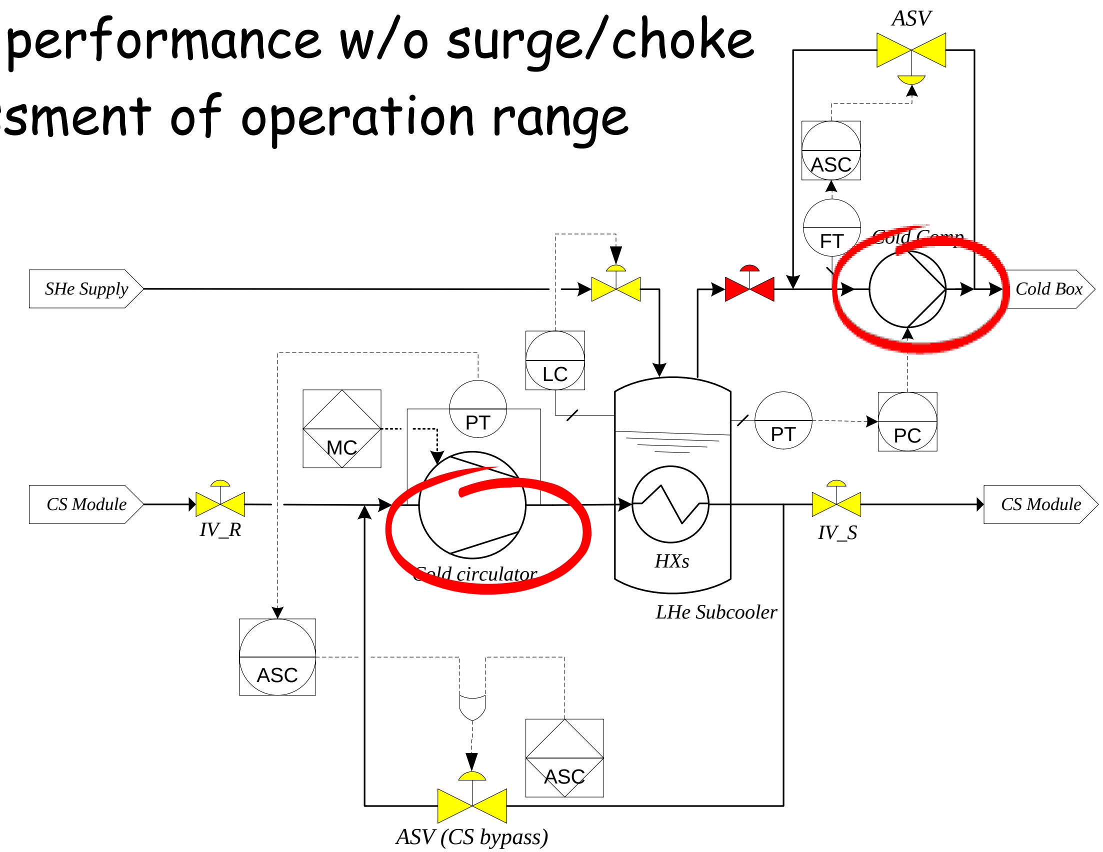




15 MA Baseline-nominal

- Requirement→ Constant SHE supply to CS
- Neglecting the impact on circulator & compressor
  - Ideal performance w/o surge/choke
  - Assessment of operation range

Return from CS



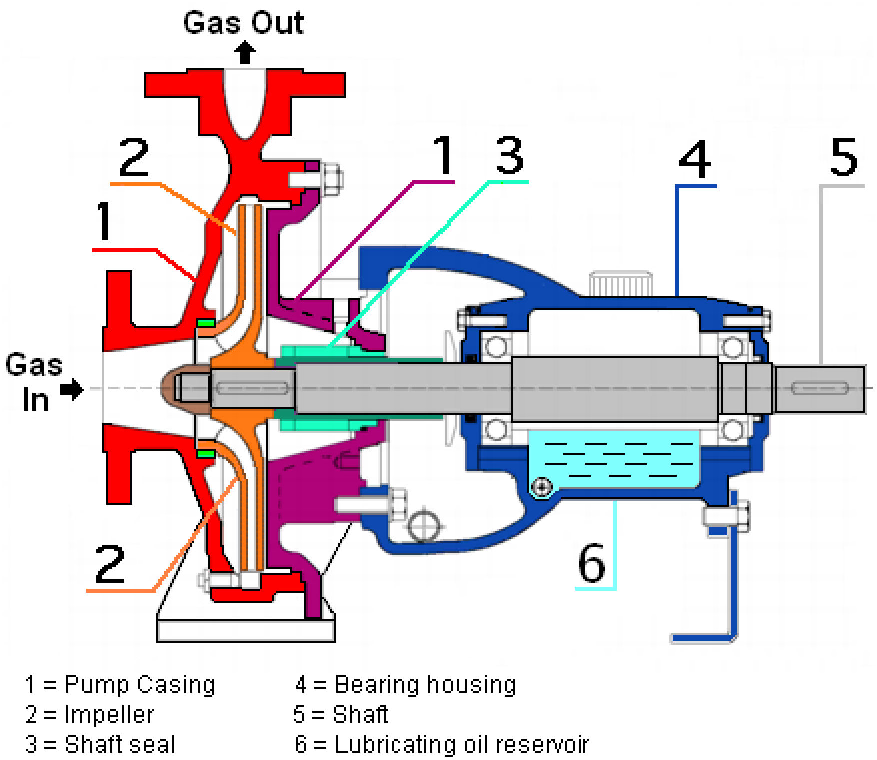
Supply to CS

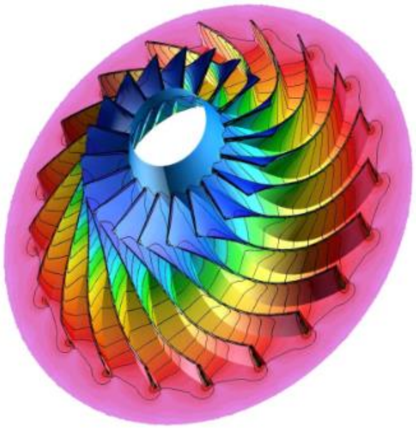
ASC: Anti-Surge Controller
PT: Pressure Transmitter
MC: Mitigation Control

ASV: Anti-Surge Valve
LC: Level Controller
FT: Flow Transmitter

IV_S: Isolation Valve Supply
PC: Pressure Controller

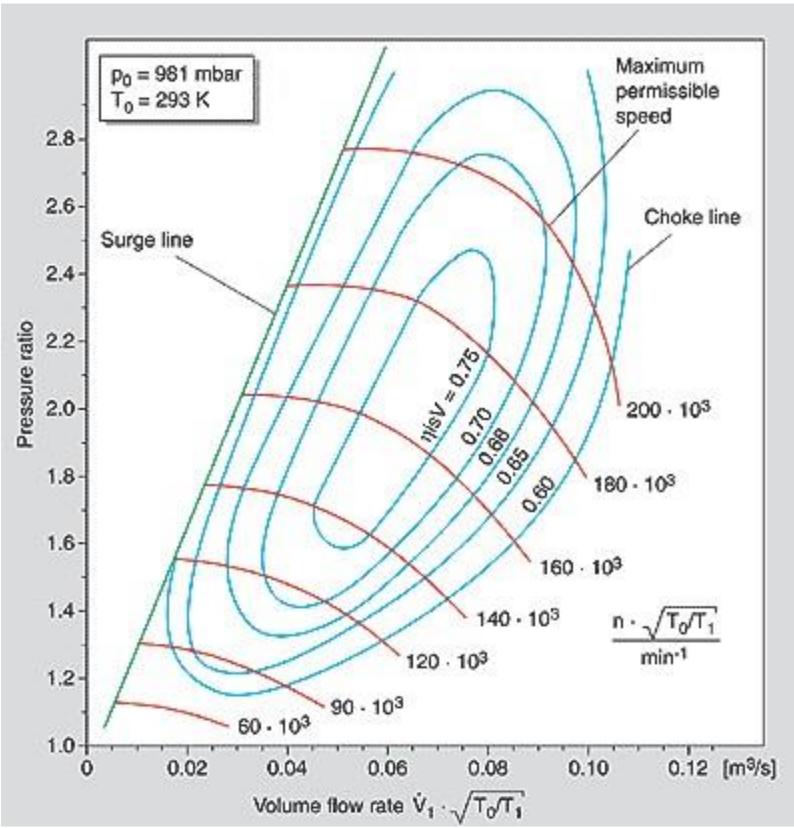
IV_R: Isolation Valve Return
HX: Heat Exchanger





CENTRIFUGAL TYPE CIRCULATOR/COMPRESSOR

Centrifugal type cold circulator/comp.

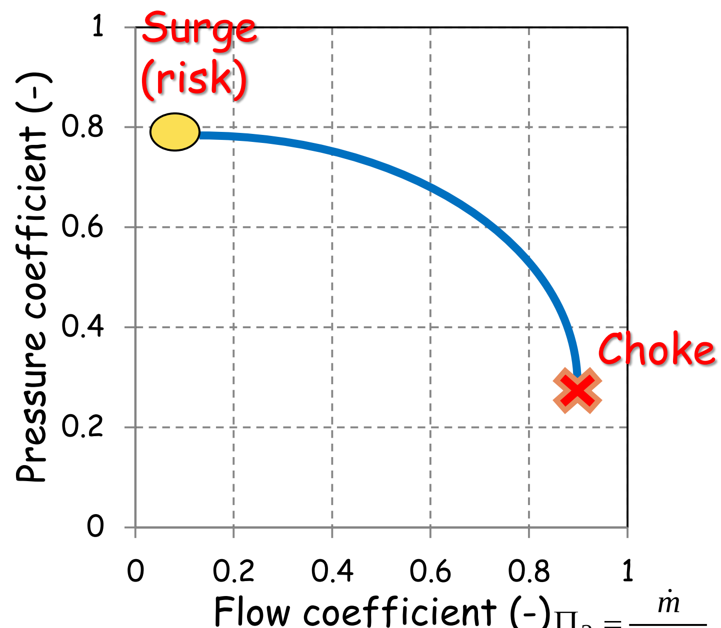


From
http://www.theturboforums.com/turbotech/img_21_principle_g.jpg

http://www.grc.nasa.gov/WWW/5810/rvc/swift.htm

<u>Characteristic Curve for circulator/comp. normalized</u>

$$\Pi_1 = \frac{dP}{D^2 n^2}$$



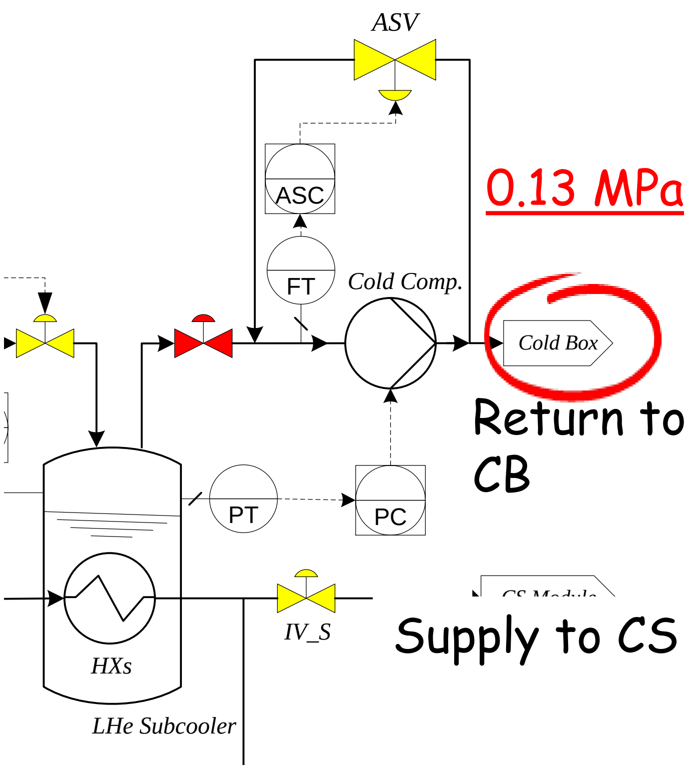
$$\Pi_2 = \frac{\dot{m}}{\rho D^3 n}$$

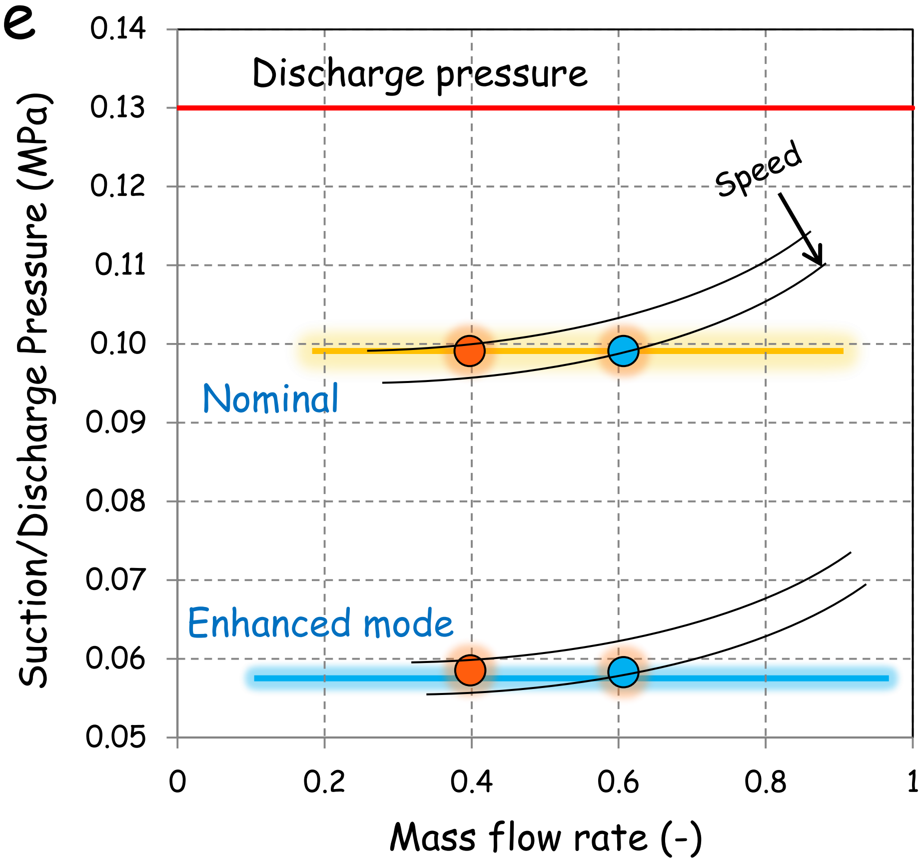
Operation boundary

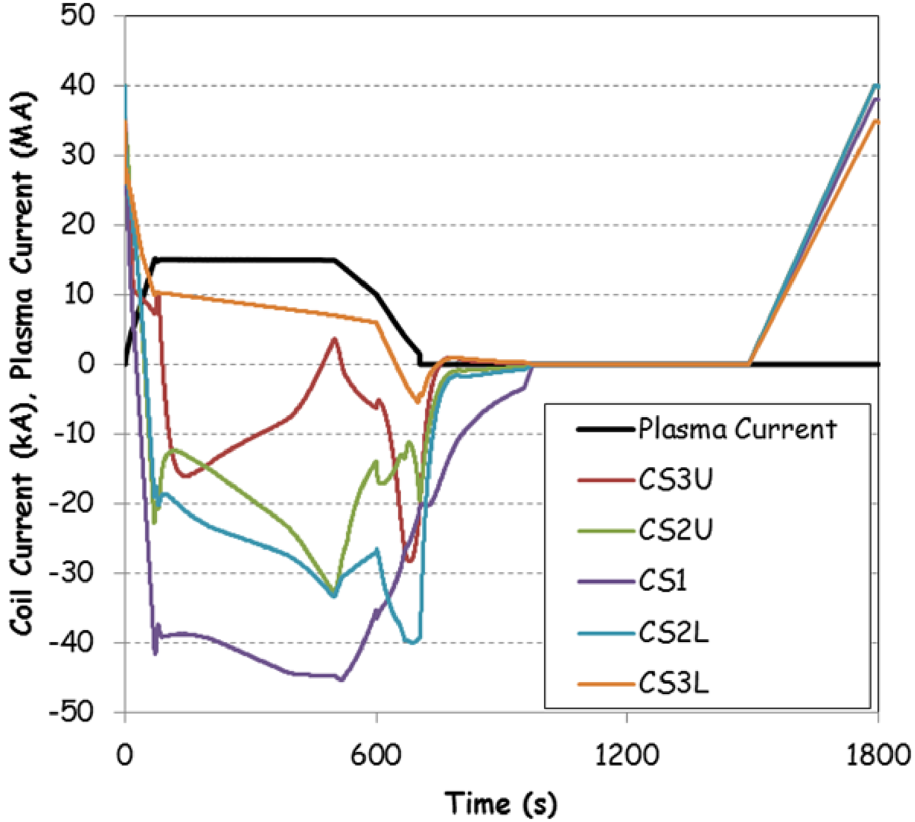
- Surge/choke
- <u>Self protection sequence</u>

Centrifugal type cold compressor

- Imposed boundary condition at the discharge side!
- Limited operation range

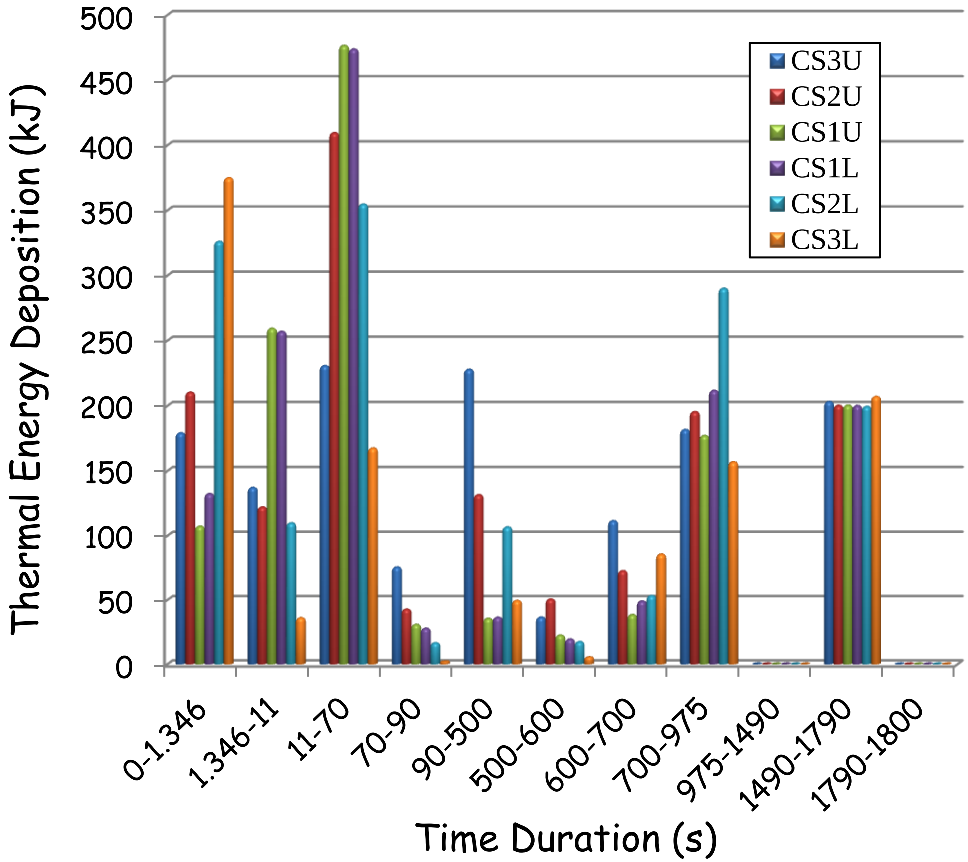






15 MA BASELINE-NOMINAL

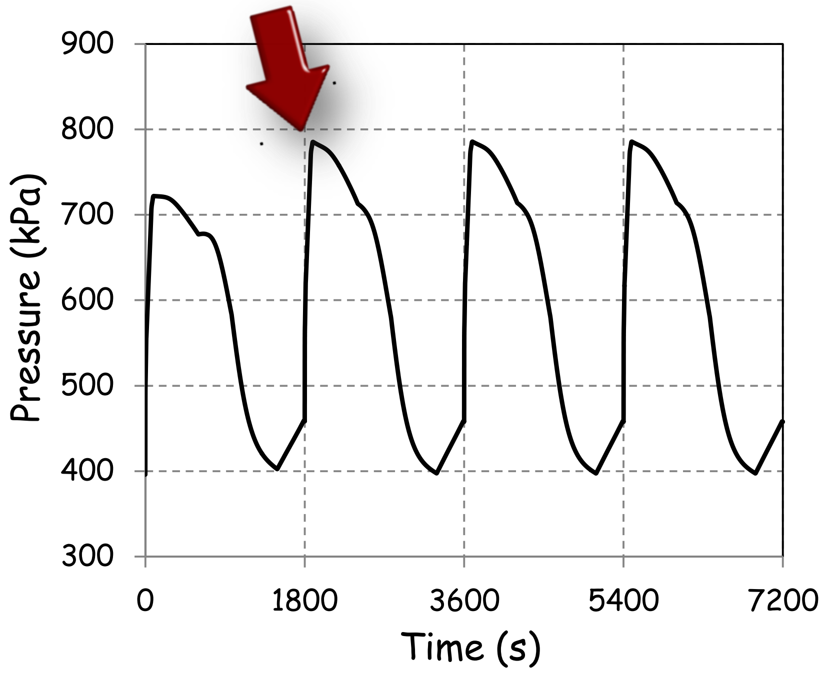
Dynamic heat load (Plasma Operation State)

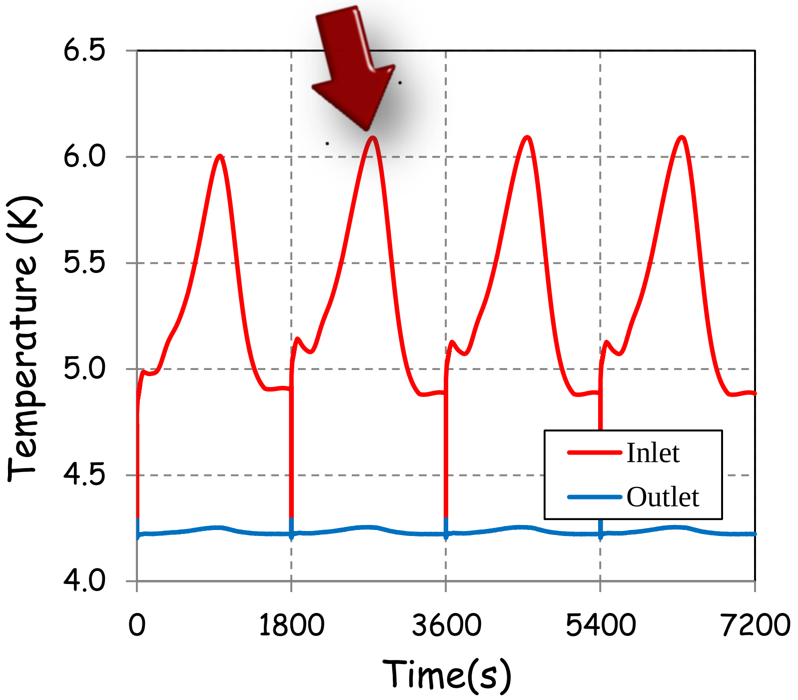


- 8 MJ in 1800 s
  - 50% deposition within 70 s

Impact on the Cooling loop

- Substantial variation of P and T
  - Identical pressure/temp. profiles after 2nd pulse
  - "stability of operation"

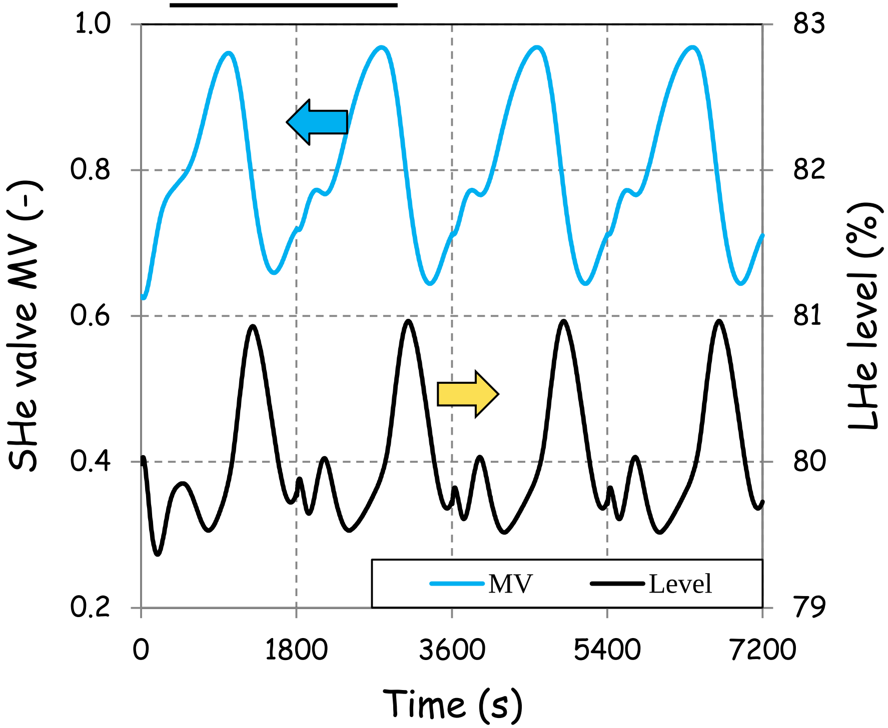




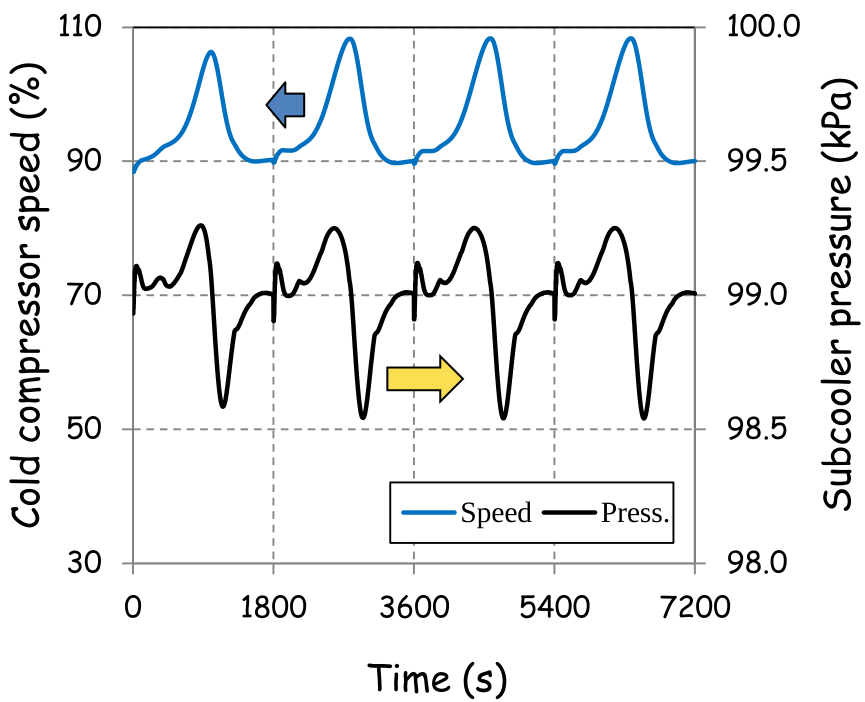
Regulation at LHe subcooler

- Good tracking performance against huge variation of process values

LHe Level

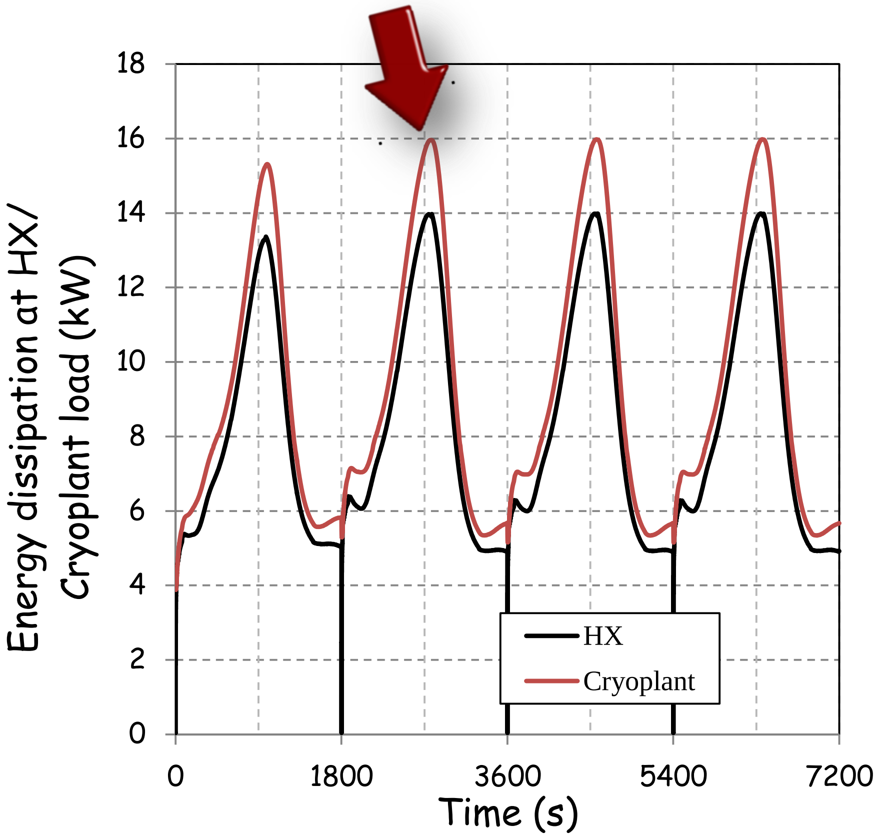


PRESSURE



HX & Cryoplant

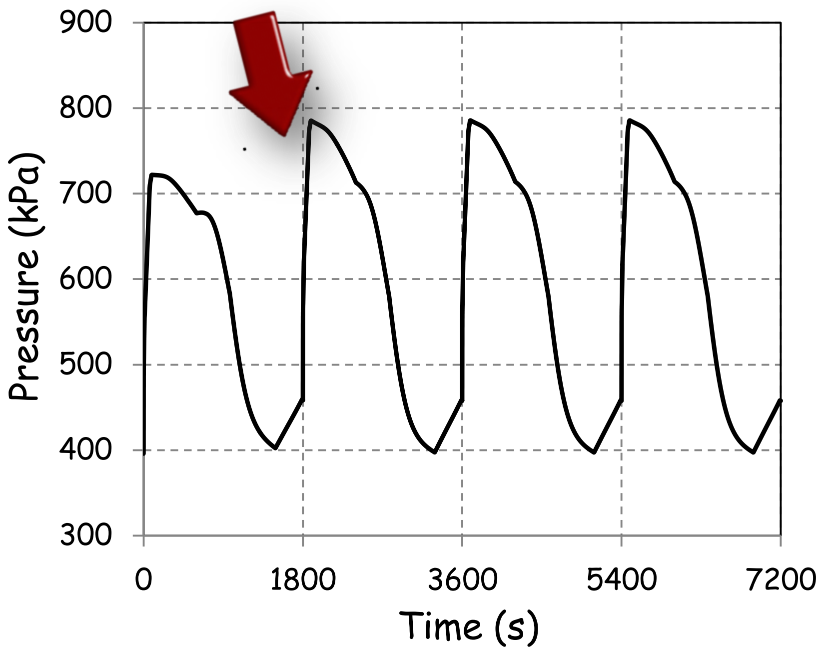
- Thermal energy dissipation at HX→ sizing
- Resulting heat load to Cryoplant



Process control-nominal operation

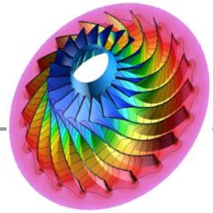
- Demonstrate satisfactory tracking performance w/ a classical PI control
  - Feasibility of sustaining CS operation

- OPEN ISSUE
  - Assessment of cold Circulator/Compressor…



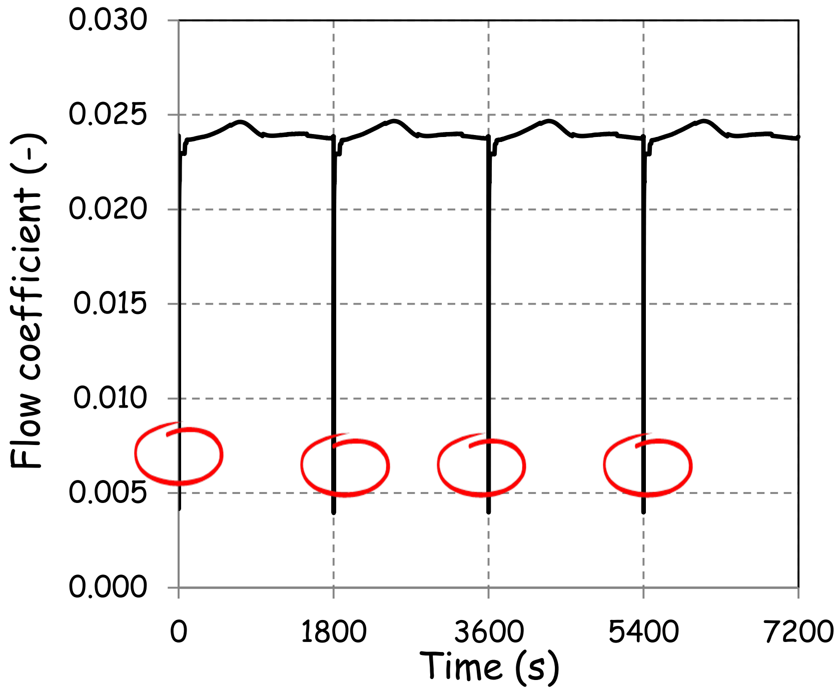
IMPACT ON CENTRIFUGAL TYPE COLD CIRCULATOR AT IM

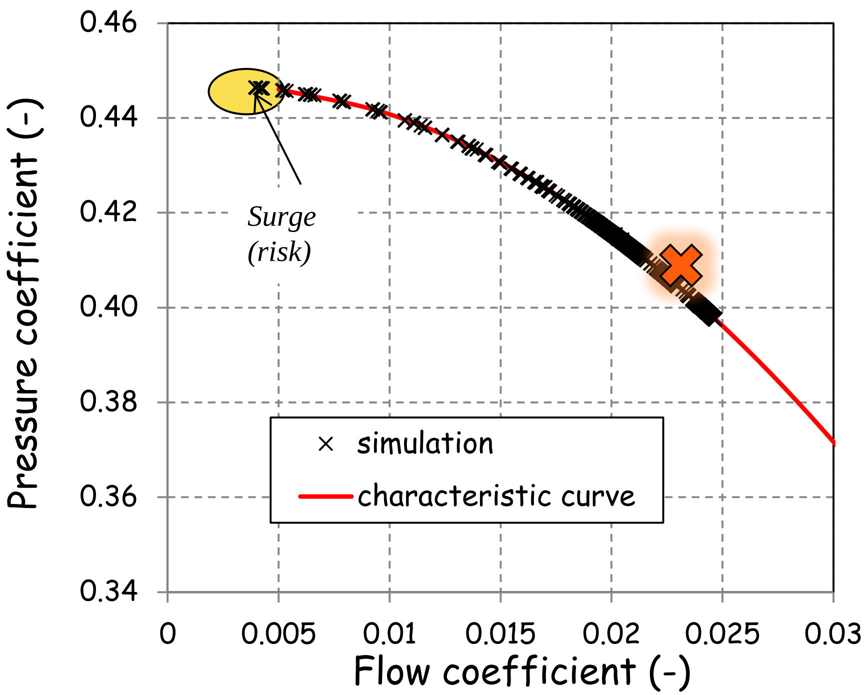
Cold circulator- flow blockage



- Risk to go into surge at the IM due to drastic P increase
  - Driving operation point in a short time, a few seconds

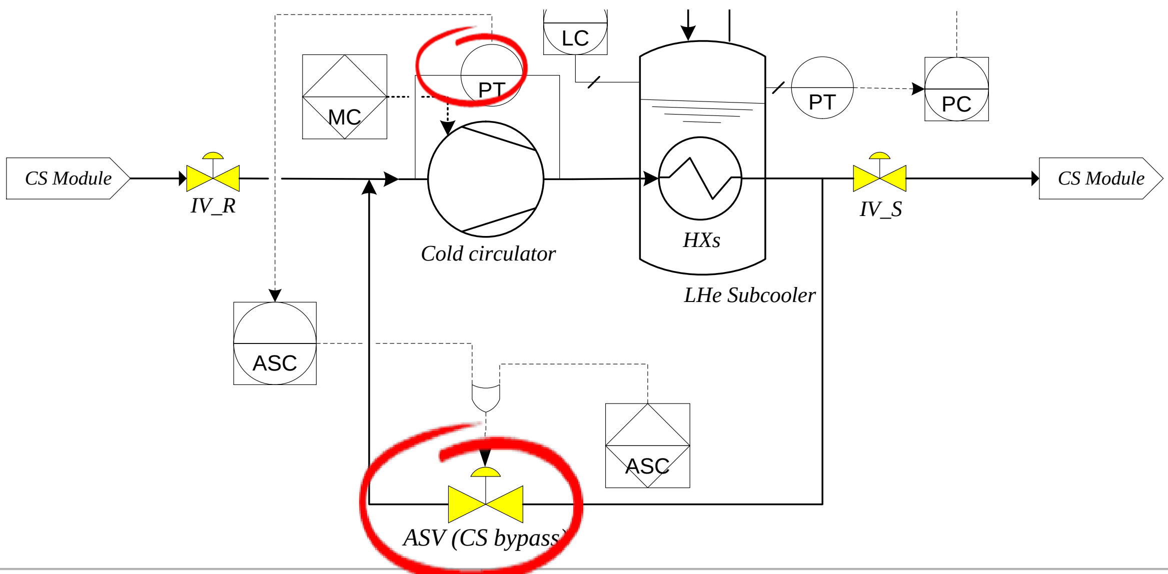
Impact at the onset of CS pulse

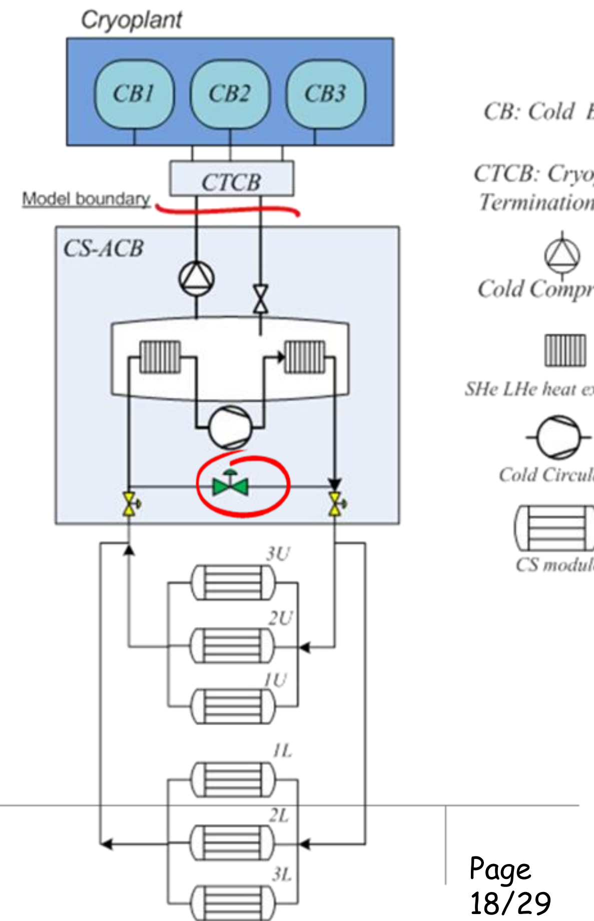




Anti-Surge-Control (ASC)

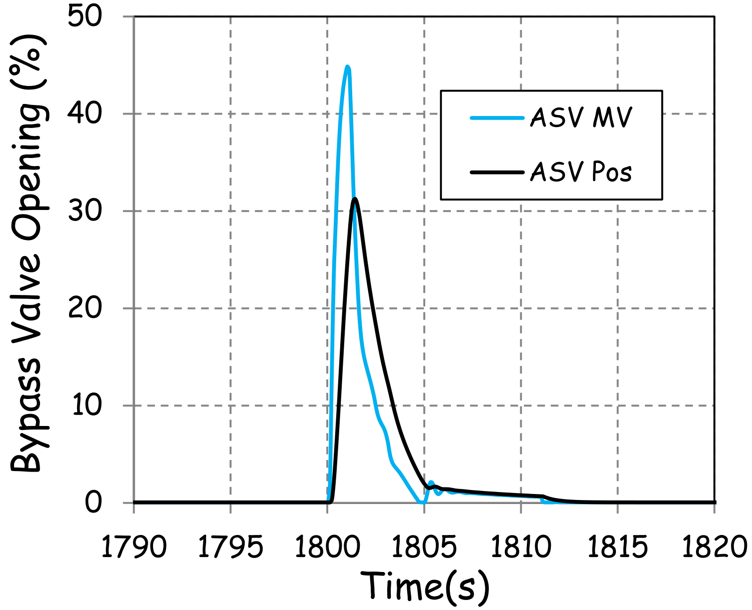
- Feedback control-pressure head
  - ASC
    - » 100 ms sampling PLC
    - » Time lag 0.7s of valve response

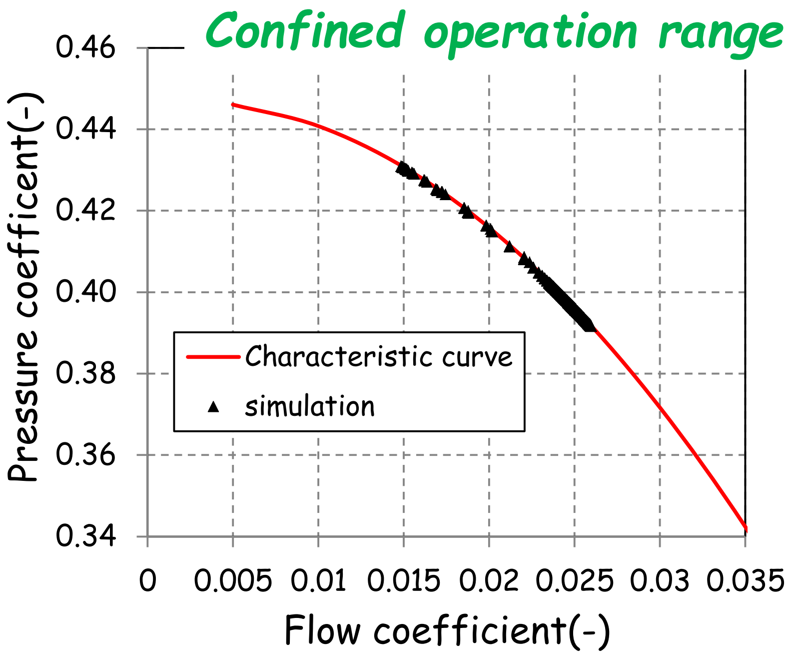




Feedback control

- Utilization of circulator pressure head to take control action on ASV
  - Shows a good tracking w/ less demanding operation range
  - Feasibility w/ real system 100 ms sampling rate w/ 0.7 s time lag

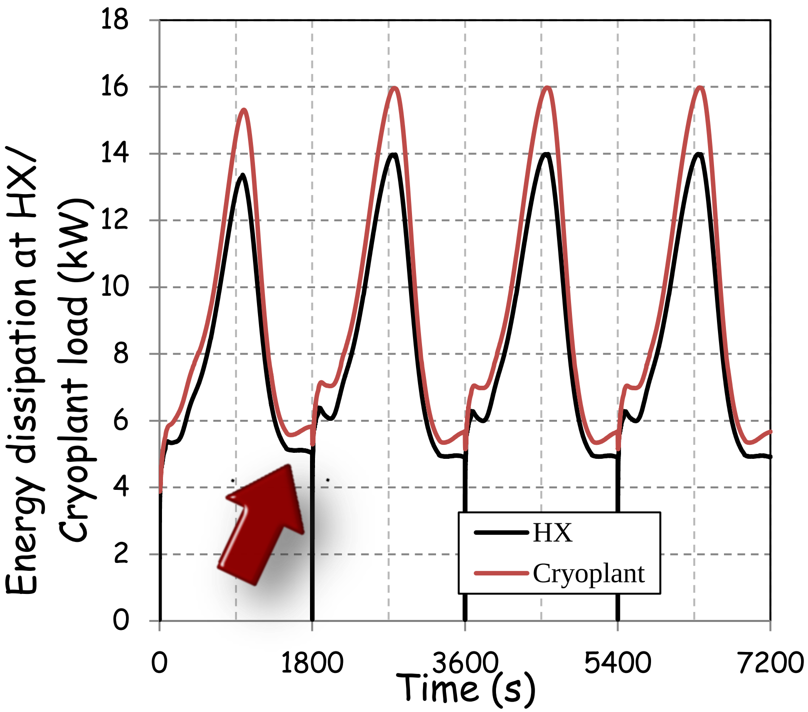


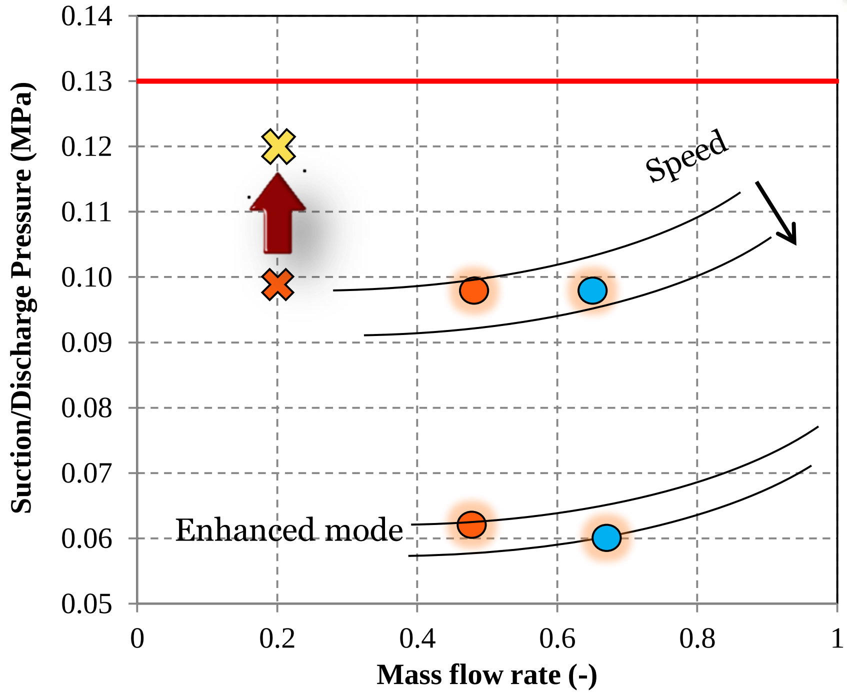


CS IM- SURGE RISK

- Good tracking performance w/ a classical feedback
  - Regulation of pressure head leads to better boundary establishment for circulator

- Temporary reduction of $\dot{m}$ will not impact CS operation
  - Robustness of magnetic bearing could sustain the operation



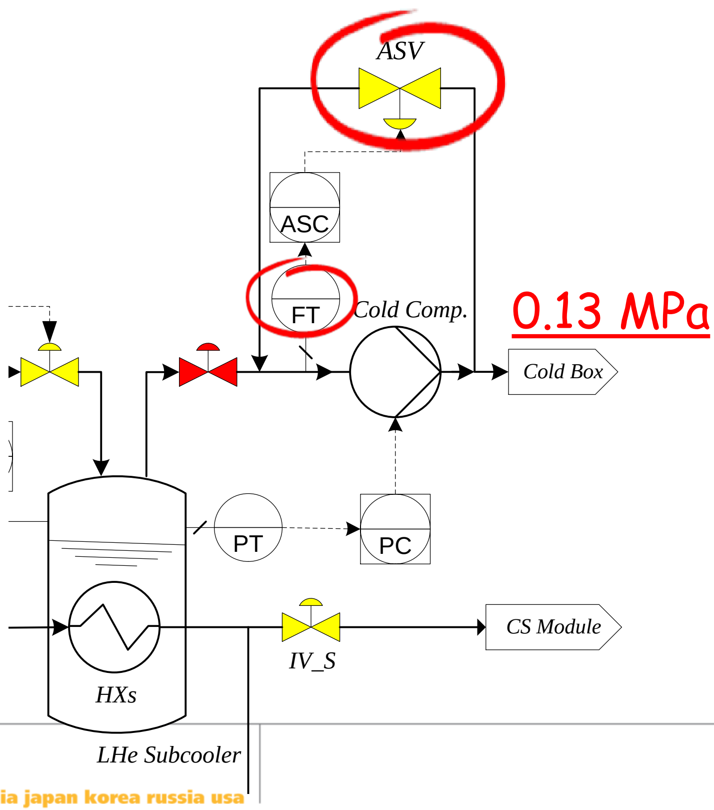


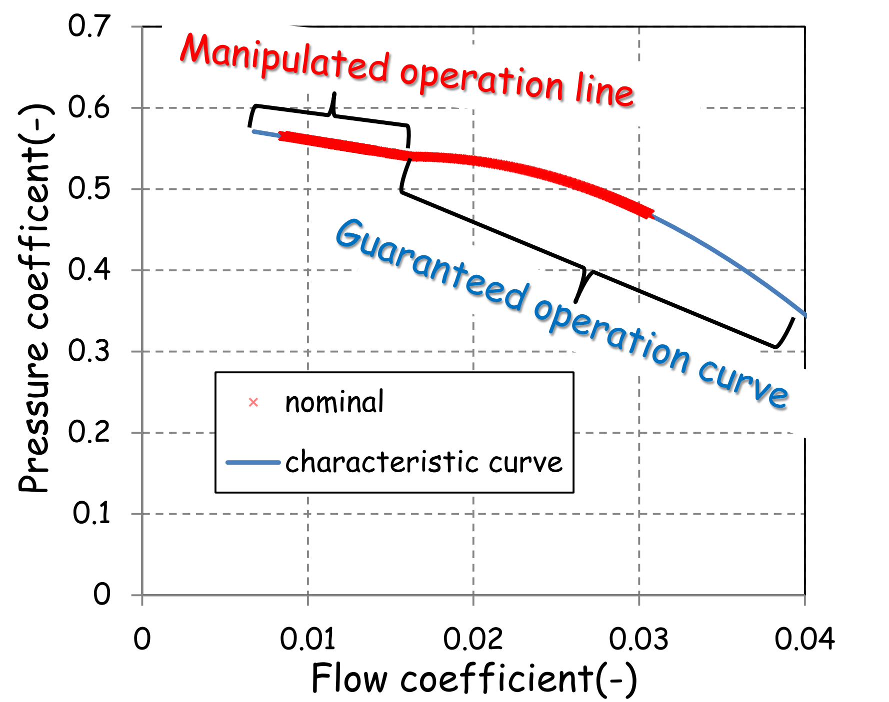
IMPACT ON COLD COMPRESSOR DURING DWELL

Cold compressor- ASC

- Demanding wide operation range w/ imposed discharge pressure
  - Challenging to adapt substantial dynamic heat load from 5-16 kW
    - Lack of mass-flow rate to achieve required compression ratio

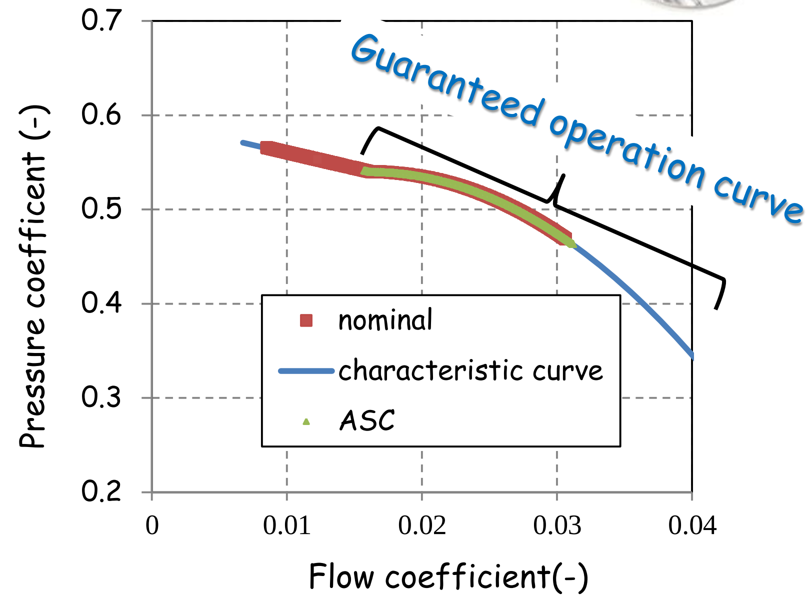
- ASC is inevitable w/ the current CC design

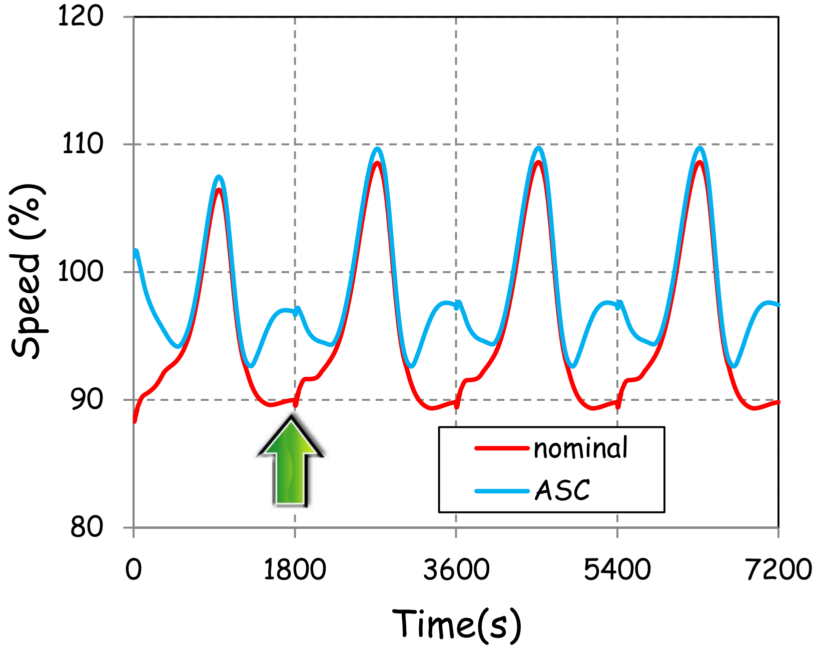


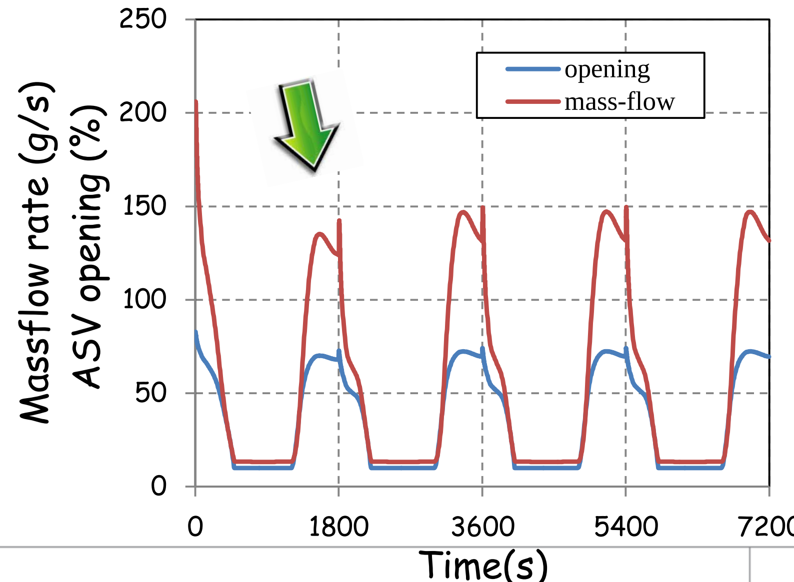


Cold compressor operation-ASV

- Recycle mass-flow rate via ASV
  - Impose lower boundary of speed



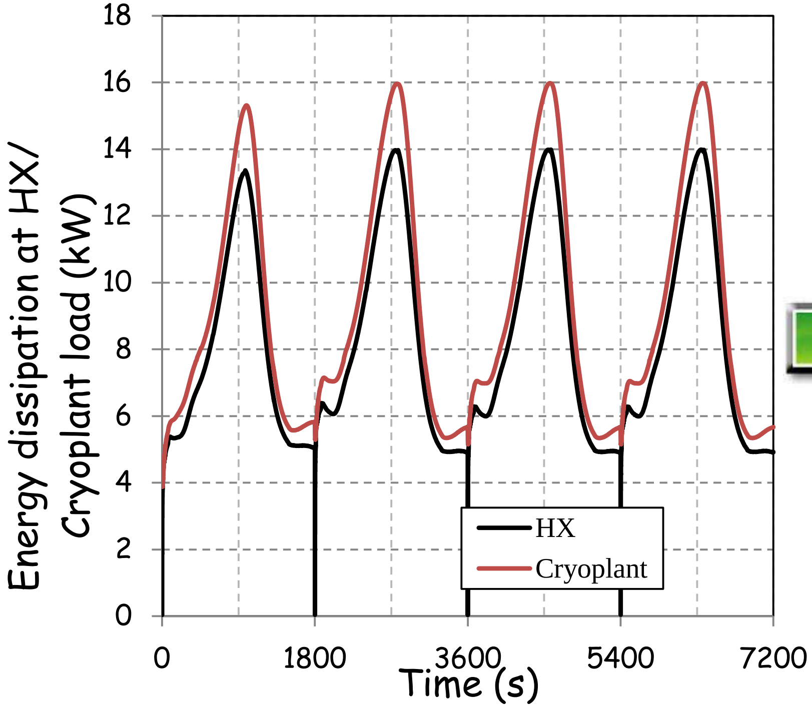


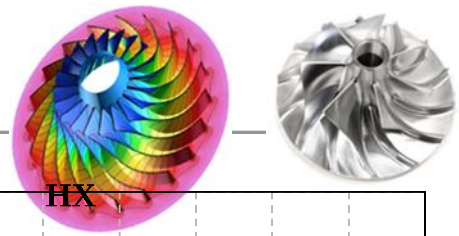


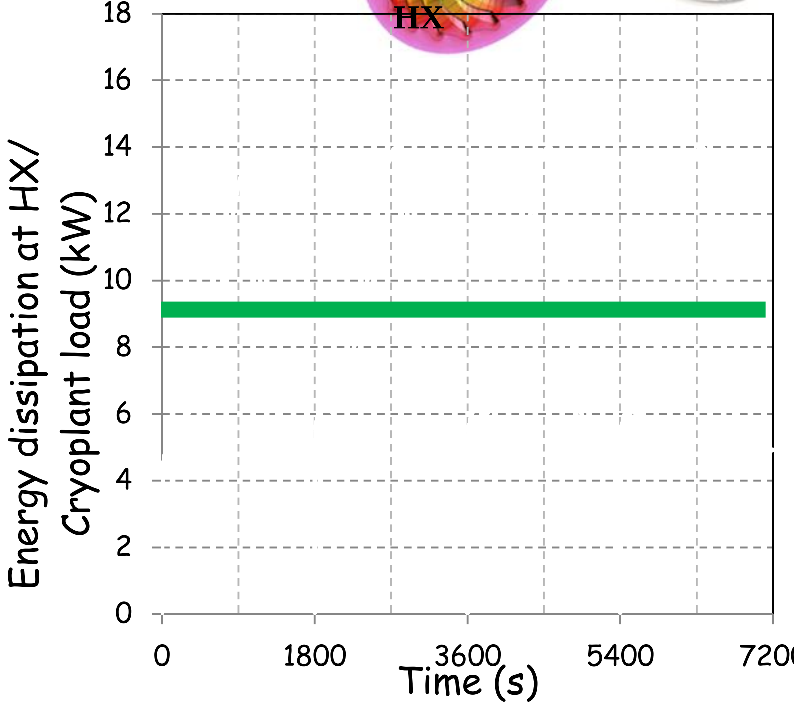
Control strategy-Cold compressor

- A classical PI should give satisfactory result due to the long characteristic-time of process→POS
- <u>Compensation of efficiency</u>
  - <u>"~40% more compression work" compared w/ nominal</u>

- POSSIBLE SOLUTION…
  - Design needs to take different approach for adapting wide operation range
  - Having dedicated compressor → technical challenge



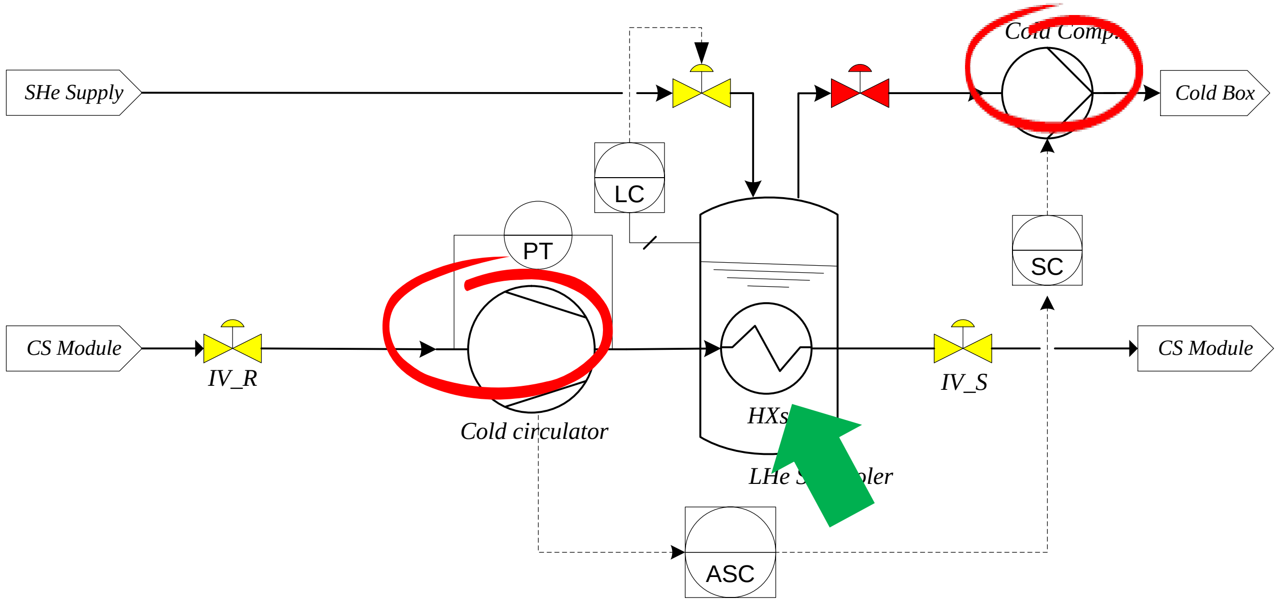




MITIGATION TO REDUCE THE IMPACT ON COLD COMPRESSOR

Mitigation-Thermal Energy

- Cold circulator speed to regulate the cold compressor
- Imposing upper bound of cold compressor speed



ASC: Anti-Surge Controller
PT: Pressure Transmitter
MC: Mitigation Control

ASV: Anti-Surge Valve
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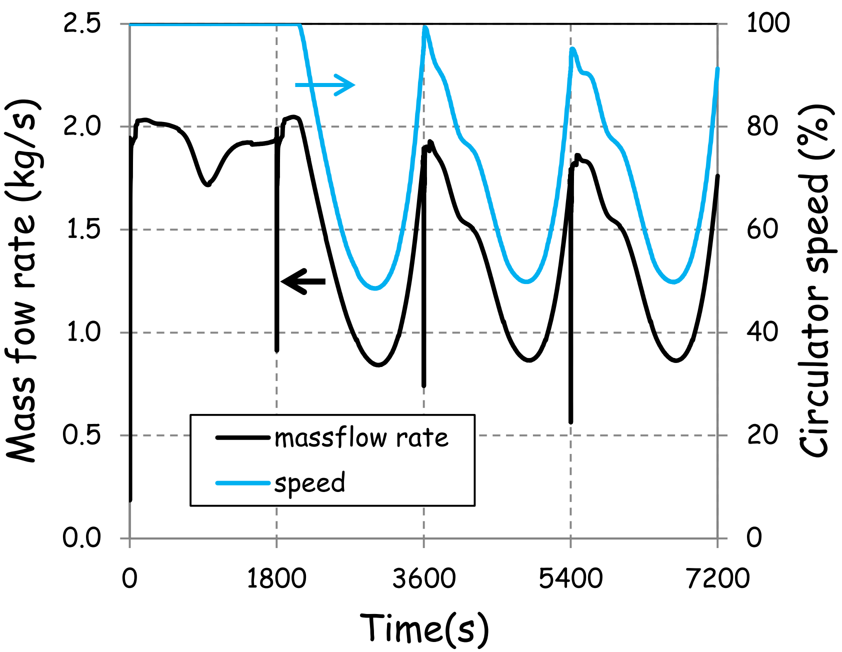
FT: Flow Transmitter

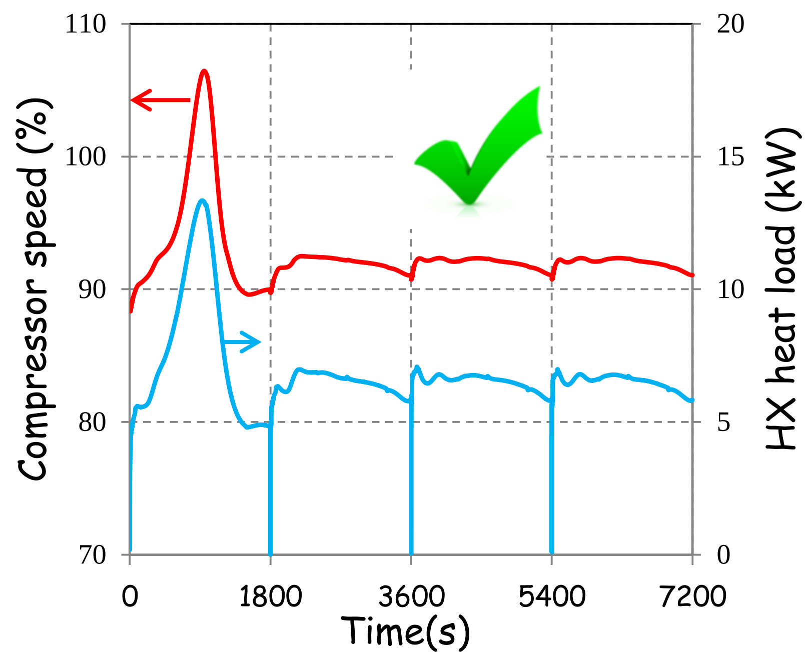
IV_S: Isolation Valve Supply
PC: Pressure Controller

IV_R: Isolation Valve Return
HX: Heat Exchanger

Mitigation-Cold compressor regulation

- Thermal energy mitigation leads to comparable effect on cold compressor boundary set-up
  - Imposing upper bound of HX energy dissipation with circulator speed

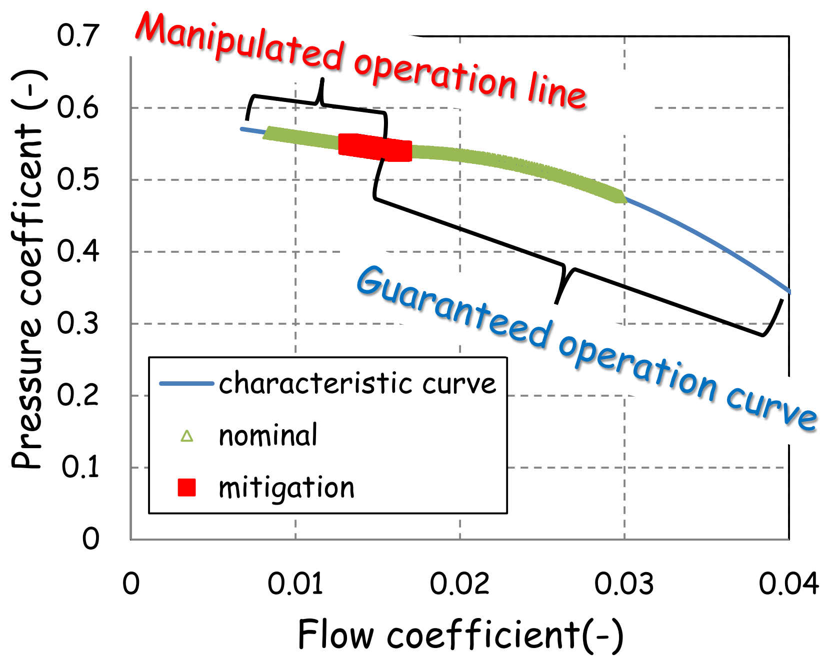




Impact on operation field

- **Mitigation demonstrate satisfactory performance**
  - Impose optimized boundary condition (well confined range)
  - Practical approach for the operation

- **Optimal operating point selection**



Conclusion

15 MA reference

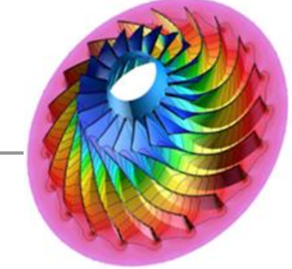
- Nominal operation
  - Disclose the potential risk for machinery
    - Identify the impact on circulator/compressor
  - Feedback control demonstrated satisfactory results
    - Confirmation w/ real system to ensure fast control response
    - (CS-IM: Robustness of magnetic bearing withstand the temporary reduction of mass-flow rate…)
  - Mitigation could provide better stability of cold compressor operation
    - Stability of CS conductor will not be the issue as reducing the mass-flow rate (confirmed by D.B on Sep9, 2015)

SUPPLEMENT SLIDES

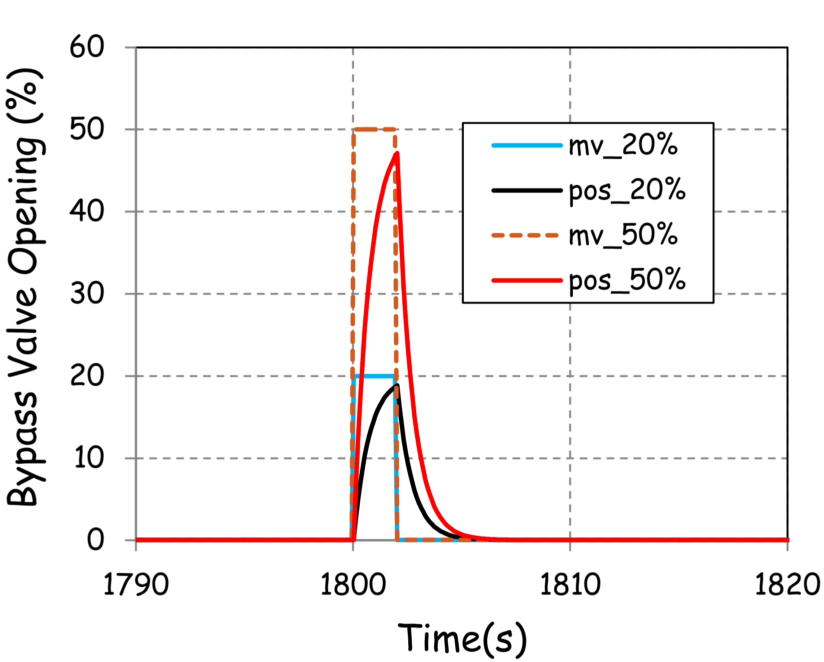
Cryogenic Process REal-time SimulaTor

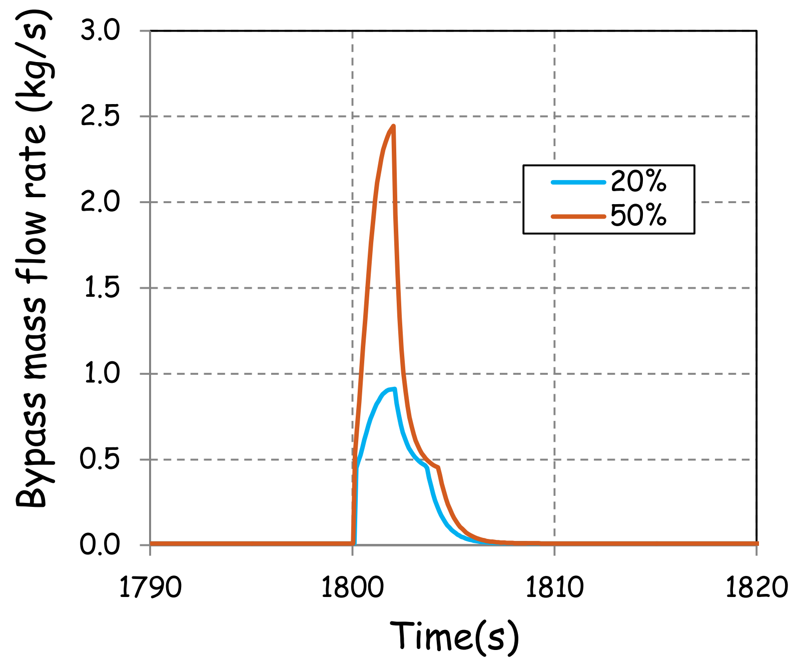
- C-PREST
  - 2003: Start development based on Visual Modeler® (omega simulation)
    - 10kW helium refrigerator (NIFS)
  - 2010: SHe forced-flow cooling loop under dynamic heat load (ITER)
    - Validation with test conducted at CEA-Grenoble
  - 2013: TF structure cooling loop→ Mitigation
    - Benchmarked w/ SUPERMAGNET, VINCENTA & 4C
  - 2014: Development of CICC model
    - Validation w/ test results of CSMC (JAEA in 2000)
    - Data analysis w/ 2015 data for CSMC
  - 2015: CS model and process study

Active ASC



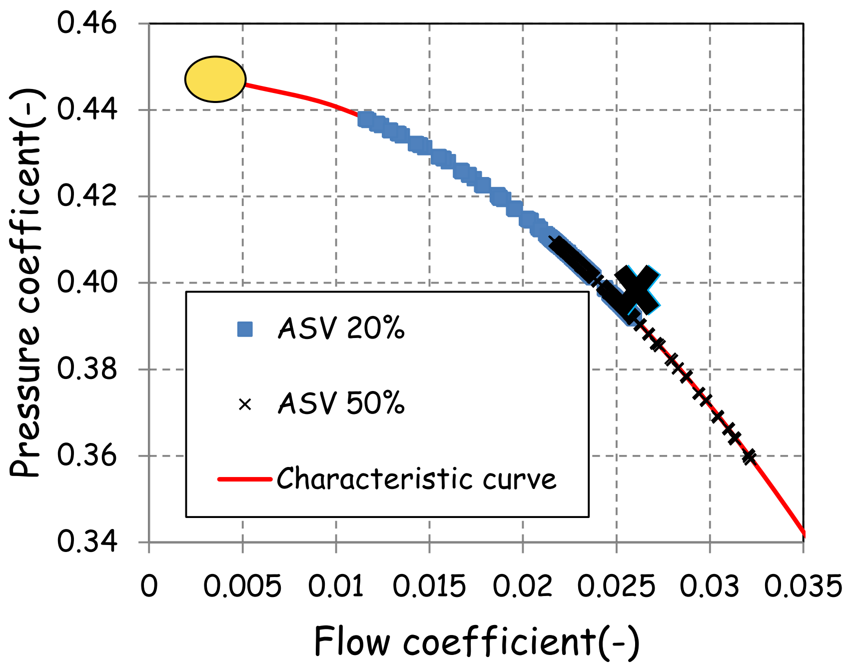
- Time lag shows some impact on the opening
  - Optimization of opening- valve characteristics
  - Temporary increasing bypass flow (circulator + back-flow)

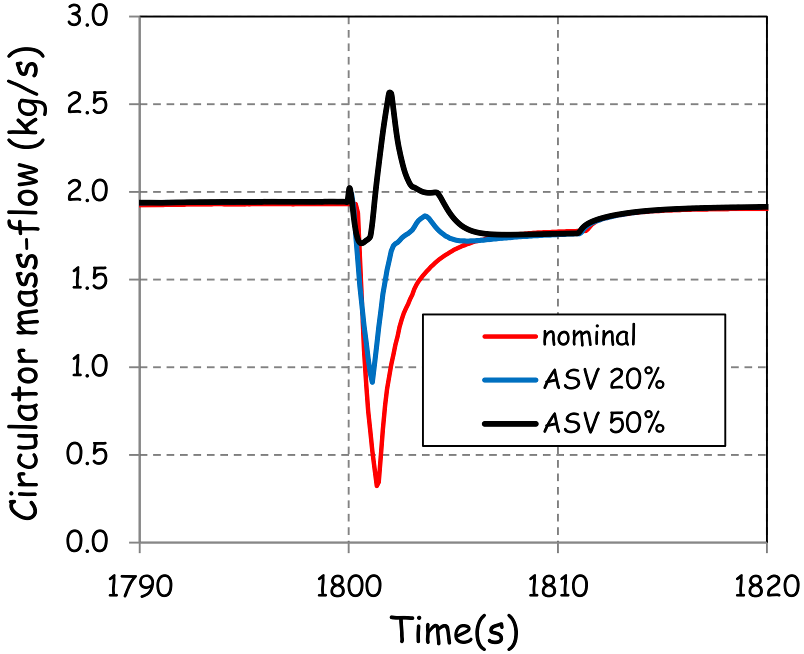




Operation Field

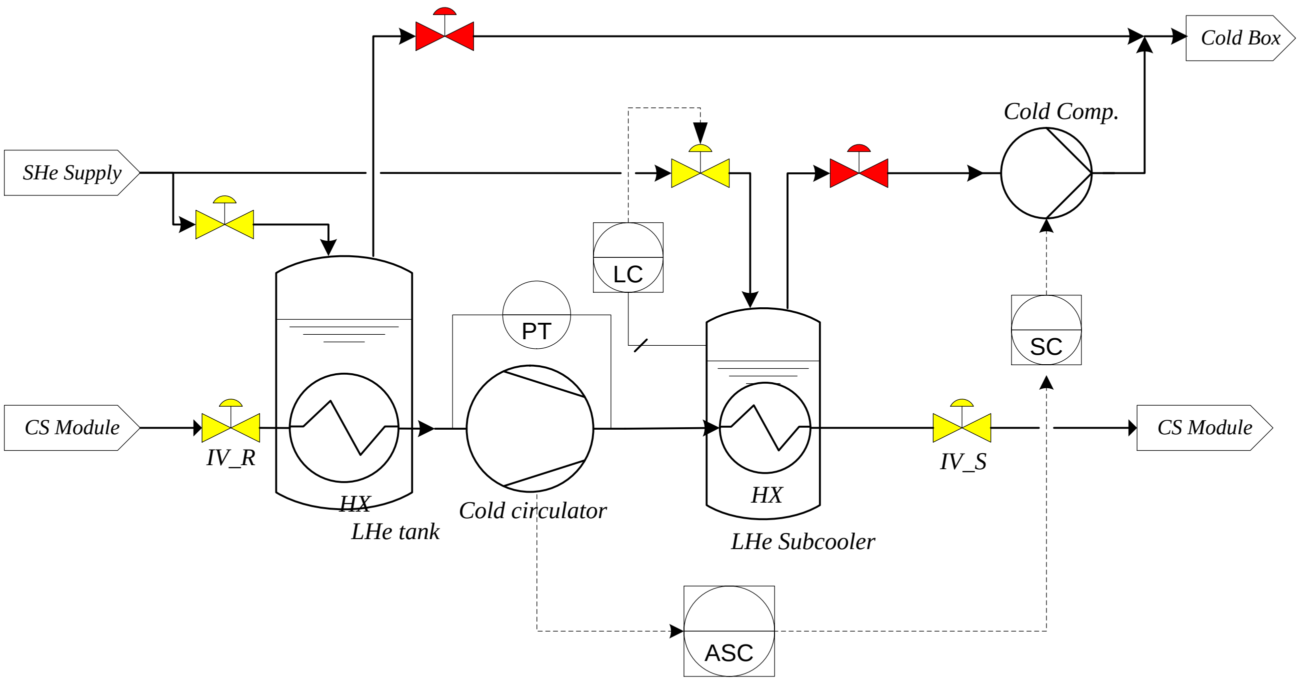
- Confine the operation range but…
  - Extending the operation points to the other end…
    - Too much opening with 50%
    - Optimization w/ a real set-up





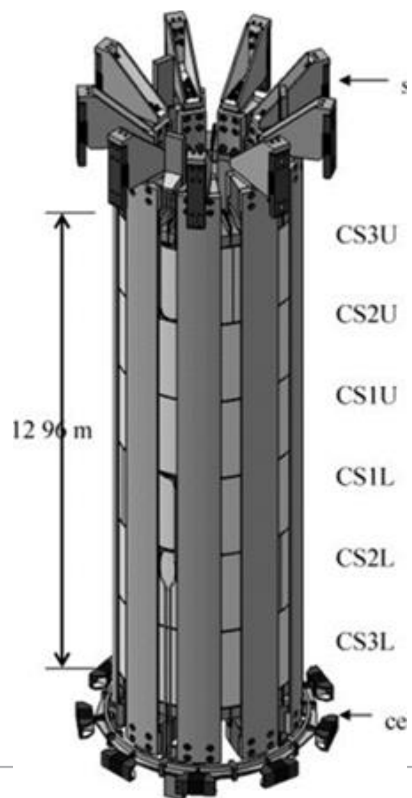
New configuration

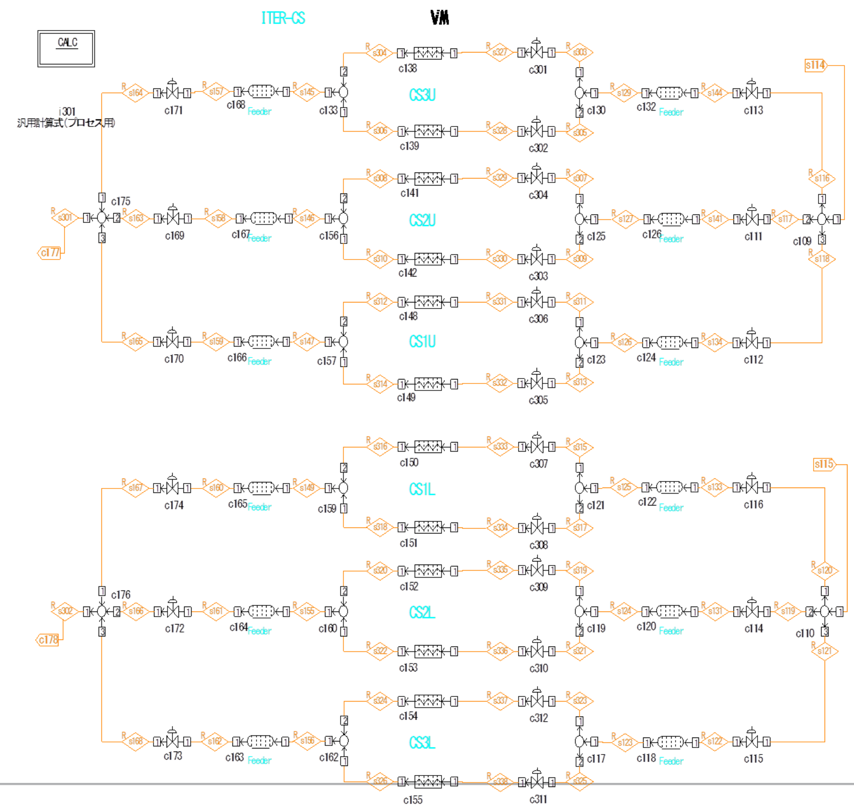
- Two independent LHe baths
  - Saturated
  - Subcooled-reduce the demand of cold compressor operation



Modeling approach

- CICC based on CSTR model
  - Integration of 20 layers to achieve real-time computation (12 modules in the model)
  - Spatial discretization 70 in each module





Open issue

- FD-sizing case for HX-impact on the CC design
  - Implementation of Mitigation Scheme
- Quench Scenario…