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Blade failures on an axial compressor by unexpected gas compositions

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Before joining the site in Houston in 2017 he was employed for more than 9 years at MAN Diesel & Turbo, Zurich/Switzerland where he was heading the MAN | PrimeServ's application engineering. He was mainly responsible for thermodynamic revamp designs, technical customer support and trouble shooting on axial and centrifugal compressors.

He received his diploma in Mechanical Engineering FH from the University of Applied Science in Zurich in 2008 and post-graduated in General Management EMBA FH. Parallel to his studies he started his career as design engineer in the textile industry in 2002.

Synopsis

A fifteen stage axial compressor including a bleed extraction was subject to a major overhaul after nearly 20 years of trouble free operation. Shortly after re-commissioning and resumption of the production the compressor faced three major failures within two weeks.

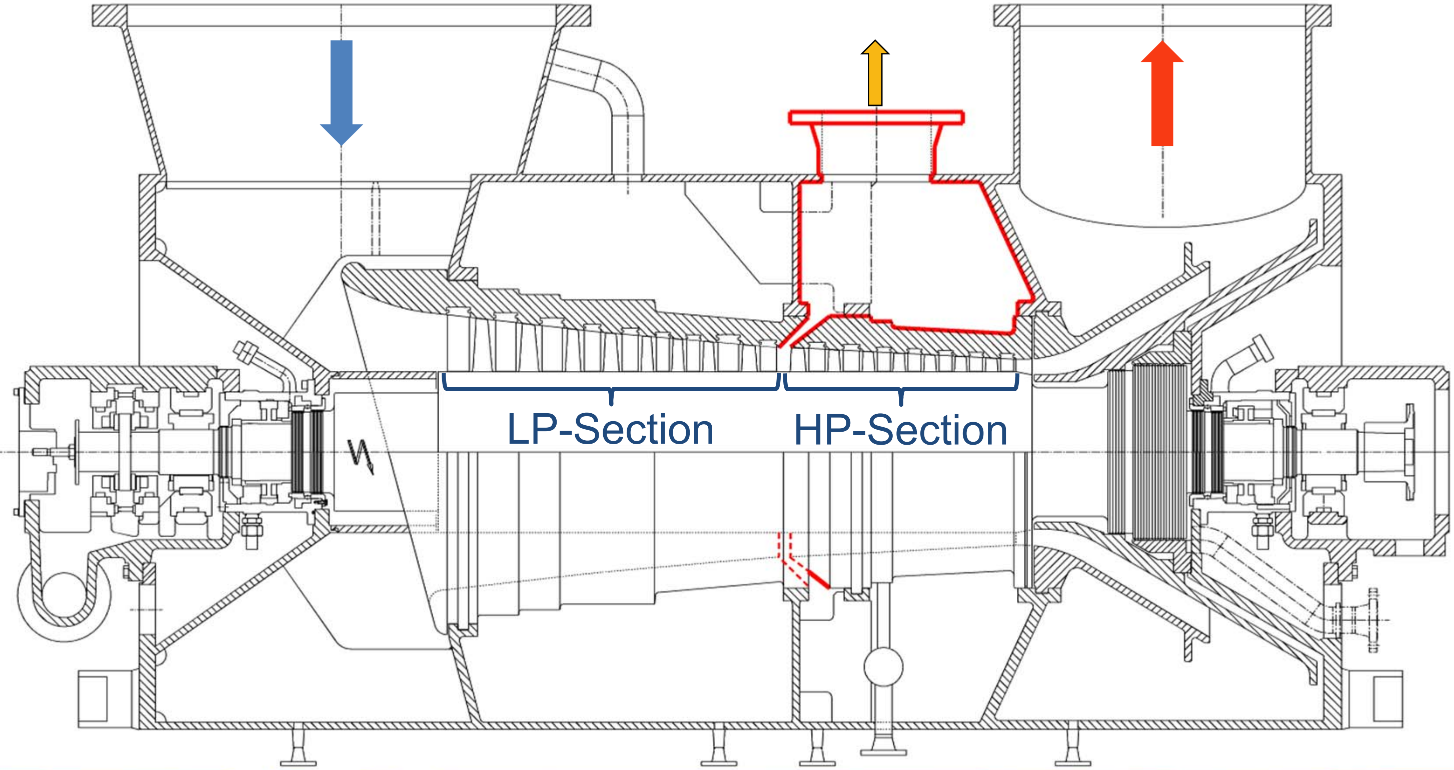
A root cause failure analysis was conducted and revealed that the process plant start-up procedures caused gas compositions which deviated strongly from the design conditions. The valve designs as well as the available control parameters were not able to protect the compressor from off-design operating conditions.

For future compressor failure prevention, the process start-up procedures were adapted and the existing control parameters/logic was upgraded. The new control logic reacts to the transient process behaviours during start-up by continuous harmonization of the safety valves.

Outline

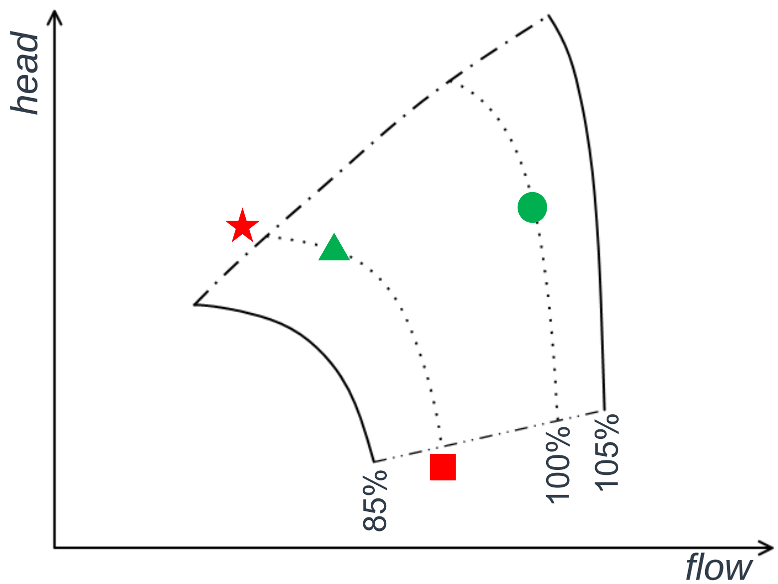
Initial Situation

- Compressor design:
  A45-15, speed controlled
- Application:
  MTBE (REC)
- Process gas:
  H_2 + HC
- Design MW:
  24 – 30 g/mole
- Special feature:
  Interbleed
  discharge (IB)

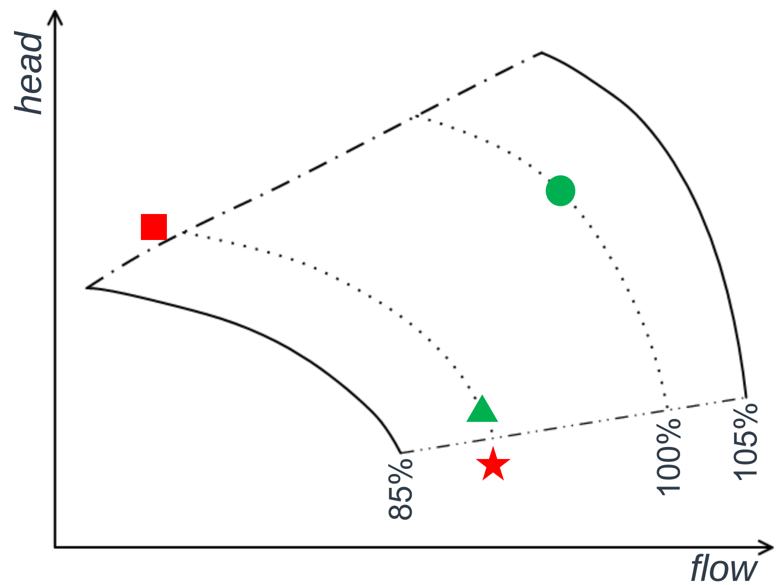


Background: Thermodynamic consideration

LP-Section:



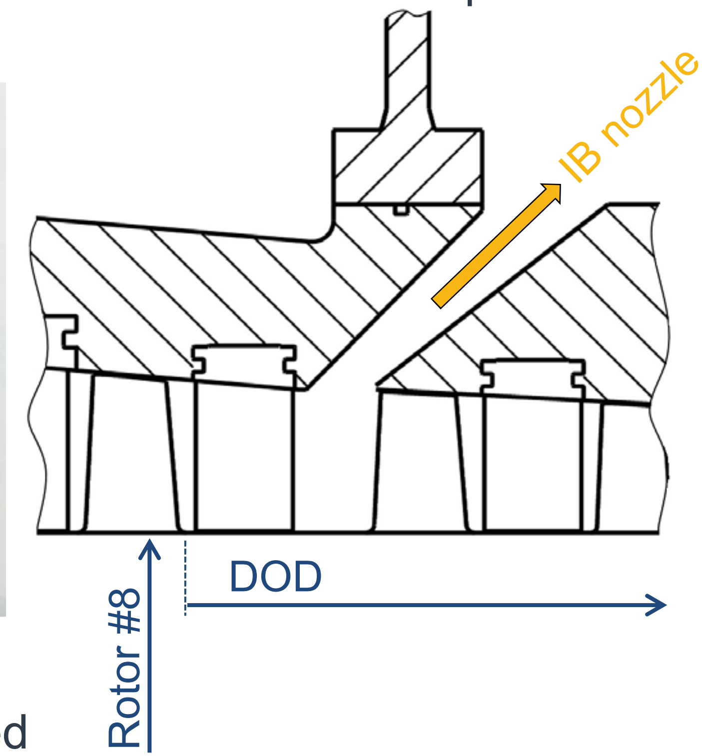
HP-Section:



● Normal operation	30 g/mole,	IB closed	
▲ H_2-strip	24 g/mole,	IB partially open	(correct)
★ H_2-strip	24 g/mole	IB too little open	(faulty)
■ H_2-strip	24 g/mole	IB too much open	(faulty)

Failure #1, January

- Compressor tripped after 2,5 days of operation from the re-start after a planned outage due to high vibrations:



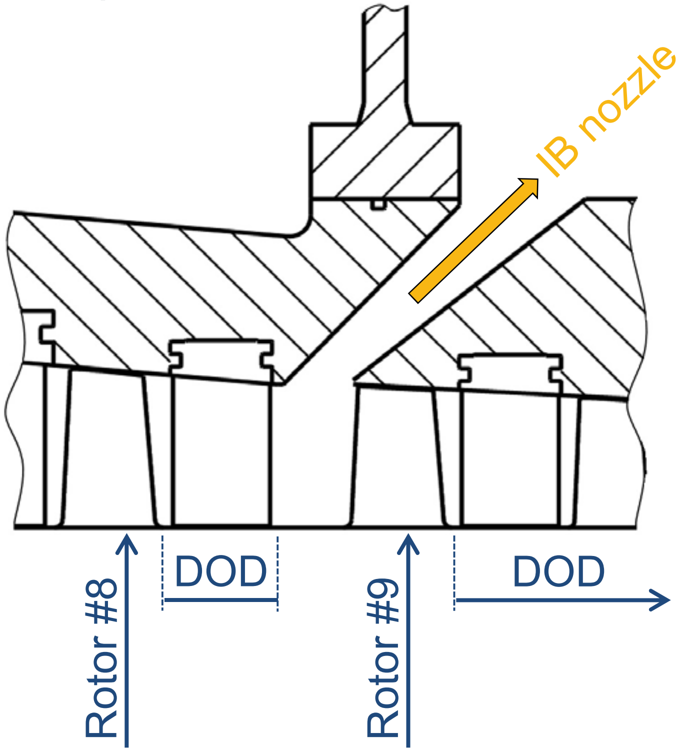
- Four blades of rotor #8 liberated
- Several blades of rotor #8 fractured
- Downstream rows damaged by Domestic Object Damage (DOD)

Failure #2, February

- Compressor tripped after 3 days of operation from compressor re-start:

Rotor #8:

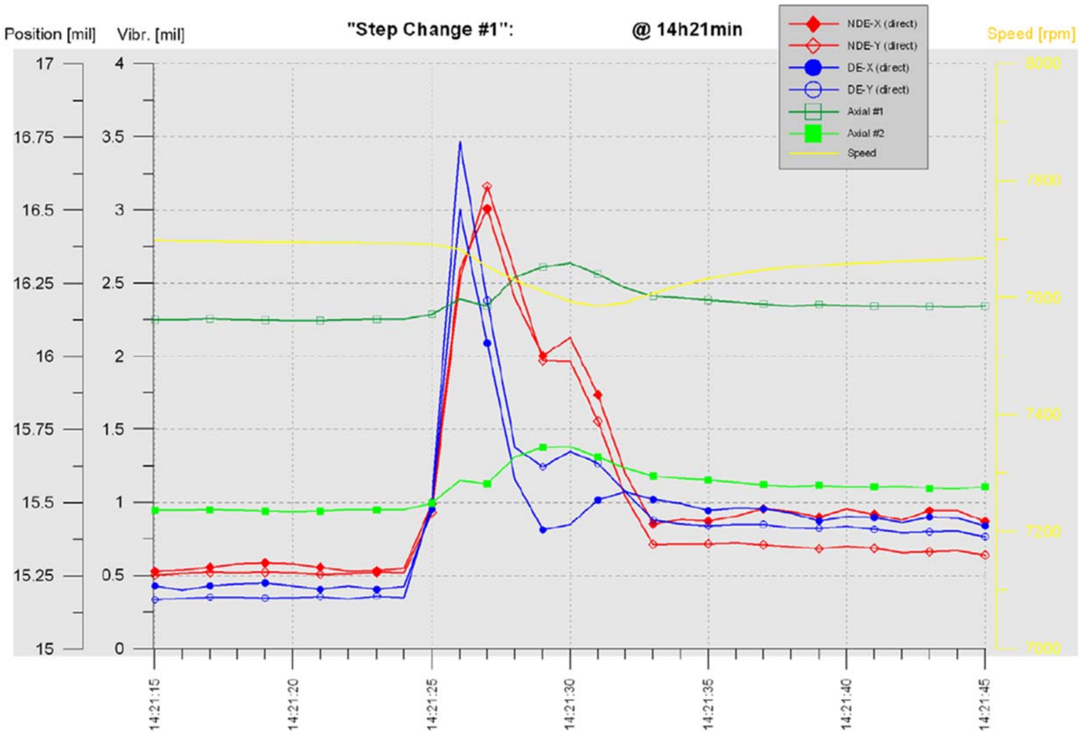
Rotor #9:



- Rotor #8 liberated completely
- Four blades of rotor #9 liberated
- Downstream rows damaged by DOD

Failure #3, March

- For the third re-start, several immediate countermeasures implemented. However…
  - Significant step changes in vibrations shortly after third restart but no compressor trip
  - Step changes in vibrations indicate further liberation of four blades of rotor #8…
  - Due to non-availability of further spare parts:
    Keeping the unit in operation as long as possible (goal: ~7 month)



RCFA: Failure Mechanisms

Failure mechanism Failure #1

IB fully open during start-up sequence

Choked flow rotor #8
Surge stage 9?

Pitting corrosion

Resonance of B1-mode of rotor #8

Fracture initiation points

Blade failure rotor #8

Failure mechanism Failure #2 & Incident #3

IB fully open during start-up sequence

Process instabilities: MW = 17 g/mole

Choked flow rotor #8
Surge cond. rotor #9

Resonance of B1-mode of rotor #8

Fracture on rotor #9 (mech. overloaded)

Blade failure of rotor #8 and rotor #9

Summary, Main Challenges, Countermeasures

<u>Main Challenges:</u>

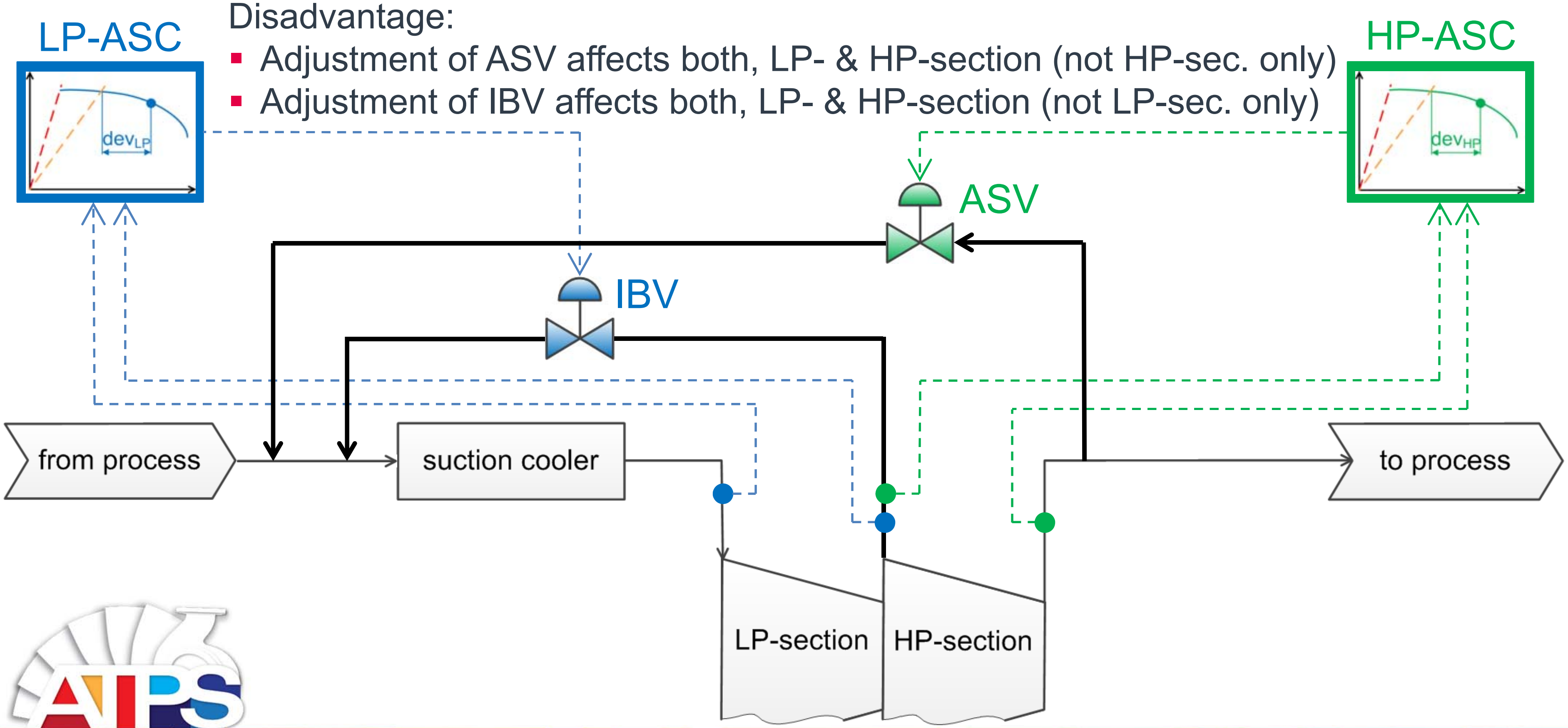
- Process-wise:
  Process is very difficult to be controlled during process start-up
  → molecular weight can hardly be controlled
  → major deviations to design values can cause catastrophic failures
- Control logics:
  The existing control logic was not capable of controlling the safety valves during periods with heavy gas composition fluctuations

<u>Countermeasures:</u>

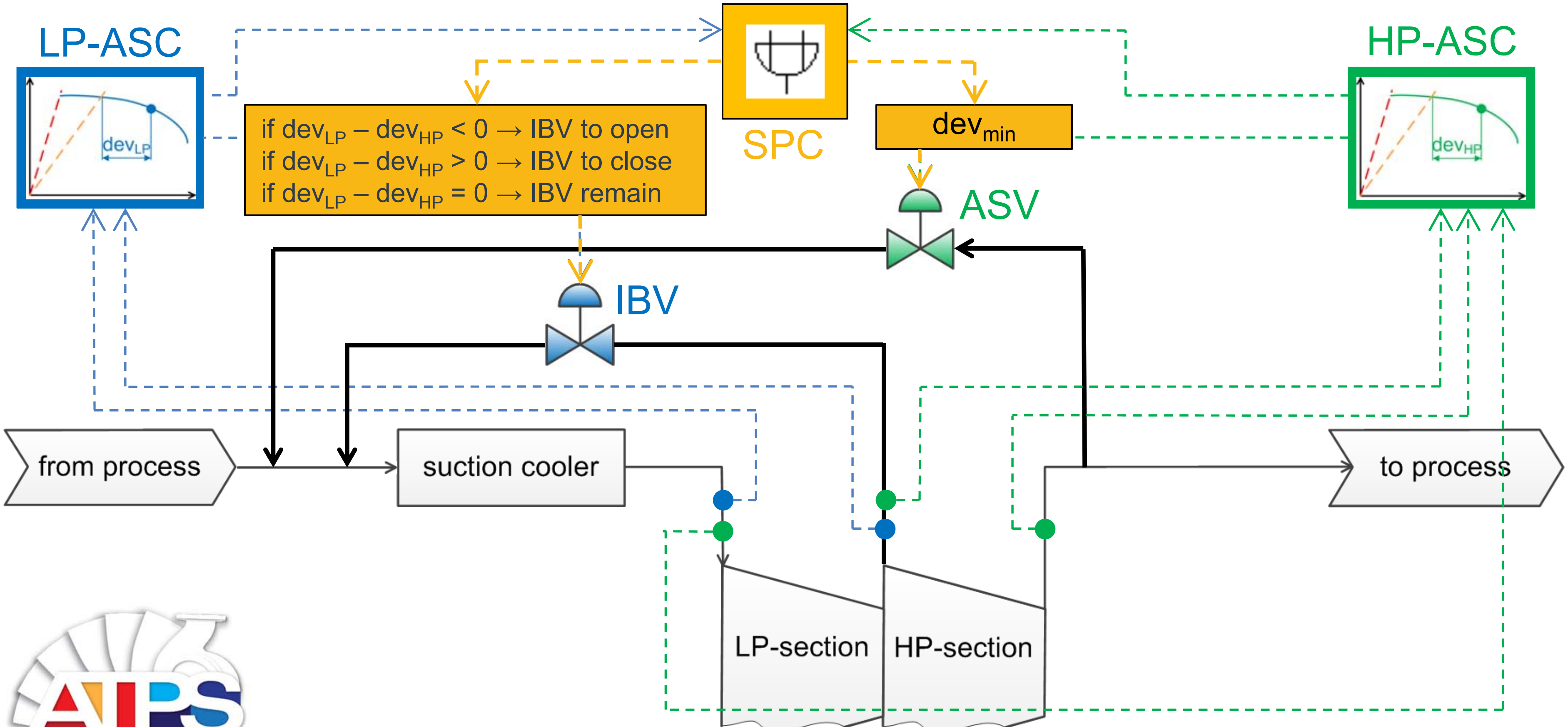
- Installation of additional IB-measurements (pressure and temperature) within the compressor blading
- Control logics:
  Optimization of the anti-surge control logics

Original Valve Control Logic

Disadvantage:
- Adjustment of ASV affects both, LP- & HP-section (not HP-sec. only)
- Adjustment of IBV affects both, LP- & HP-section (not LP-sec. only)



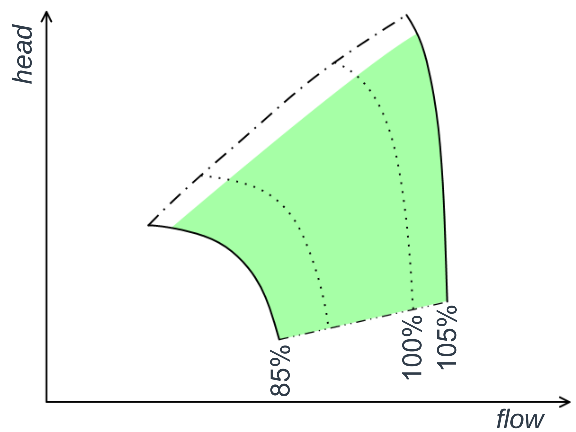
Optimized Valve Control Logic



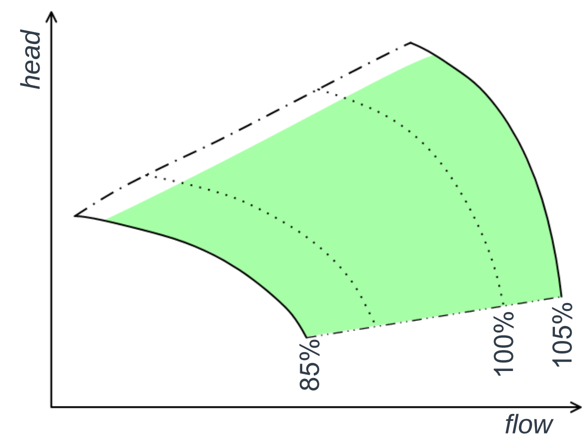
Results After Field Implementation

- No more adverse operations outside of the operation envelopes, not even at low molecular weights

LP-Section:



HP-Section:



- No further failures or compressor trips due to related issues

Lessons Learned

- Special attention must be paid for configuration of multi-sections (axial, but also centrifugal) compressors; especially different operation with deviations of molecular weights is a challenge for the proper running of the machine
- During the design of the control logic, several cases (even unexpected and theoretically excluded) shall be considered (at least during design reviews between operator and manufacturer)

Disclaimer

All data provided in this document is non-binding.

This data serves informational purposes only and is especially not guaranteed in any way. Depending on the subsequent specific individual projects, the relevant data may be subject to changes and will be assessed and determined individually for each project. This will depend on the particular characteristics of each individual project, especially specific site and operational conditions.

Case study

Thank you !

Do you have any more questions ?