OST
Eastern Switzerland
University of Applied Sciences

IES Institute for Energy Systems

2024

Mogens Weel

Weel & Sandvig
ENERGY AND PROCESS INNOVATION

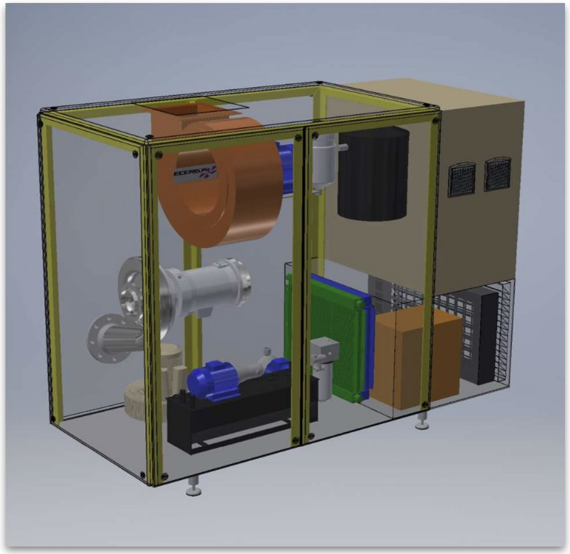
High-temperature heat pump test result and further development of high-speed centrifugal compressors for steam production

Steam generating heat pumps, OST Webinar, 18 March 2024

High Temperature heat pump test result and further development of high speed centrifugal compressors for steam generation

Mogens Weel mwh@weel-sandvig.dk

OST Webinar, 18 March 2024



Motivation : Green transition

Phase out fossil fuel to prevent excess green house gases and global warming

Replace fossil fuel in a thermodynamic and cost-effective manner using high temperature heat pumps powered by electricity from renewables (wind, sun, hydro, nuclear etc)

High efficiency compared to other Power to X technologies:

- Power to heat 0.95
- **Power to thermodynamic heating 2 – 10 (High temperature heat pumps)**
- Power to Hydrogen 0.65
- Power to Ammonia 0.6
- Power to Methanol 0.5

Company:
WS-TURBO: a joint venture between Weel & Sandvig and Ecergy
WS-TURBO joint forces has more then 40 Years experience designing and manufacturing of high speed micro gas turbines, turbo compressors and industrial process knowledge.

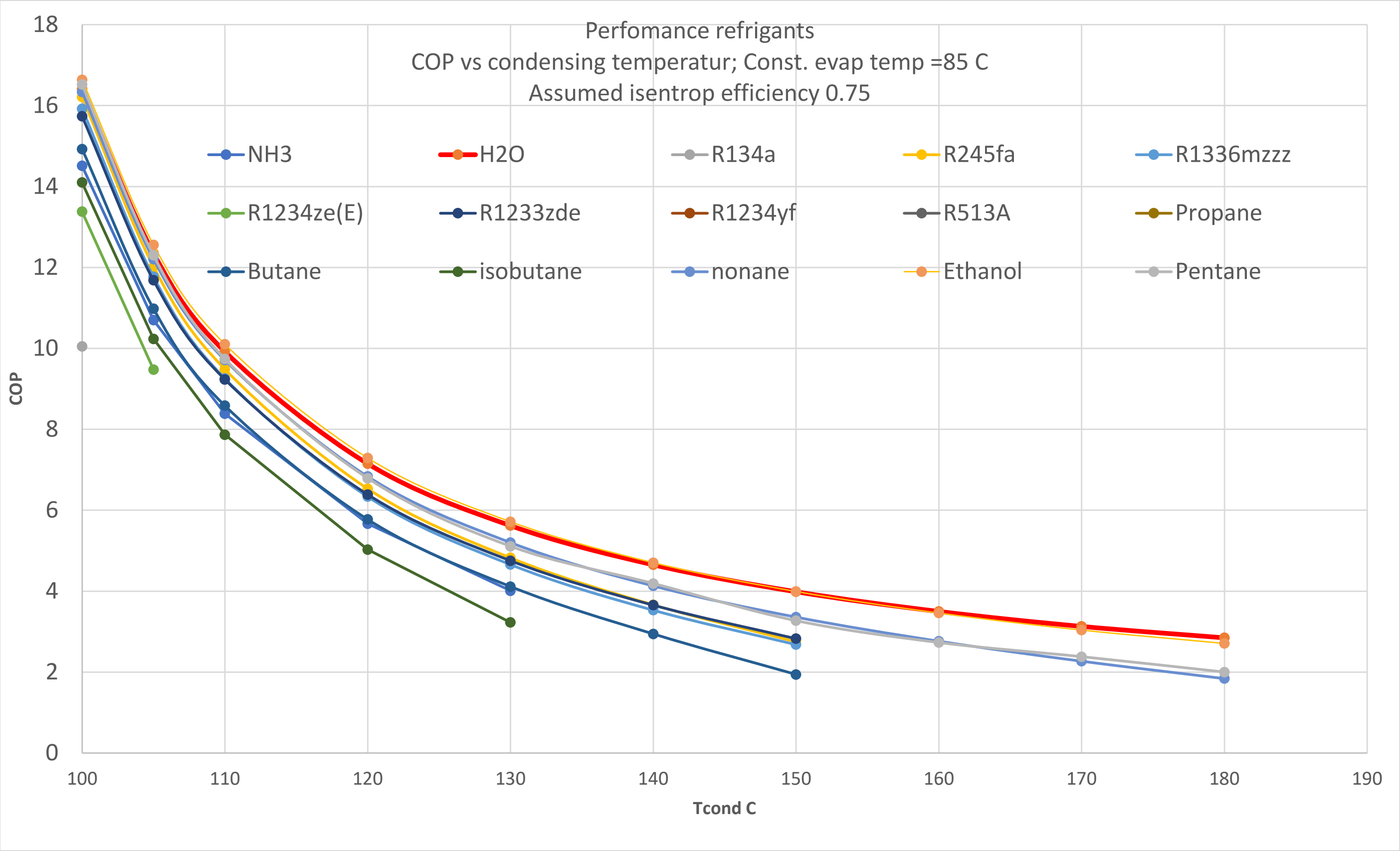
Why using water

Benefit:

- No flammability
- No green house or ozone effect
- No health effect or environmental concern
- Highest COP
- **Can generate steam**
- High temperature capability > 200 C
- Low pressures
- Well, know in all industry
- Very Low cost

Draw backs:

- High volume suctions flow
- Need very high tip speed (530 m/s for a dT= 30 C)
- Low temperature glide if needed



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WSE-Turbo Technologies (joint venture Weel & Sandvig + Ecergy)

Our mission:
Develop new High speed Compressor technology for high temperature heat pumps or MVR applications with sink temperature from **100 – 180 C** and heat effect between **600 – 1800 kW/unit**:
Typical industrial process application:

- Distillation dT = 30 - 60 K
- Evaporation (MVR) dT= 15 – 55 K
- drying dT = 50 – 80 K
- **Steam generation**

- SpeedUp Project funded by EUDP 2020 – 2024 (funding 5.7 mio. DKK from EUDP) :
  - Development of a compact gearless turbo compressor for heat pump applications with water vapor as working media.
  - Use High speed motor and bearing designs technology <u>derived from micro gas turbines</u> with already demonstrated high reliabiliy (>5 mio. Accumulated fleet hours, and 30.000 hour between major overhaul).
  - Demonstrate technology in labatory enviroment
- Project Partners Weel & Sandvig, DTU and Ecergy
- New EUDP project" Powless" (10 Mio. DDK grand from EUDP): Demonstrating of Heat Pump technology on a biogas production plant (project partners W&S, Ecergy, DTU, Nature Energy) 2024 - 2027

1st prototype test plant under construction and finish “gas loop”

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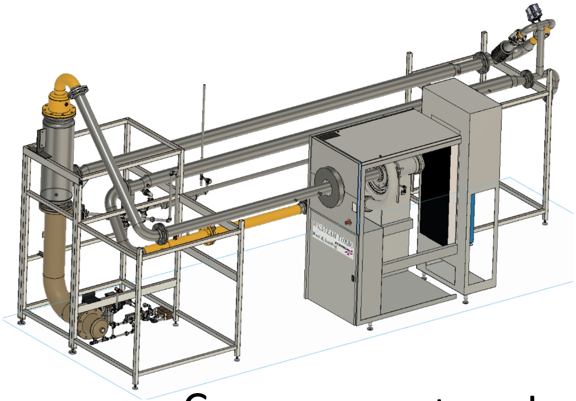

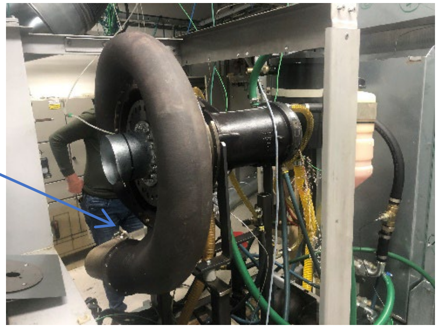

Compressor + motor

Compressor impeller
PM Rotor, Tie bolt

Inverter
& control system

Oil pump + sump
Motor gap cooling blower
Oil coolers and water coolers

Compressor performance map derived from test campaigns

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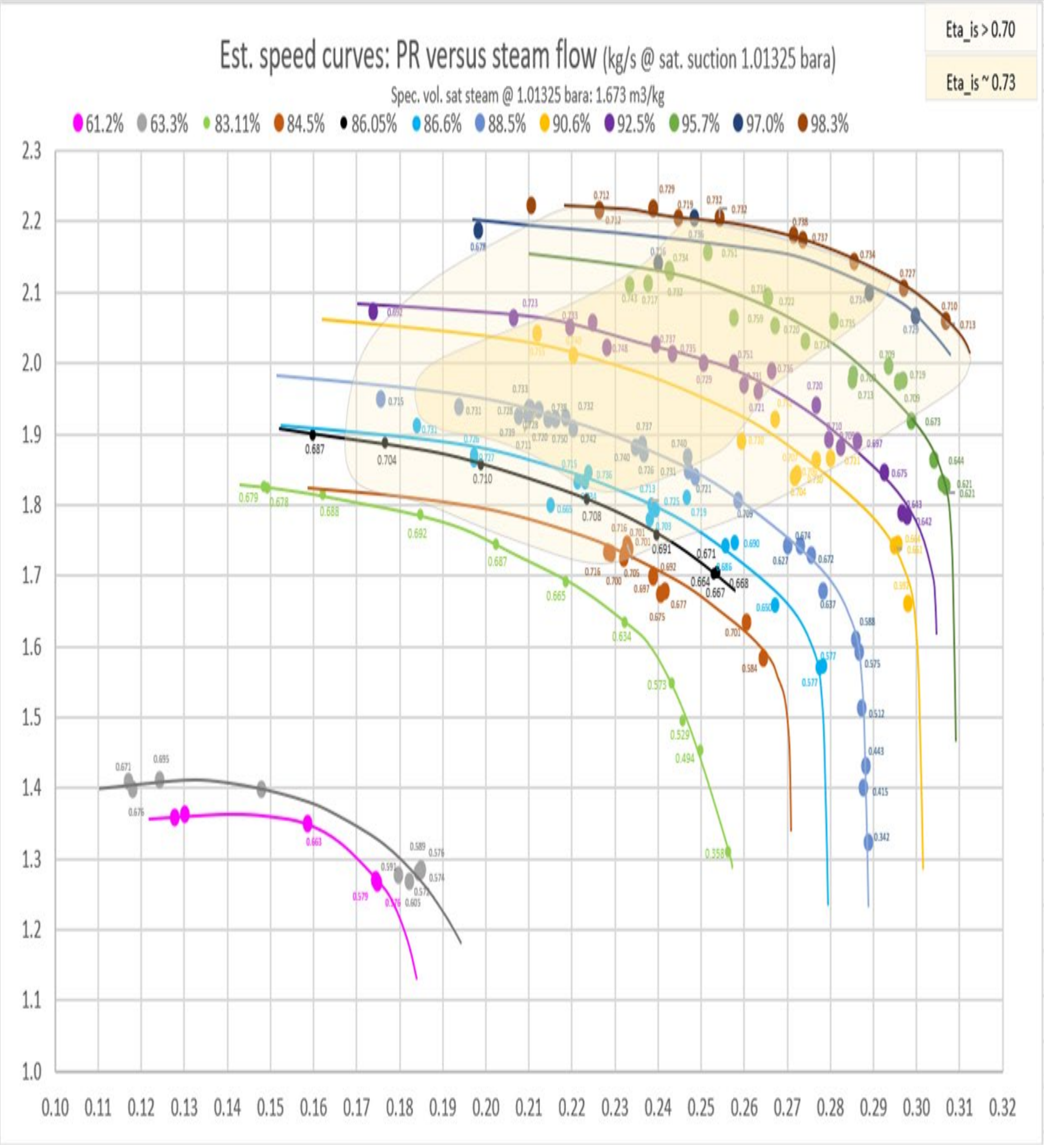


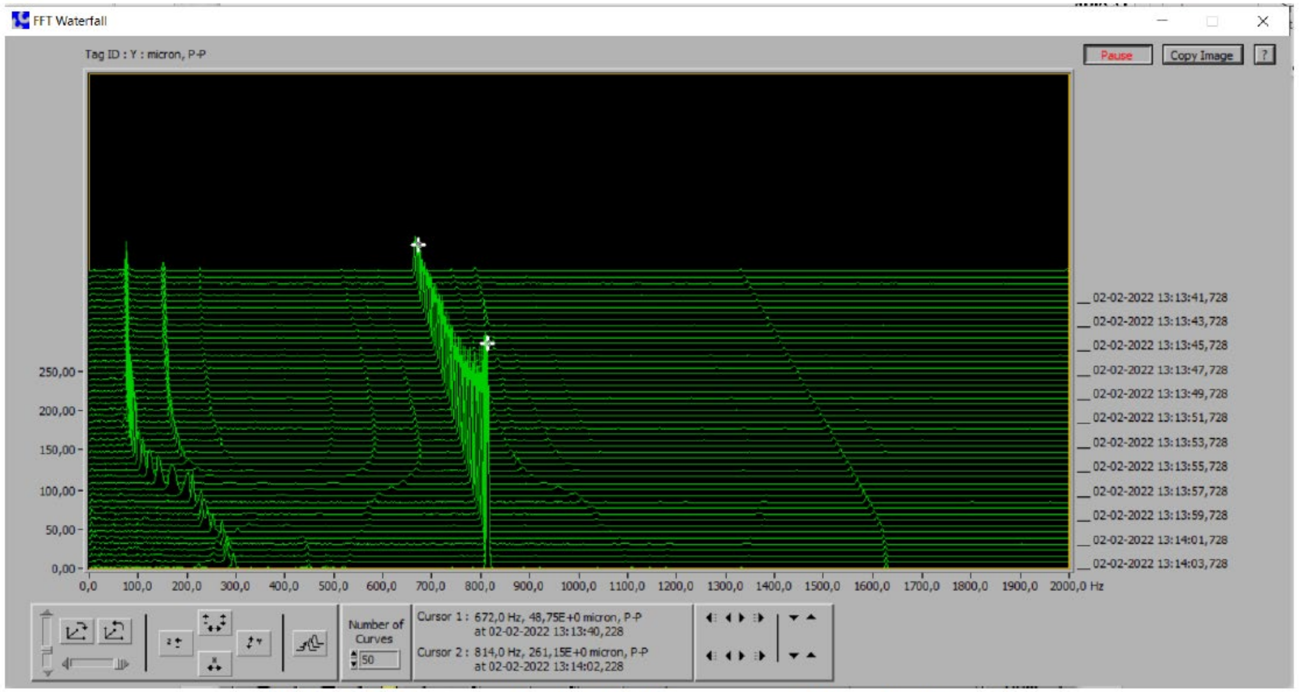
- Flow capacity as expected
- Isentropic efficiency 73 % (78 % expected)
- Explained by increased impeller tip clearnce:
- 100 % increase tip clearance=> <u>Δή =5 % point penalty.</u>

- Tip clearence was increased due to serve rubs at initially testing because of high undamped virbration at critical speed.
- Very smooth and low vibration at full speed.

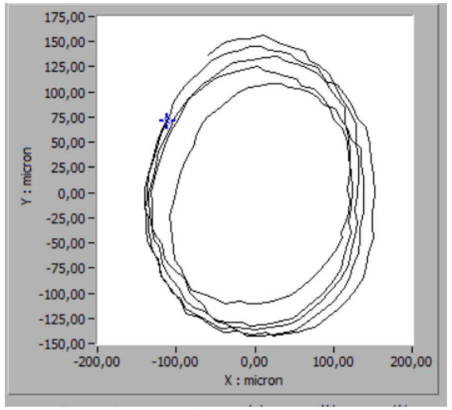
- Test with steam about 200 hours with 50 start.
- No damage to the impeller has been shown from water drophlets etc.

- Demonstrated steam oulet pressure of 2.9 bara (132 C saturation temperature)

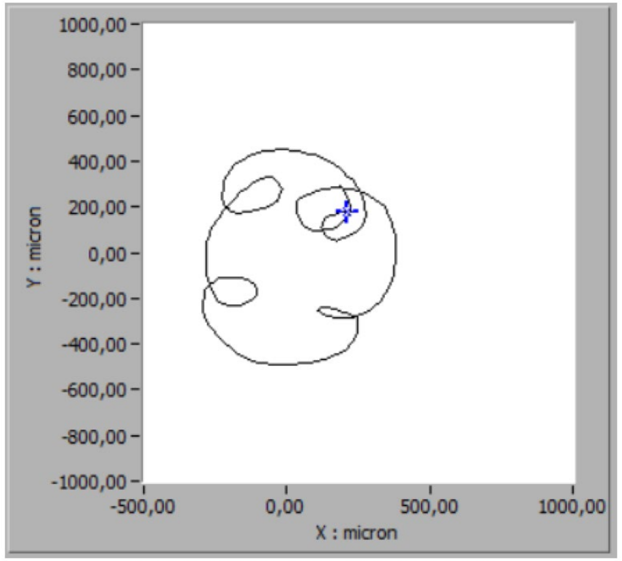
Vibration and rubs during intial test 1st. prototype



Waterfall, run up to just before suspected rub, Y probe

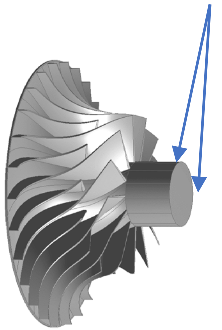


Orbit just before suspected rub



Suspected rub orbit, proximity probes

Proximety probes location



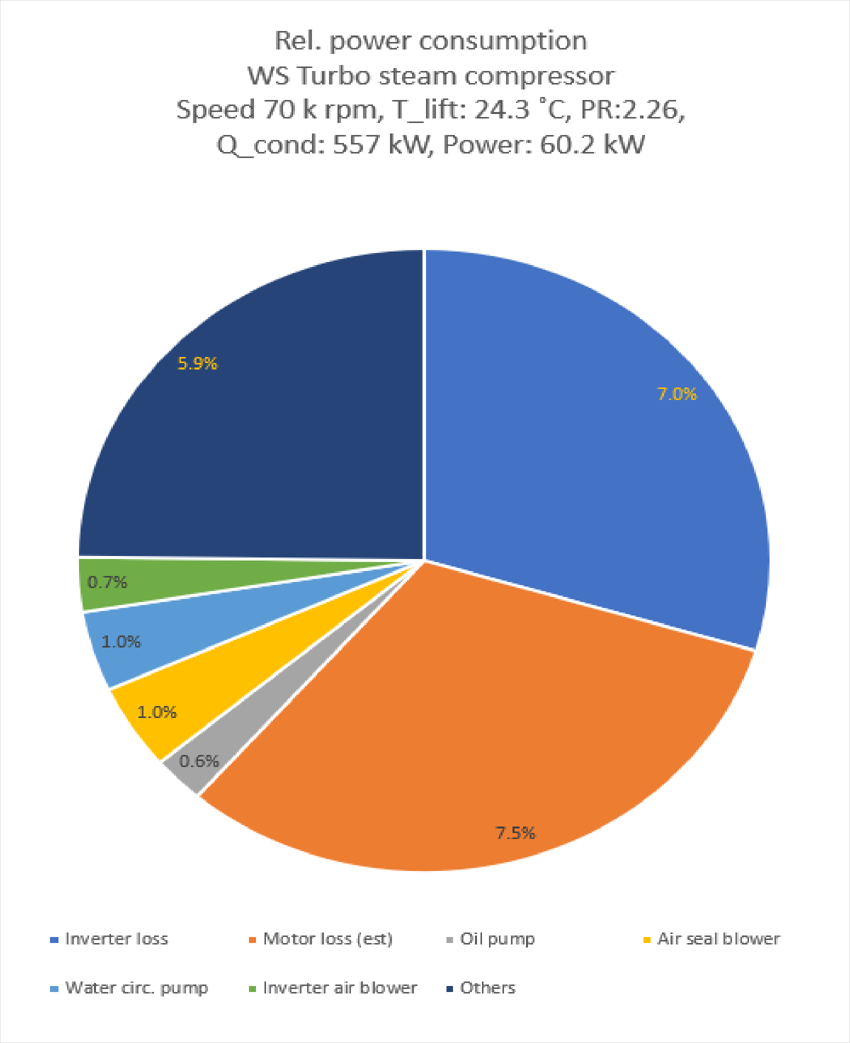
Critical speed 56000 RPM very high vibration => Rubs

Solution:

- Increased tip clearance on prototype
- Change of high diameter balance piston
- Very fast passing critical speed

Speed above 60000 RPM:
Very low amplitydes < 40 micron proximity probes

Parasitic loss distribution 100 % speed 60 % Power input

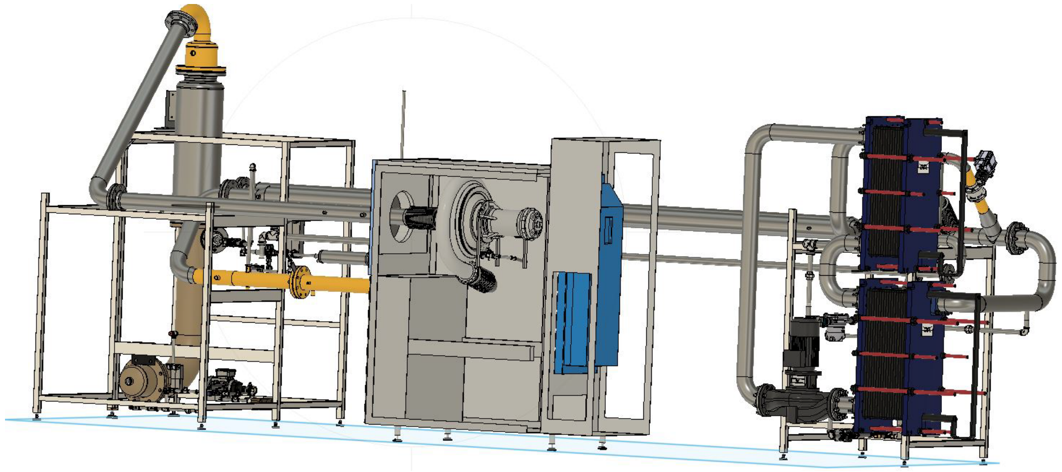


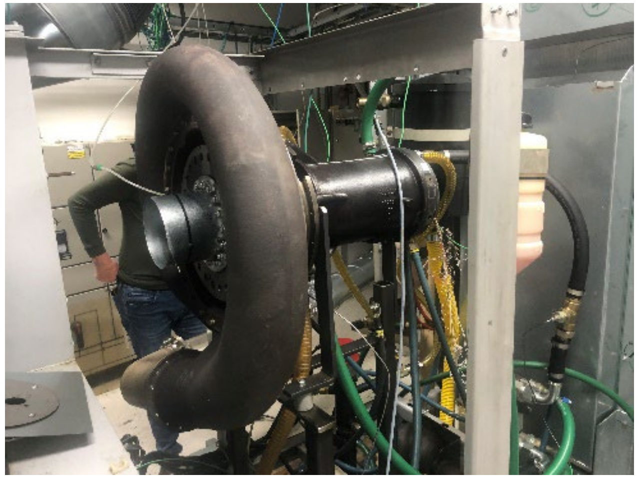
Loss in motor, Inverter and aux system higher then expected:
Parasitic losses about 18 % at 60 % power for 1st protype.
At 100 % Power expected parasitic loss is about 12 %.

Line filters for inverter has a loss about 1- 1.5 kW

Ongoing work "speedUp-2"

- Rebuild of test stand on DTU to a closed cycle heat pump
  - To "simulate" a closed cycle industrial operation of condenser and evaporator.
  - To achieve practical experience in operating with small or eventual no superheat on suction steam.
  - To measure pressure drop in HX
  - Test runs will be started in February 2024
- Design study of compressor family to meet suction flow range from 0.2 – 3 M3/s (constrains: 70000 RPM, 100 kW motor)
- Design of bearing, sealing and improved axial thrust balance system up to 10 bar discharge pressure (180 C saturation temp. for steam production))
- Motor 400 Volt design (1st.prototype was designed for 500 V)
- Reduce parasitic losses (aux system).





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Heat pump test plant simulation

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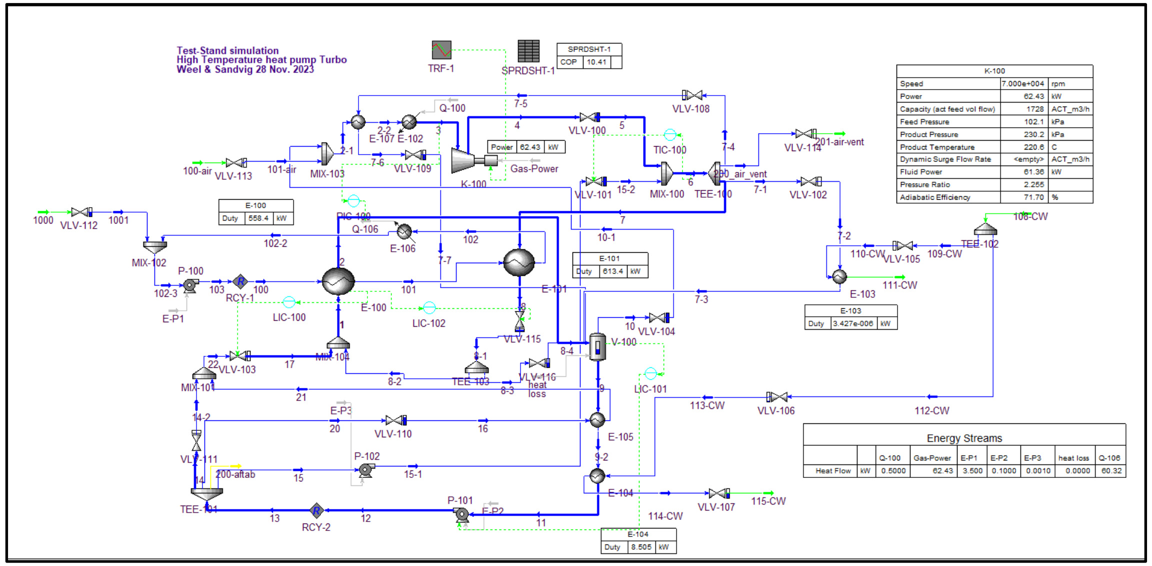

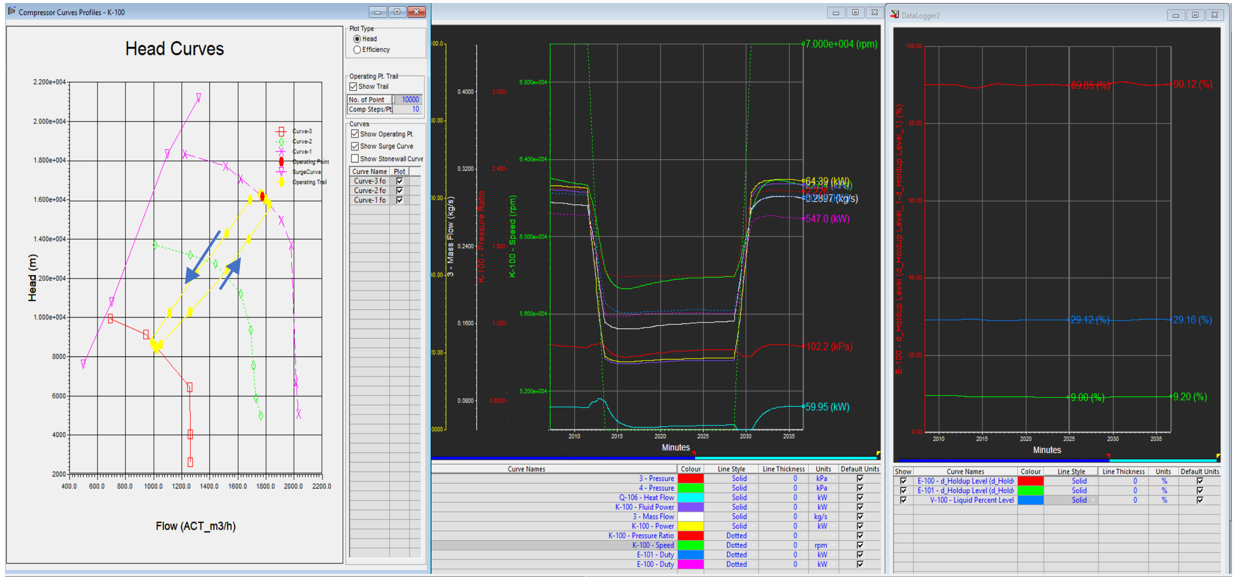

Simulation to demonstate control sytem robustness:

- Control Water level in evaporator
- Super heat a compressor inlet
- Control suction pressure
- Path in compresser during transient. The path shown is countra clockvice.
- Remark that during speed decrease, inlet pressure rise shortly => Risk for water condensation in compressor inlet.

Design of a new family of compressor aero dynamic parts for 1 – 2 or 3 stage application’s

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Goal:

- Pressure ratio up to 2.8 and Temperature lift of 31 C in 1-stage
- A Temperature lift of 83 C can be achieved in a 3-stage application
- Common 100 kW motor system, Inverter and auxiliaries
- Compressor and motor speed 70000 RPM
- Oil free compression

Temperature lift	C	20	28	29	56	57	83
Capacity Heat (Heat production)	KW	1167	851	1647	912	1347	963
Compressor stage		1	1	2	2	3	3
Power input	KW	105	105	210	210	315	315
COP		11.1	8.1	7.8	4.3	4.3	3.1

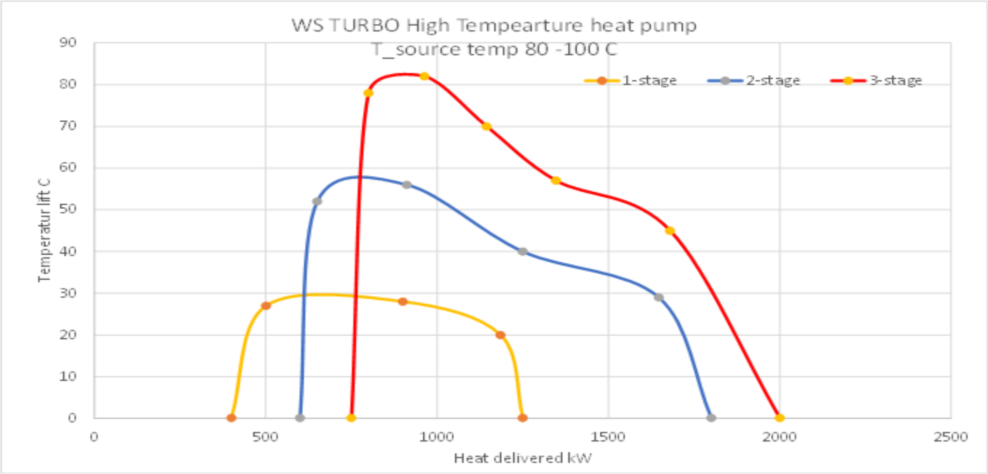
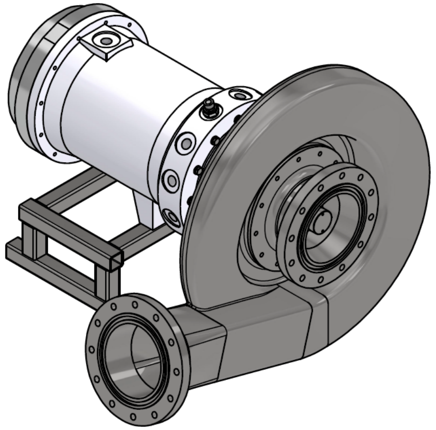
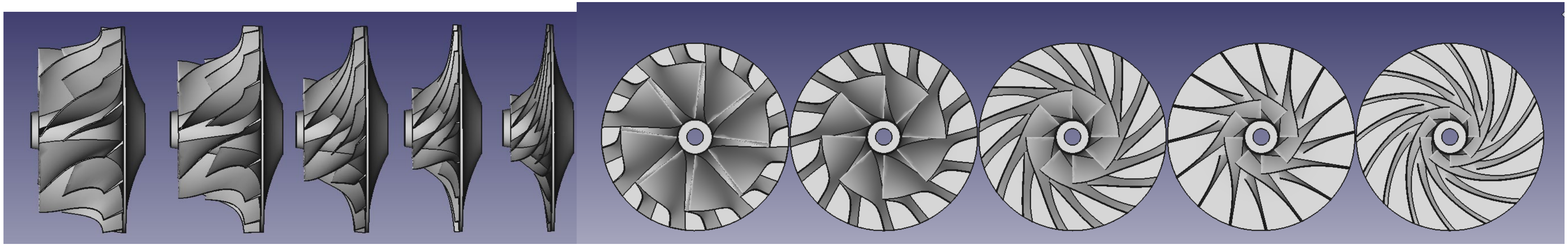


Figure 1 Performance chart WSTURBO high temperature heat pump (different compressor trims)



Initially main dimensions “New compressor family”



		Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Suction Volume	M3/s	3.1	1.67	**0.67**	0.32	0.15
Inlet pressure	bara	0.2	0.40	**1.0**	2.2	5
Pressure ratio		2.15	2.66	**2.7**	2.8	2.1
T_lift	K	18	26.3	**31**	31.5	28

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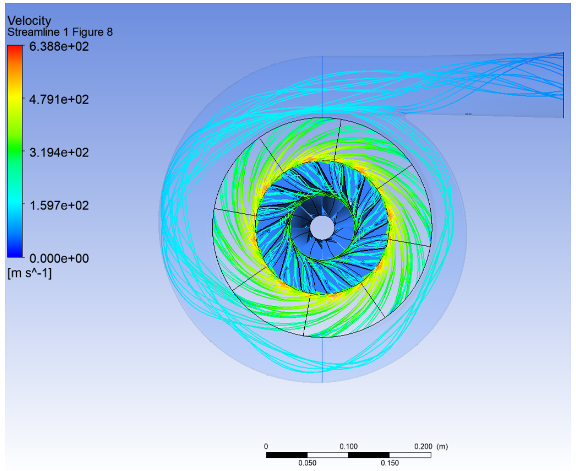
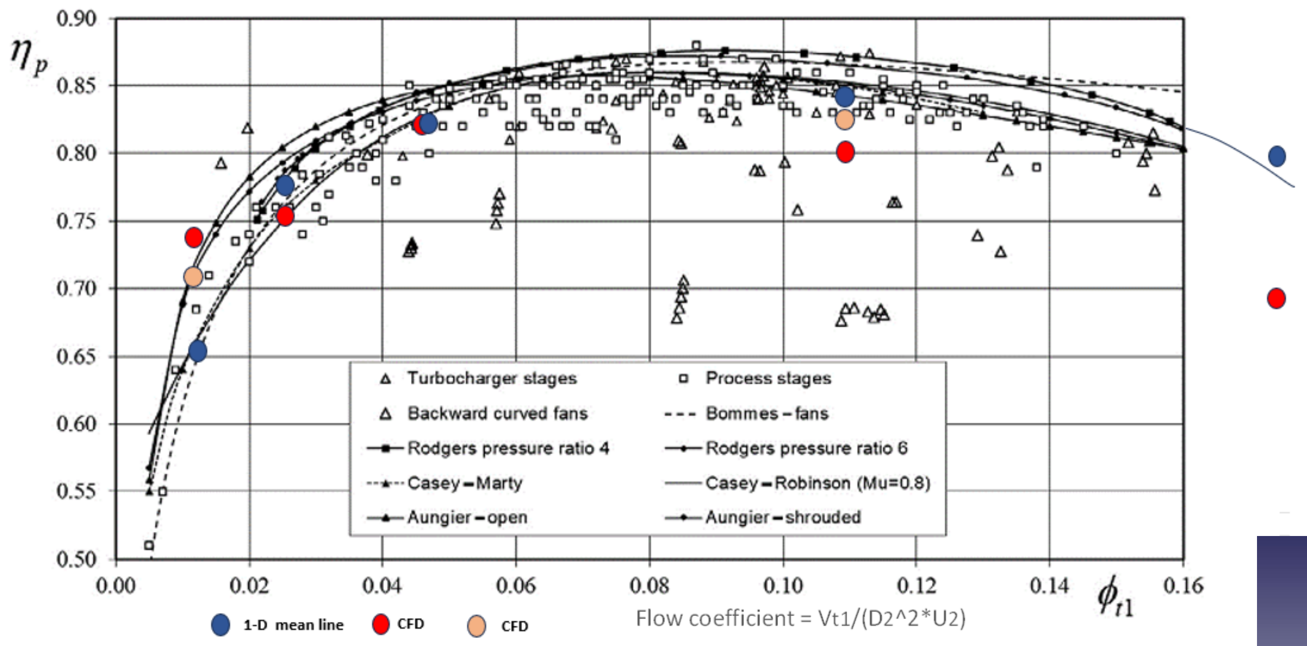
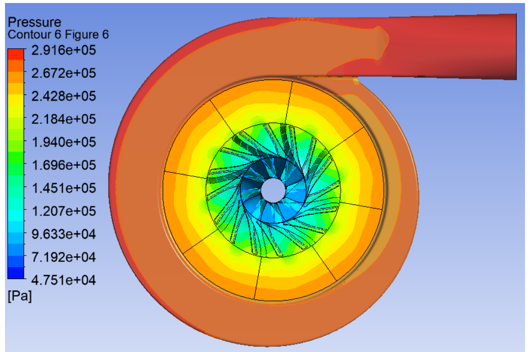
CFD analysis of compressor aerodynamic “optimized”

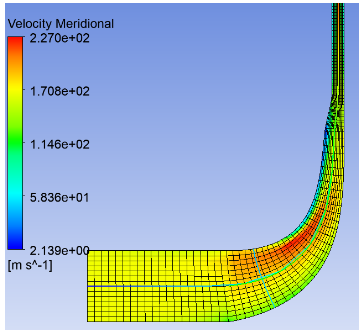
	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	
Pressure ratio	2.15	2.66	2.72	2.8	2.06	
Inlet pressure bara	0.2	0.4	1.0	2.2	5	
Flow coeff	0.187	0.115	0.046	0.021	0.01	
Corrected Isentropic efficiency %	61	77.1	80	72.7	71	
Polytropic efficiency	68	80.0	82.1	75.3	73.1	



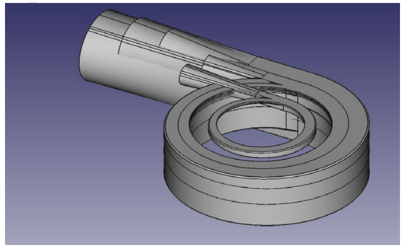


Polytropic efficiency versus flow coefficient.





- Very promising efficiency for stage 1
- Stage 2, 4 and 5 is being optimized further both for efficiency and stress.



Volute geometry stage 2, 4 and 5 need refinement

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Mechanical Stress, deformations & Clearance

Axial /radial clearance		”stage 3”	“stage 3”
		0 RPM	70000 RPM axial displacement mm
Impeller outlet (axial) deformation	mm	0	0.145
Impller inlet radial deformation	mm	0	0.045
Bearings axial play	mm	0	0.15
Thermal deformation fra shaft (0.5 m)l etc	mm	0	6.000E-02
Vibration bidrag, gætter axialt outlet	mm	0	0.01
Tie bolt force			
d2	mm	159	159
d1s	mm	79.4	85
d1h	mm	30	30
b2	mm	7	7
Clearance (shroud -casing at oulet), axial at tip	mm	0.65	0.285
Clerance impeller inlet radial direction	mm	0.35	0.295

Titanium alloy:
Yield strength: 880 MPa

Max stress: 503 MPa (725 MPa at 20 % over speed)

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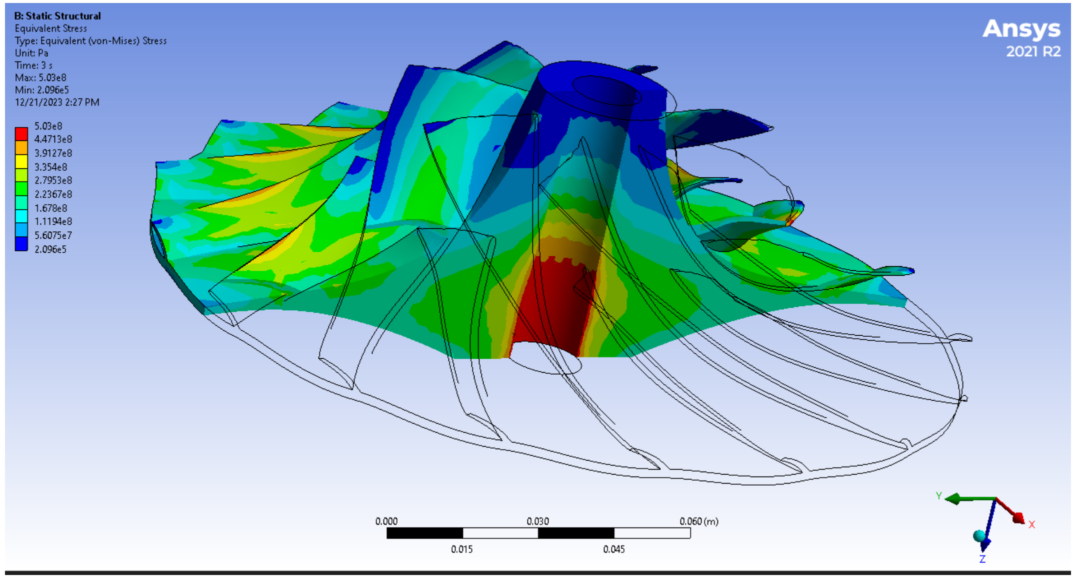
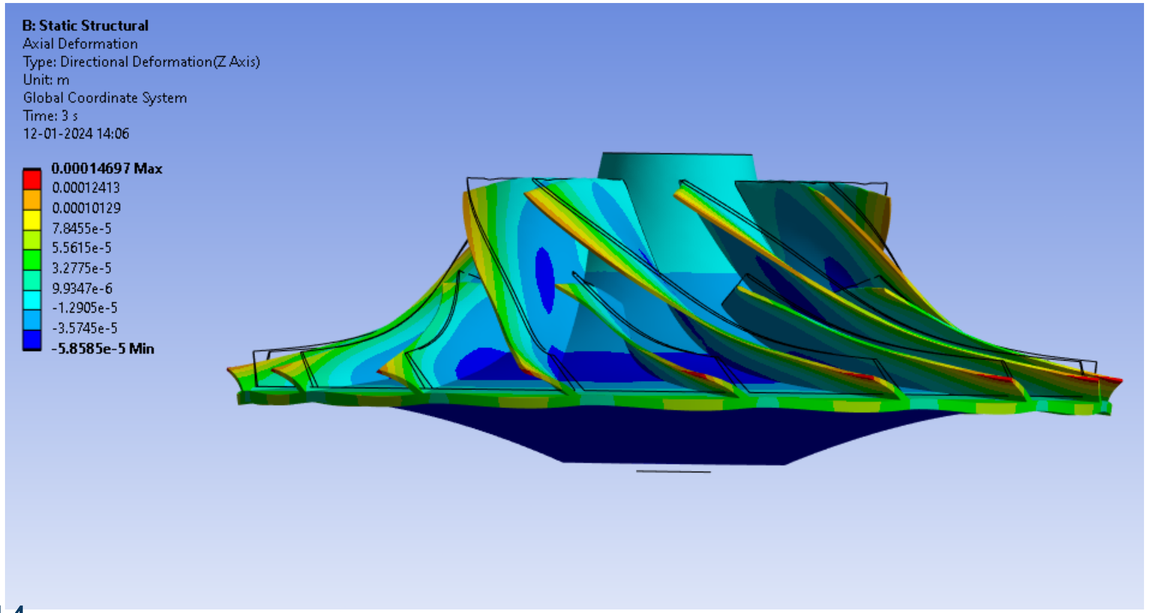
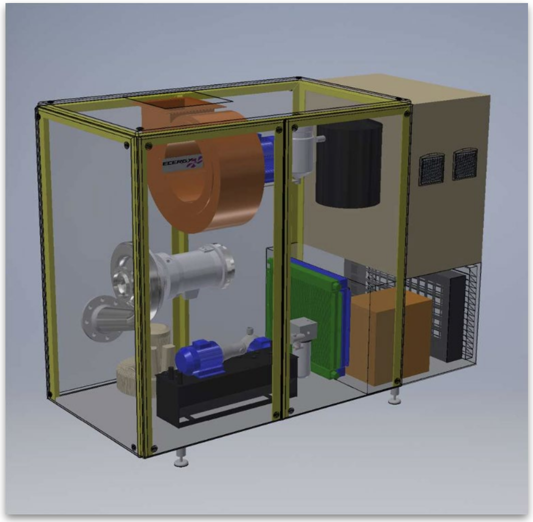


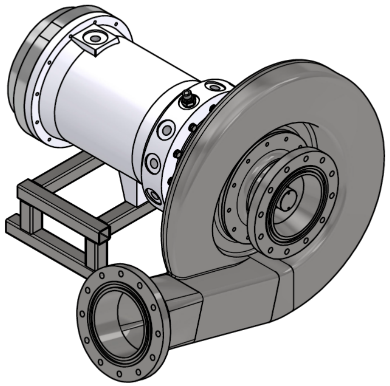


Next step

- New Improved prototype compressor unit will be build and tested during 2024
- Futher Optimazation of compressor aero dymanic to increase aerodynamic efficiency for stage 1 , 2 and 4.
- Final design of a compressor heat pump unit for demonstration at Nature Energy plant (Installation is planned to take place ultimo 2025)

- Thank you for your attention





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