

SpeedUP High speed direct drive Turbo compressor for Heat pump applications

IEA IETS Task 19 Workshop 14 Oct 2022

Mogens Weel mwh@weel-sandvig.dk

Jens Mikkelsen jmi@weel-sandvig.dk

Weel & Sandvig
ENERGI OG PROCESINNOVATION

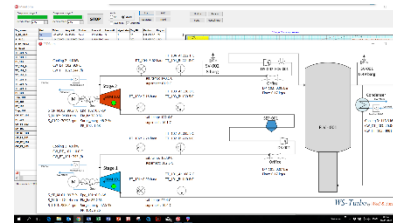
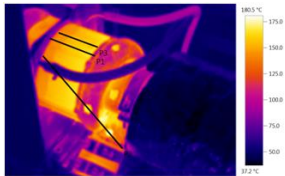
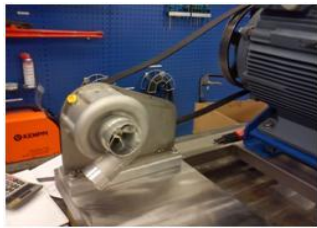
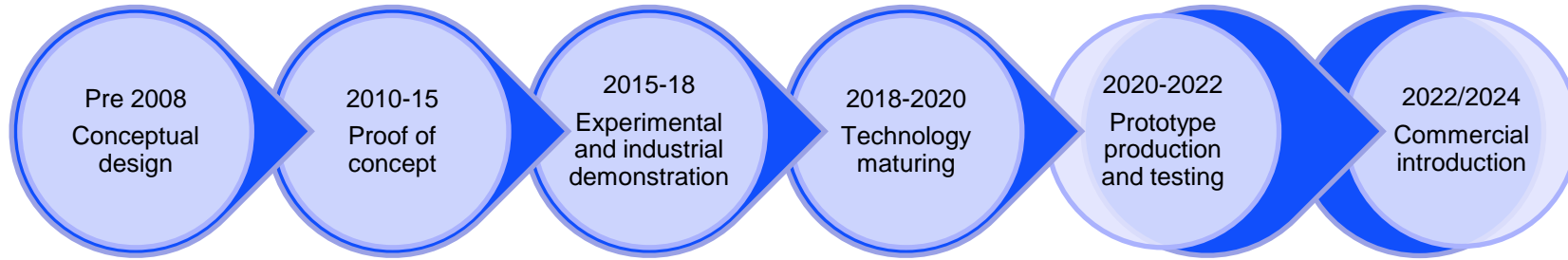
Diplomvej, Bygning 377-stuen, 2800 Kgs. Lyngby

Telefon: 2671 0045 eller 2671 0046

email: weel-sandvig@weel-sandvig.dk

web: www.weel-sandvig.dk

W&S “Long journey” with high temperature heat pumps with water



ROTREX™

**TEKNOLOGISK
INSTITUT**

nnovationsfonden

**ENERGI
STYRELSEN**

HALDOR TOPSOE

**MARS
incorporated**

SINTEF

**DTU
kergy**

High speed Turbo and gear derived from automobile industry
Lessons learned: can't meet Durability

High speed motor direct drive compressor
 Derived from micro gas turbine technology



SpeedUp: direct drive high speed Turbo Compressor for HTHP applications

Heat Pump technology Intended to meet potential high temperature heat pumps with sink temperature from 100 – 165 C and heat effect between 600 – 1500 kW/unit:

Typical industrial process application:

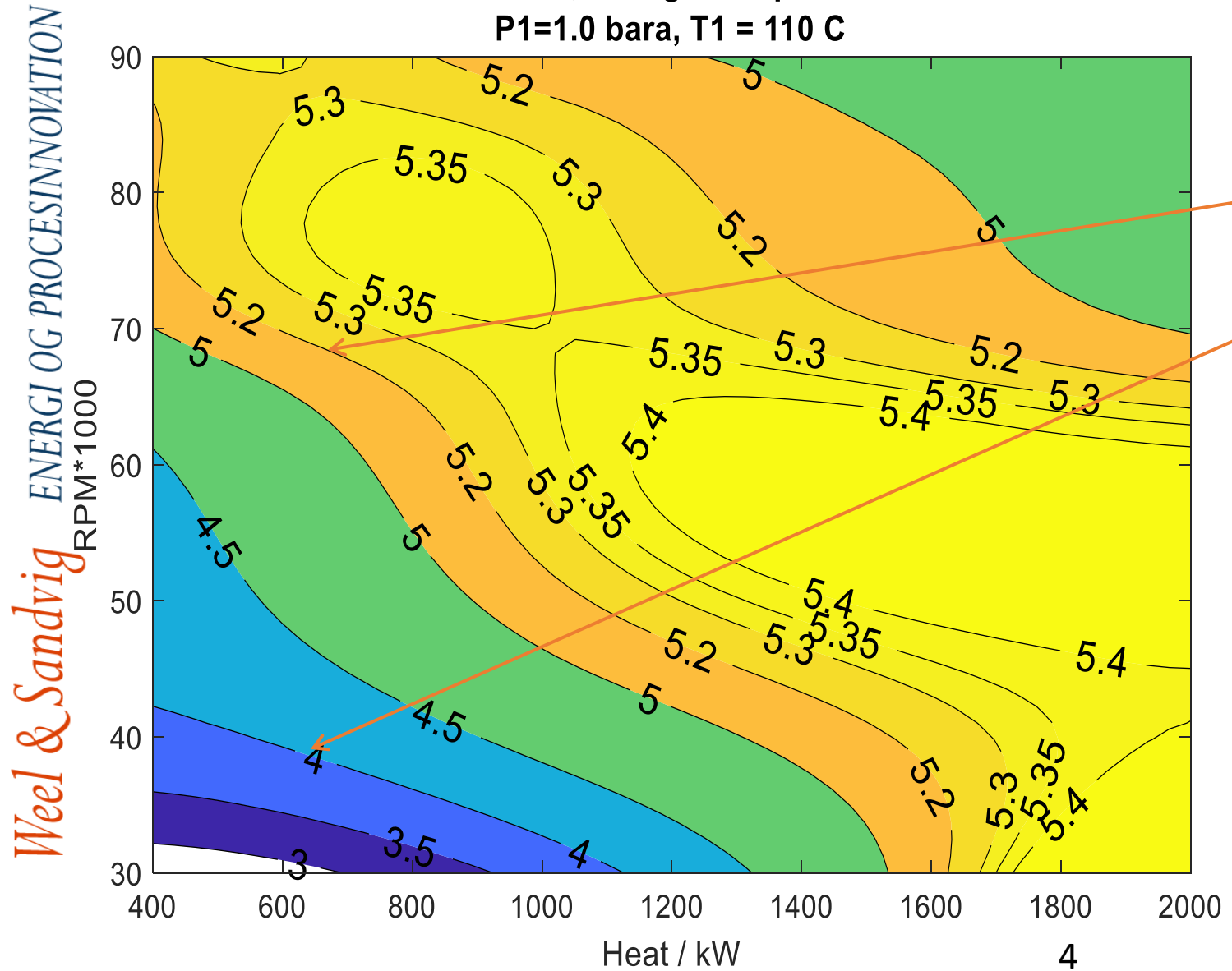
- Distillation $dT = 30 - 50$ K
- Evaporation (MVR) $dT = 15 - 55$ K
- drying $dT = 50 - 60$ K
- SpeedUp Project content:
 - Development of a compact gearless turbo compressor for heat pump applications with water vapor as working media. High speed motor derived Technology with already demonstrated high reliability (5 mio. Accumulated fleet hours, and 30.000 hour between major overhaul).
 - Improved leakage system (new labyrinth seals for oil free operation)
 - Investigate optimized Compressor flow path design (CFD and meanline analysis)
 - New balance piston to meet higher axial loads
 - Rotor dynamic
 - Design and installation of new test rig and control system
 - Demonstrate 200 - 500 hours load
- Project Partners Weel & Sandvig, DTU and Ekerly

Turbo compressor: why high speed

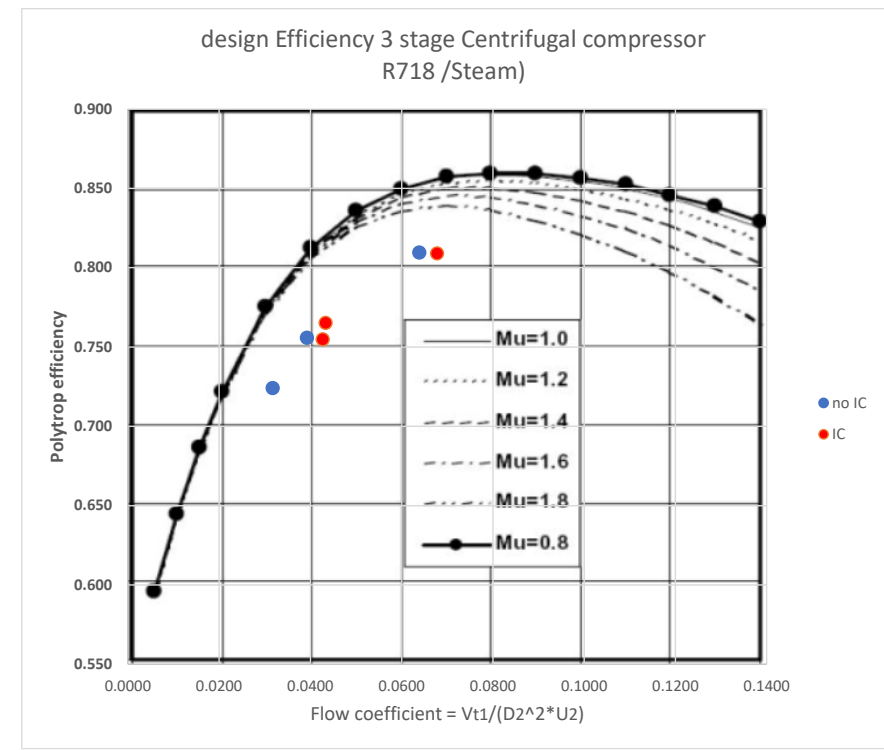
Design COP vs speed & Heat Output

dT = 52 C, 2-stage compression

P1=1.0 bara, T1 = 110 C

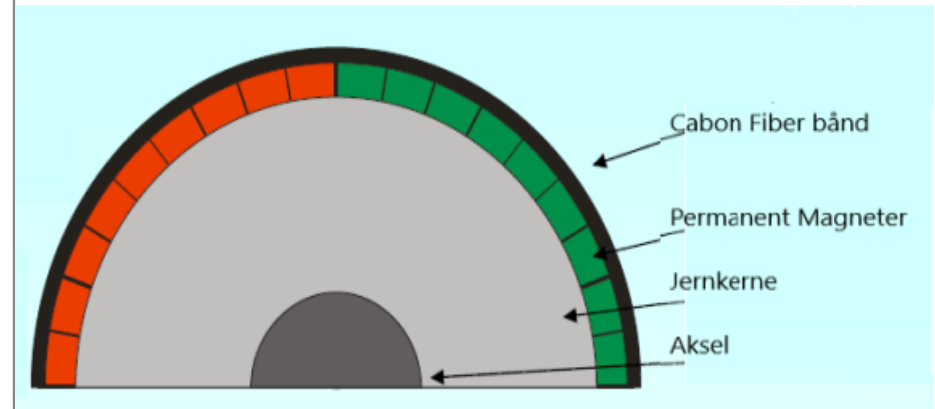
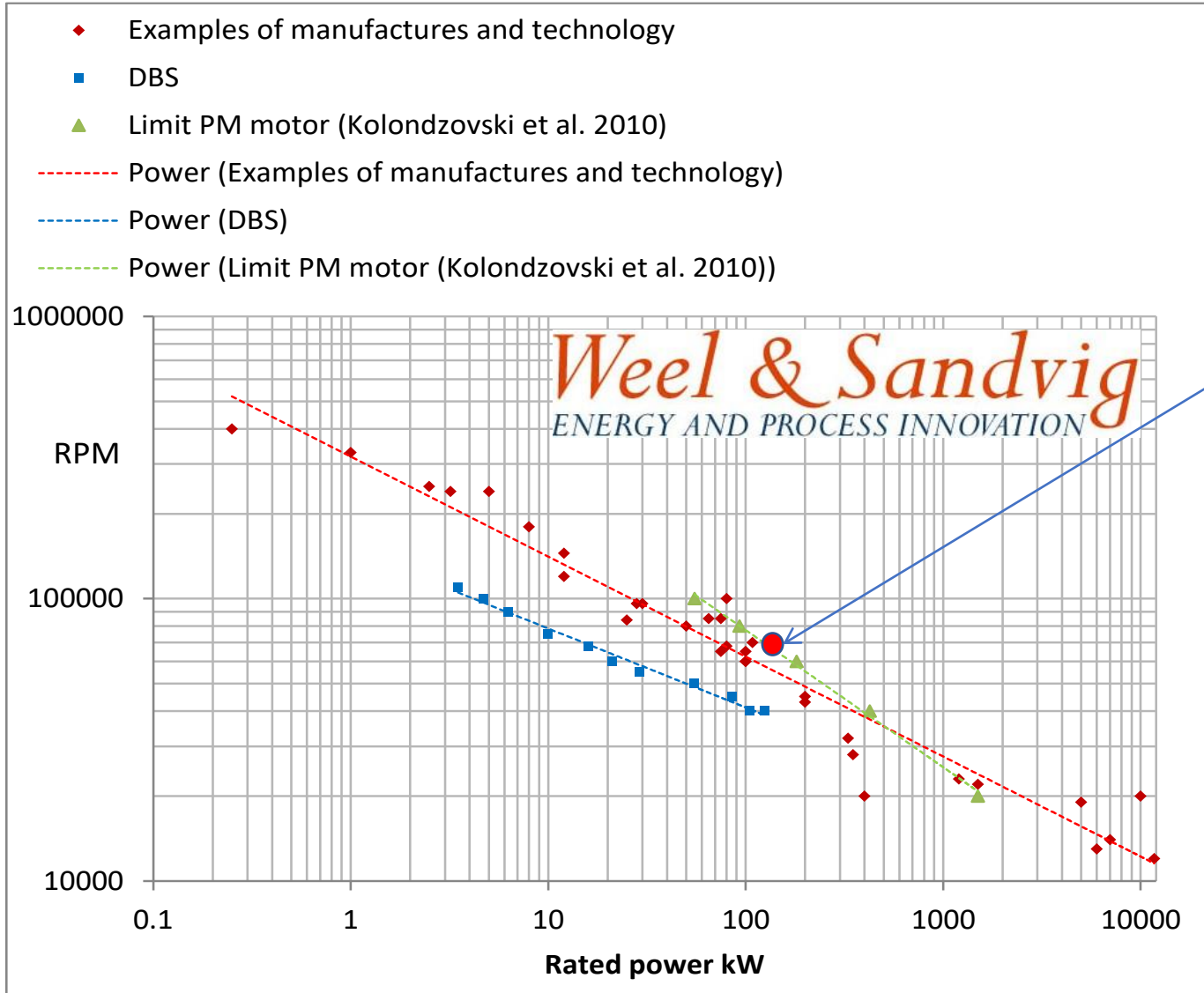


Example: Heat effect
 600 kW : Temperature lift 52 K
 Suction conditions:
 0,22 kg/s, 1,0 bara, 110 C
70000 RPM => COP=5,3
40000 RPM => COP = 4,0
 2- stages compression
 Tip speed 510 m/s
 Impeller diameter=142 mm

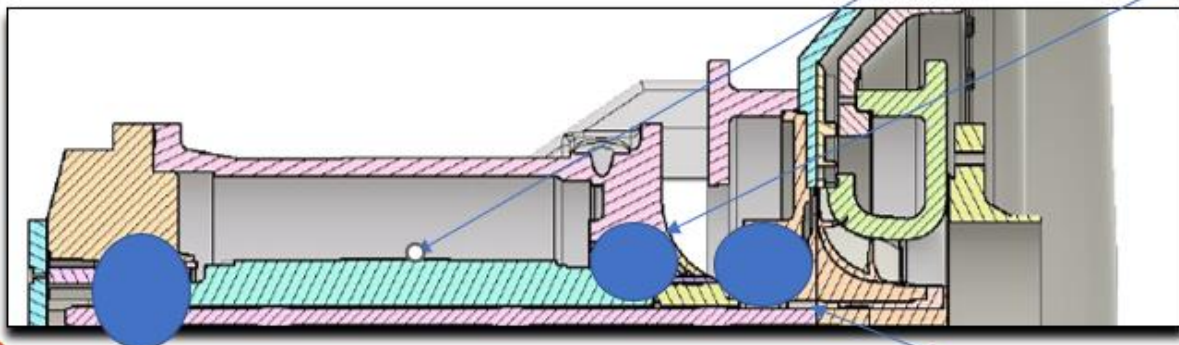


Weel & Sandvig ENERGI OG PROCESINNOVATION

High speed motors strength limits (running on the edge)

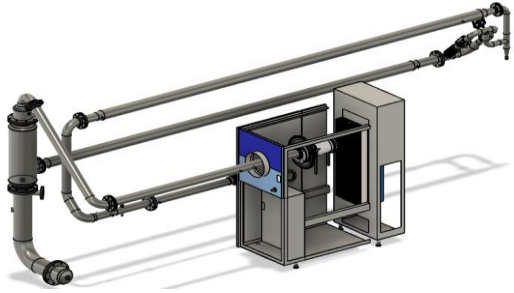
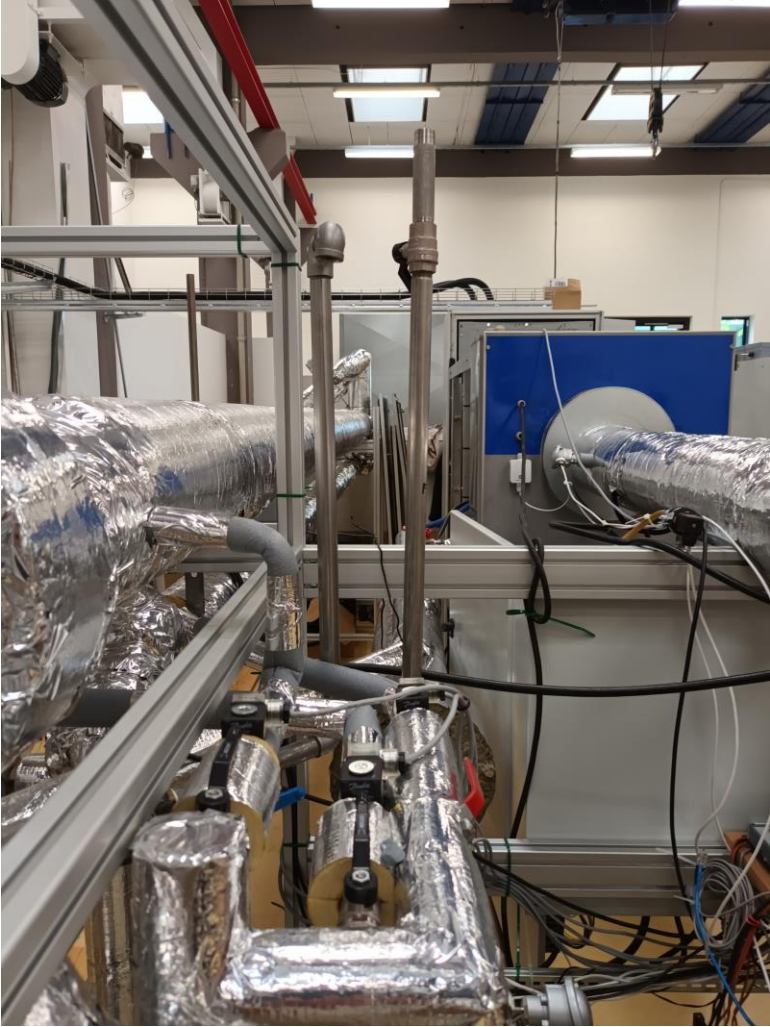


Motor Compressor design SpeedUP

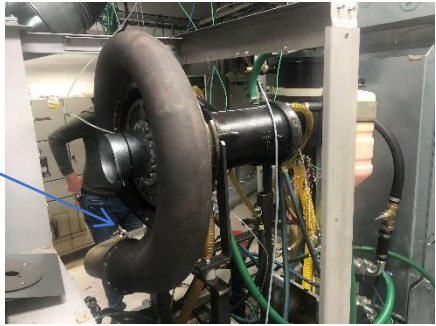


- PM high speed Motor
 - Motor design derived from Micro gas turbine : 100 kW (110 kW)
 - 4 – poles PM design)
 - Up to 72000 RPM
 - Water cooled
 - Ceramic bearings with oil lubrication
 - Bearing squess film damper
 - Air cooling of rotor stator cap
 - Speed control with inverter
 - Oil consumption lubrication 1 – 3 liter/year
- New Compressor:
 - 142 mm Impeller
 - Tip speed 520 m/s
 - Suction volume flow 0.5 – 1.2 m³/s (trim depended)
 - Pressure ratio 2 -2.5 => dT= 20 -27 K
 - Speed: up to 72000 RPM
 - Material: Titanium
 - Diffuser: vaneless or vaned
- New Sealings:
 - 3 sets of labyrinth sealings with active seal control system => oil free operation (seal steam loss 0.002 kg/s)
- New Axial thrust balance piston
- Tie Bolt design
- Heat: 600 – 1500 kW

test plant under construction and finish



Compressor + motor



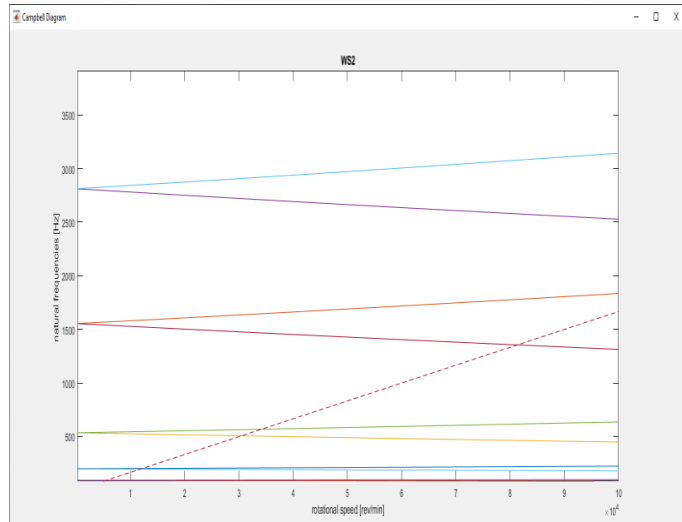
Inverter & control system



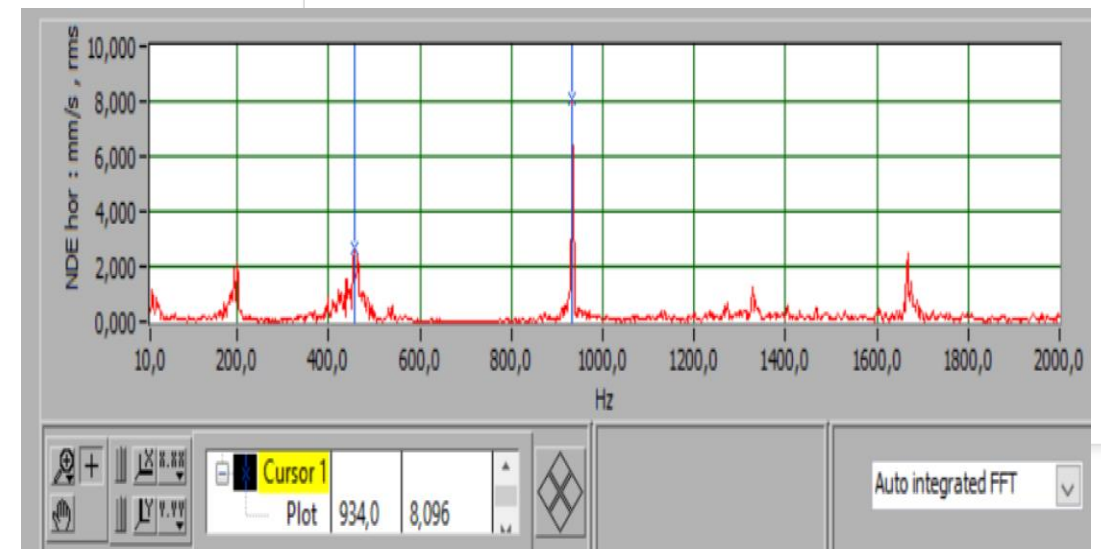
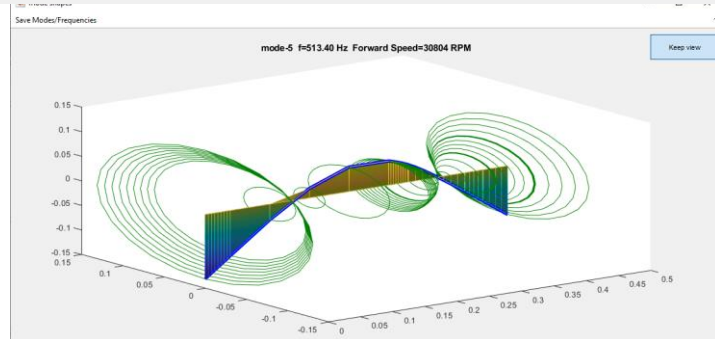
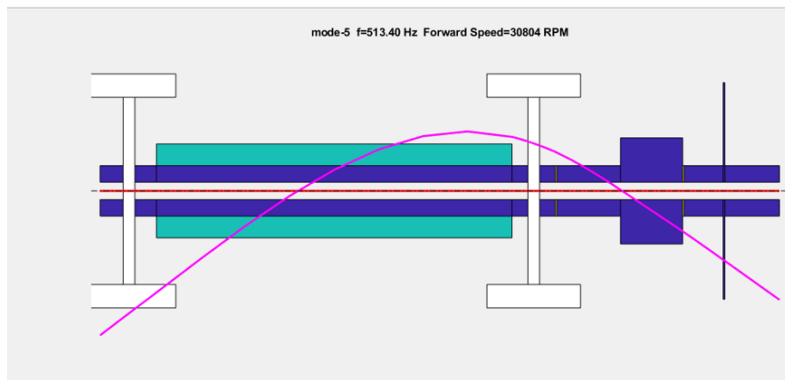
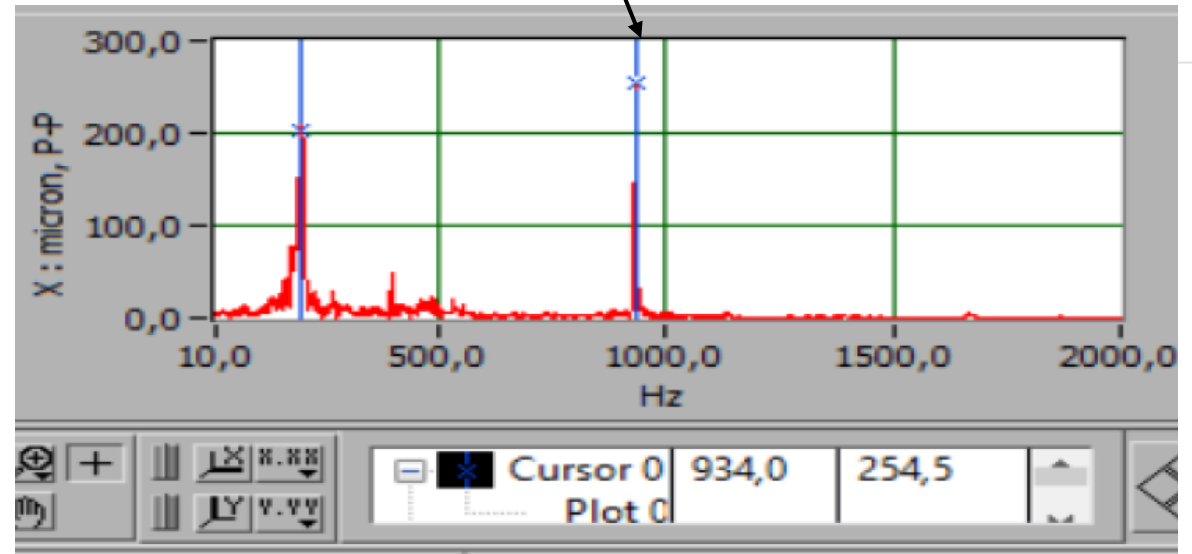
Compressor impeller
PM Rotor, Tie bolt

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

Experience from initially test Rotor dynamic (tie bolt rotor design) & critical speed



Mesured during initial test after 4th modification
56000 RPM critical speed



Test with steam started in June 2022

Weel & Sandvig ENERGI OG PROCESINNOVATION

WSTURBO-CONTROL - TeamViewer - Free license (non-commercial use only)

EMpro | EEM-MA770

Not secure | 192.168.0.2/instantaneous

Active power	
P1	15,96 kW
P2	16,54 kW
P3	16,73 kW
ΣP	49,24 kW

Reactive power

Media: Air Steam

Buttons: Stop, HMI, Modbus, Params, DataView, Trend, map2, Manual input

Save to DB Simulation

Tag ID	Device	Reg
109	WAGOPLC	9
106	WAGOPLC	6
117	WAGOPLC	17
110	WAGOPLC	10
101	WAGOPLC	1
203	WAGOPLC	20
111	WAGOPLC	11
105	WAGOPLC	5
112	WAGOPLC	12
102	WAGOPLC	2
104	WAGOPLC	4
107	WAGOPLC	7
113	WAGOPLC	13
114	WAGOPLC	14
204	WAGOPLC	21
201	WAGOPLC	18
202	WAGOPLC	19
205	WAGOPLC	22
206	WAGOPLC	23

WS-TURBO T100 Compressor map - Steam

Design point:
Speed 70 000 RPM, P_{in} 1.013 bar, T_{in} 100 °C
PR 2.25, Flow 0.38 kg/s, Isent. Eff. 0.785

Pressure Ratio vs Corrected Flow

Operation point: Current

LP SEP

Press. relief 1.5 barg

Electric tracing

Suction press. switch 0.3 barg

Main power

Expansion canister

Water circ. pump

Oil cooler

Oil tank

Oil pump

High speed motor

Air gap blower

Surge control

Compressor PR: 1,81
Speed: 90 rpm
CompEfficiency: Label26
Surge marg: Label26

Orifice
dP₀: 0,128 mBar
Flow: 0,214 kg/s

Steam condenser

Condensate air

Convective cooler

Air outlet

Manual ball valve Cv=234

TSat: 118,3 C
TSup: 30,4 C

T_{s,a}: 131,9 C
T_{s,b}: 130,4 C

T_{d,a}: 214,7 C
T_{d,a}: 215,2 C

P_d: 1,88 bara

T_J: 83,3 C

T_{inlet}: 91,7 C

T_{inlet}: 85,2 C

P_{in}: 4,5 bara

Water inj. pump

Water inj. T_J: 34 %

Condensate

Inj. water preheater 2

Inj. water preheater 1

Thermostatic mixing valve

Steam trap

Steam

Coiler inj. water

T_{CW,r}

T_{CW,fwd}

CW Fwd

CW return

Electric heater

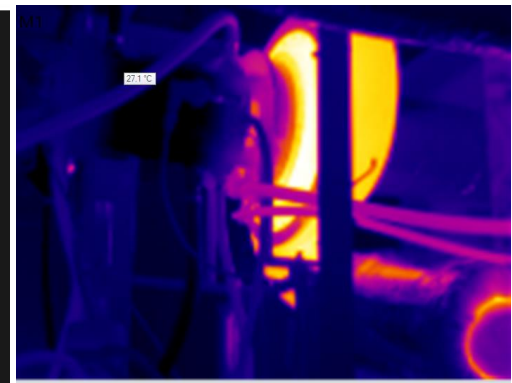
Thermostat

On / off

TrendForm

TChart

- P_d
- Speed demand %
- T_J
- T_{d,a}
- Oil_{outlet}_temp_ball_bearing
- Oil_{inlet}_temperature
- T_{s,a}
- dP_{pump}



TeamViewer

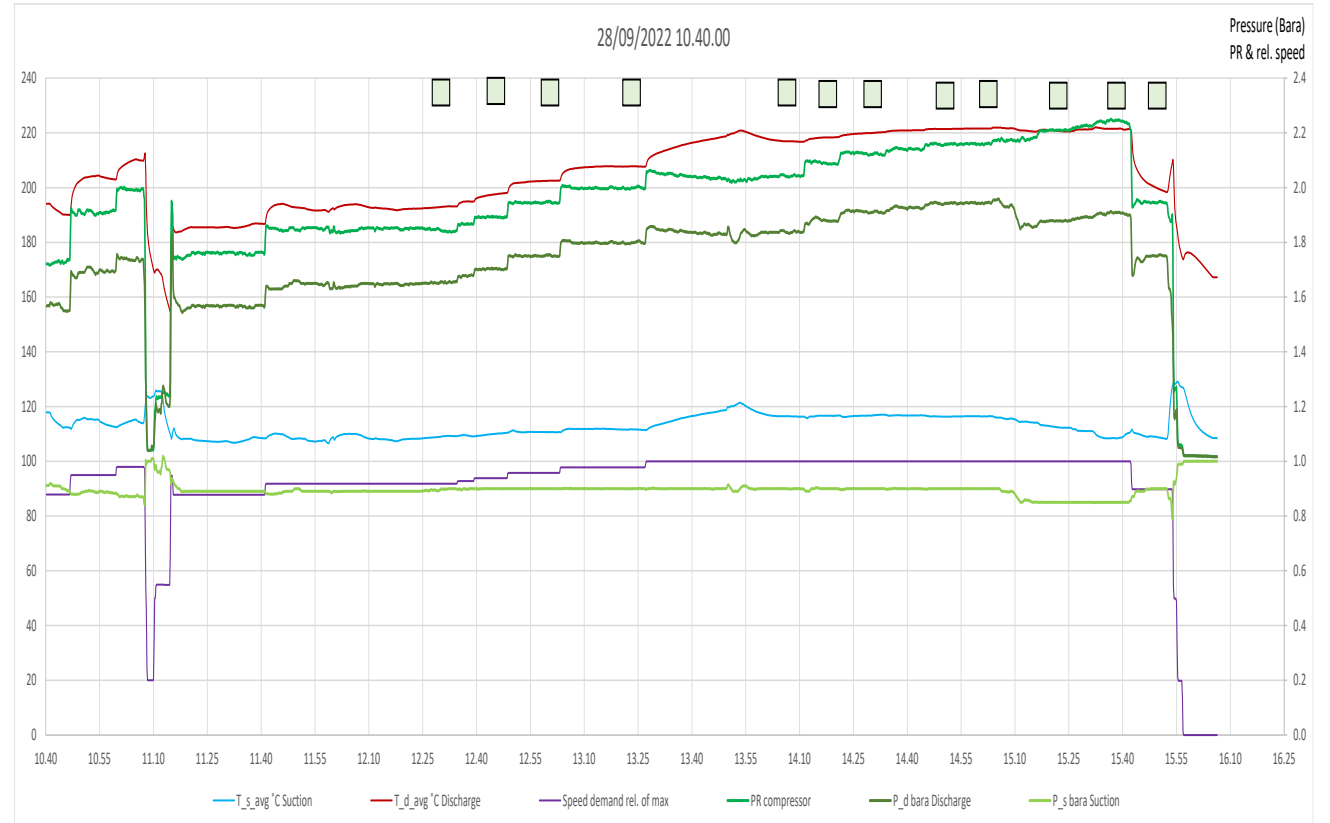
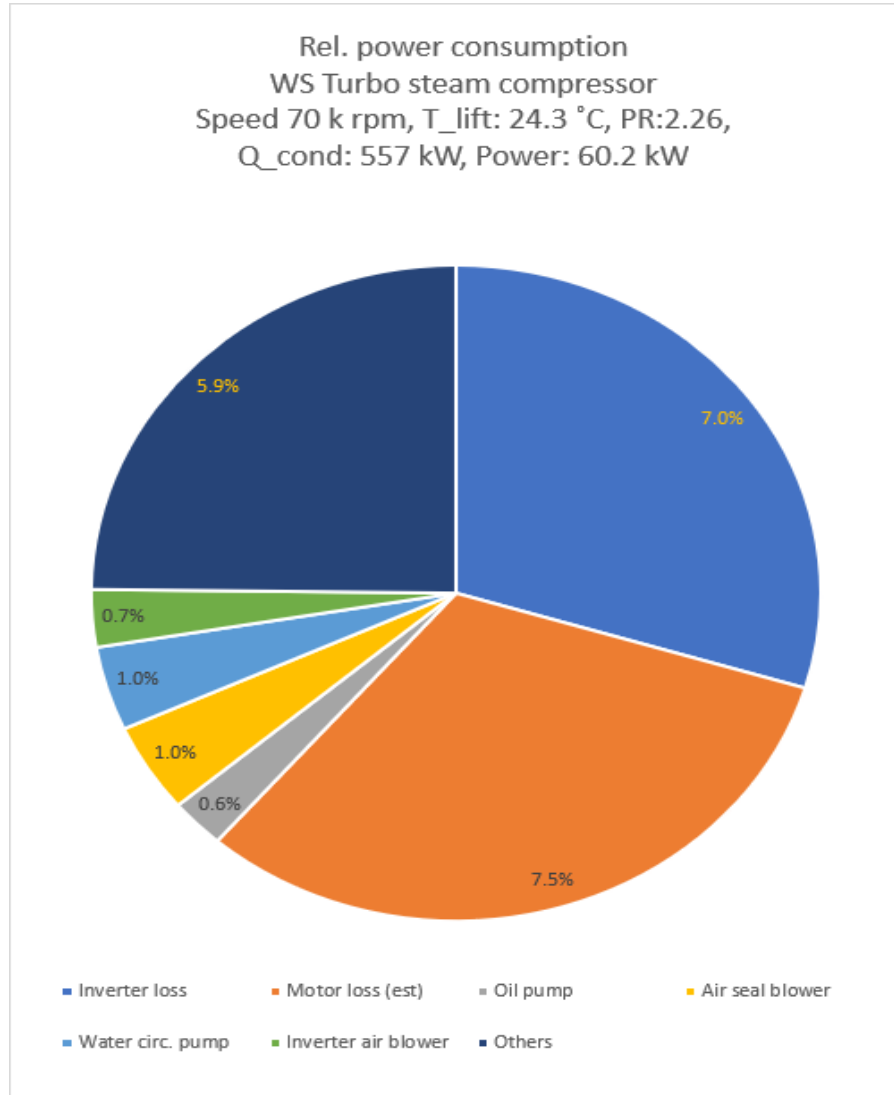
Free license (non-commercial use only)

Session list

DESKTOP-HFV6308 (498 377 4)

13:09 Friday 08/07/2022

Parasitic loss distribution 100 % speed 60 % Power input



Overall test result so far and conclusion

- About 100 hours of operation with steam, (major parts of the compressor set hours motor, inverter, aux system, bearings etc have gained 40000)
- Inlet pressure from 0.8 bara to 1.3 bara
- Steam suction capacity 0.2 – 0.6 M³/s (100 % speed)
- Inlet temperature from 110 C to 170 C
- Pressure ratio 1.8 – 2.2 (with actual test rig impeller design, New design up to 2.9 can be achieved)
- Discharge pressure demonstrated: 2.7 bara (130 C saturation temperature) discharge pressure was limited by power input
- Temperature Lift 25 K in one stage
- Measured Compressor isentropic efficiency 0.73 – 0.75
- Loss in motor, Inverter and aux system: Gas Power/Grid Power 0.82 at 80 % power.
- Very smooth and stable operation above 82 % speed (very low vibration level)
- Critical speed area from 68 – 82 % speed must be passed very quickly.
- All safety systems for compressor start up and safe operation worked as expected.
- Some challenges controlling the gas loop system used on the test rig
- Compressor system is on TRL 6-7 and will be ready to test in industrial environment

Heat Pump layout : SpeedUp 2 stage design



Goal:

Heat effect: 500 – 1400 kW/unit

Price label: 1400 -3000 Euro's/kW electricity

Temperature lift 20 – 55 K

COP : 5 - 12

Primary application's:

Source heat : 80 – 120 C

Drying (2- stages, $dT = 55K$, COP=5)

Distillation (2 stages, $dT=30 - 50K$)

UHT milk (2 stage, $dT=50K$)

MVR (1 stage, $dT= 15 -25 K$, COP= 10 -15)