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MEASUREMENT SYSTEM OF SMALL-SCALE HIGH EXPANSION RATIO ORC TURBINE

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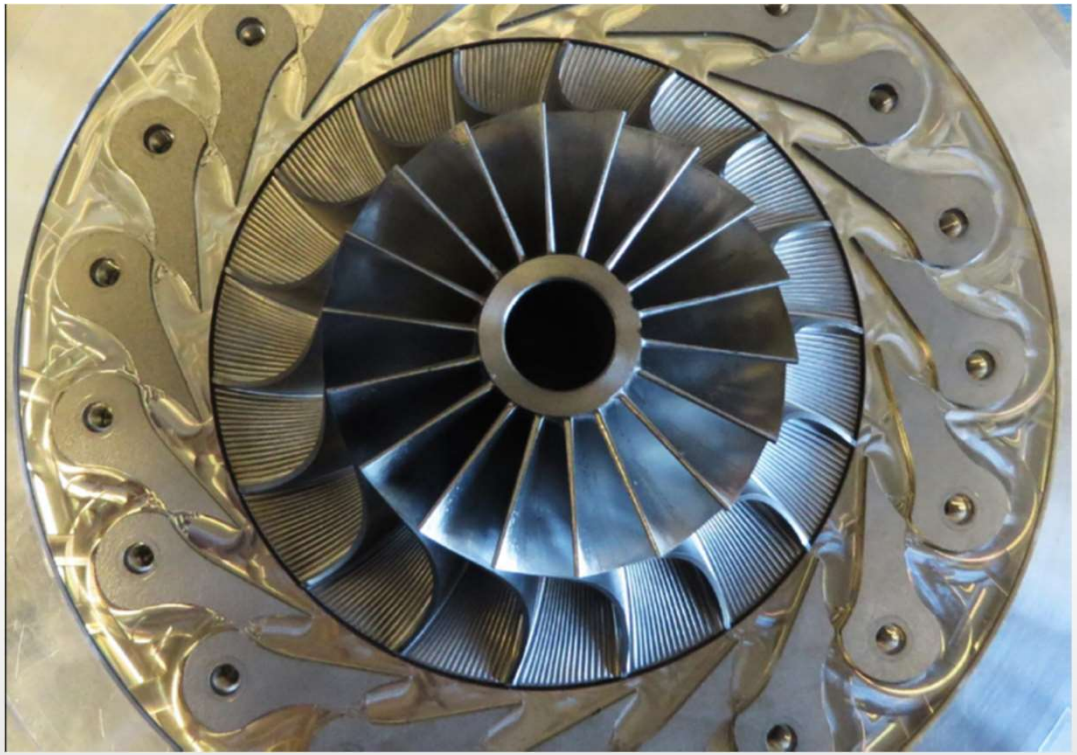
Content

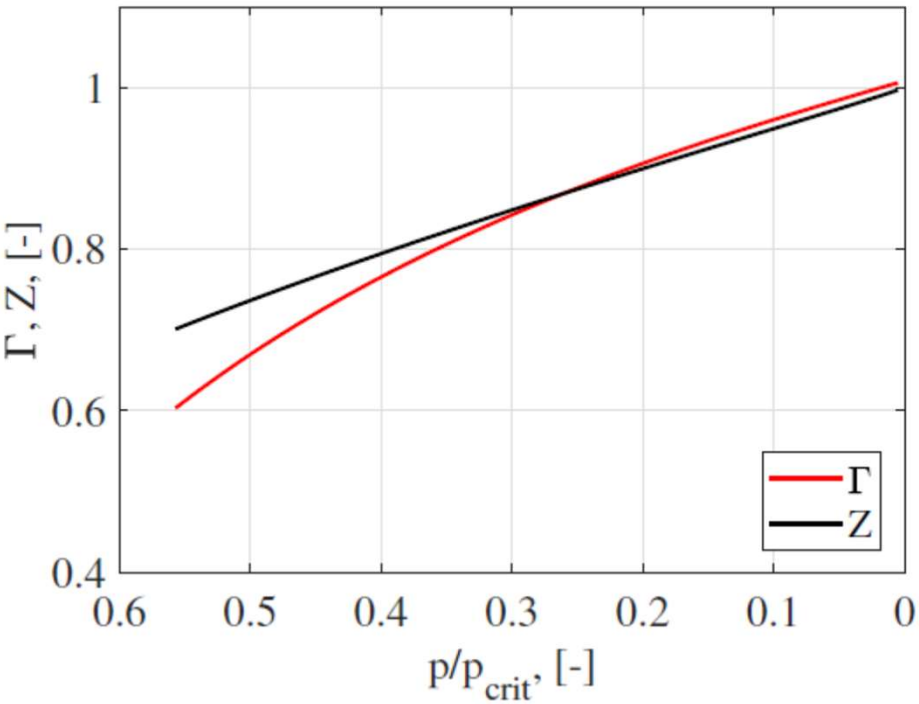
- Experimental setup
- Results with original system and uncertainties
- Updated measurement system
  - Flow rate, pressure and temperature measurements
  - Pressure measurements between stator and rotor

Experimental setup

- Working fluid siloxane MDM
- Exhaust gas heat recovery from a 150-200 kW scale diesel-generator
- Turbine power output ≈12 kW, electric power output ≈ 8 kW
- Turbine inlet temperature 265 ^{o}C, inlet pressure 7.9 bar, and mass flow 0.2 kg/s
- Design pressure ratio over 100 (turbine outlet pressure 0.07 bar)
- Hermetic high-speed turbogenerator with 31 000 rpm design speed
- Supersonic radial inflow-turbine (Ma = 2.2 at stator outlet)
- Max. measured electric power output of 6 kW

Supersonic turbine, Z and Γ

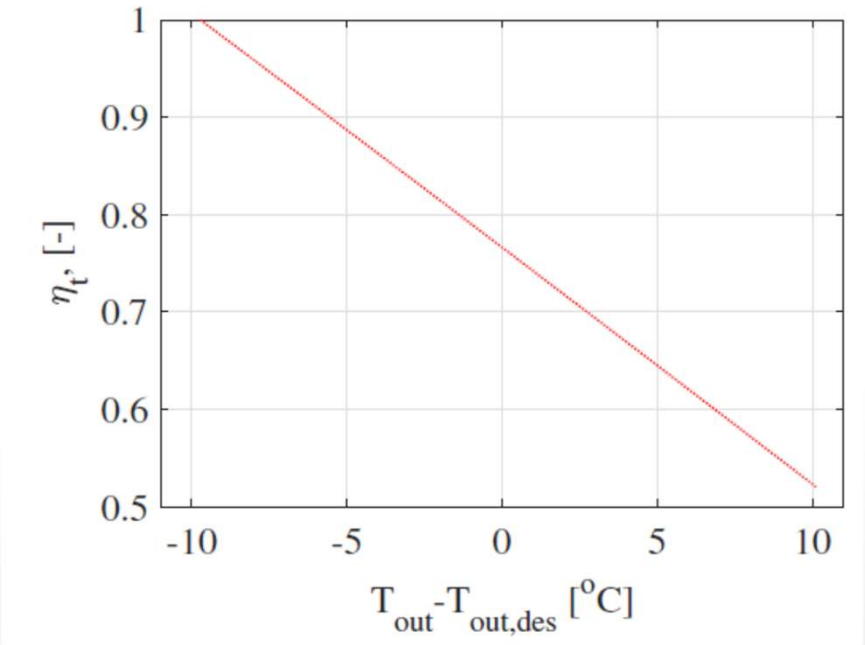


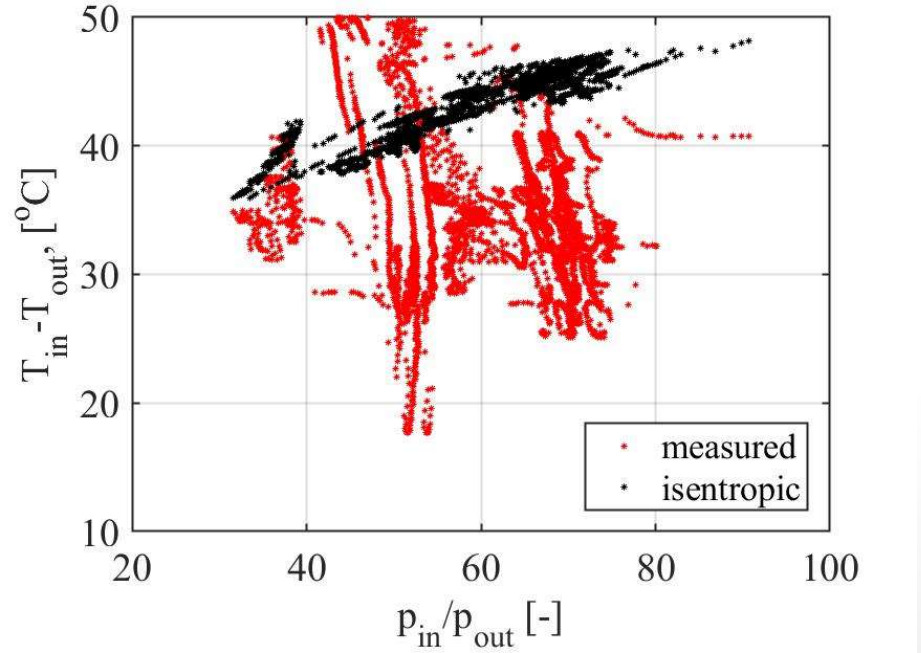


Uncertainties in the results

- High scattering in the measured turbine outlet temperatures
- Uncertainties especially at lower turbogenerator rotational speeds (20 000-24 000 rpm) and with lower pressure ratios
- Better agreement between the measurments and thermodynamic models when the turbogenerator rotational speed approaches the design speed.
- Even a small change in the measured turbine outlet temperature results in to high change in the isentropic efficiency
- Average turbine effciency of over 70 % has been analyzed from the experimental results close to the design rotational speed(Uusitalo et al. 2020)

Sensitivity of turbine outlet temperature on efficiency and measured temperature drops over turbine





Uusitalo, A., Turunen-Saaresti, T., Honkatukia, J., & Dhanasegaran, R. (2020). Experimental study of small scale and high expansion ratio ORC for recovering high temperature waste heat. *Energy*, *208*, 118321.

Updated turbine measurements

- Flow rate measurement for vapor working fluid
- Number of pressure and temperature measurements have been increased at turbine outlet

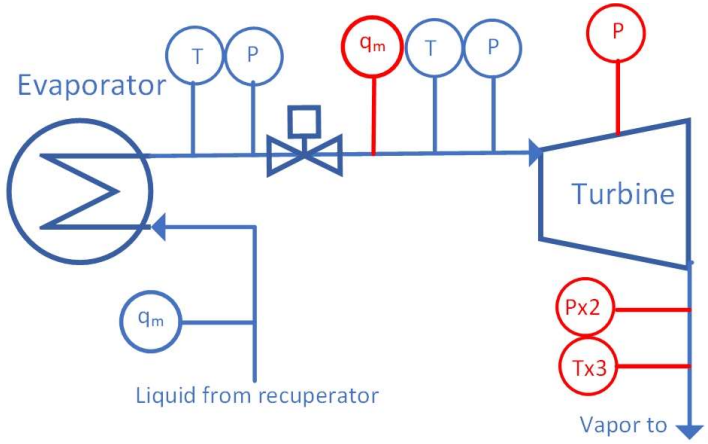


Table 1: *Measurement equipment.*

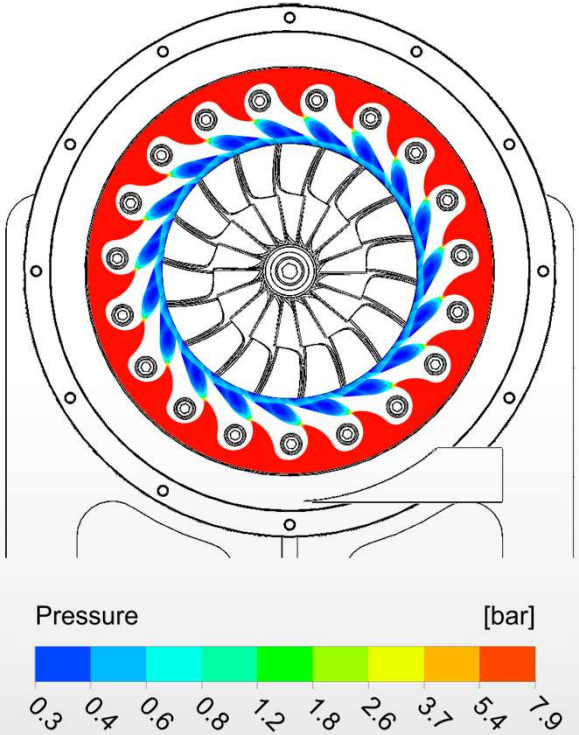
	Manufacturer	Type	Accuracy
Pressure	Gems	TR2200, [0-1,0-16 bar(abs)]	± 0.25%
Temperature	Aplisens	CT-GN1	± 0.35 K (at 100 ^{o}C temperature)
Flow rate (liquid)	Kytola Instruments	oval gear SRP-40-H	± 0.5%
Flow rate (vapor)	McCrometer	V-cone VB0CAE01N	± 0.5%

Placement of the turbine outlet temperature measurements

Pressure measurements in the turbine stator

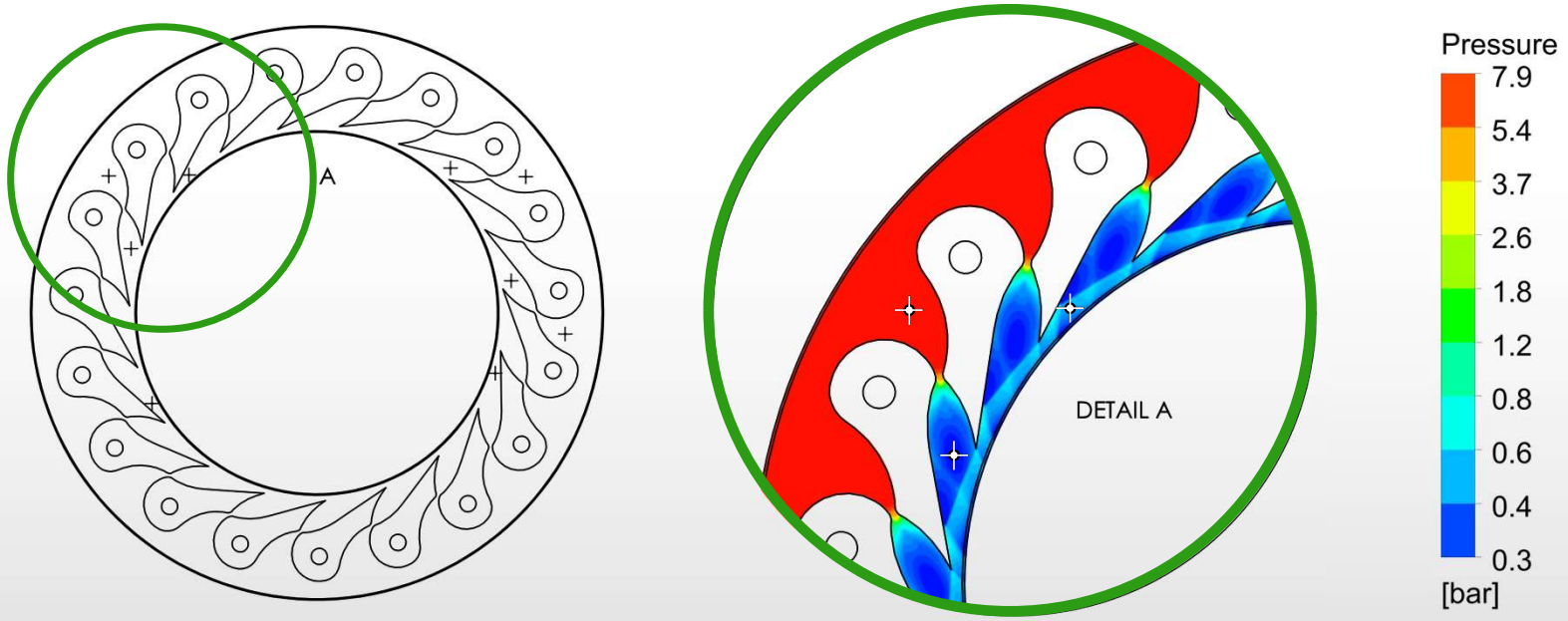
- Goals:
  - Monitor the expansion along the blade passages
  - Evaluate the degree of reaction
  - Estimate trailing-edge shock losses

- Constraints:
  - Accessibility
  - Small size of the stator ring (D_{int} =145 mm, D_{ext} = 230 mm)
  - Conventional machining processes and standard components



Positions of pressure measurement points

- 3 radial locations: convergent, divergent, stator outlet (post- trailing-edge shock)
- Measurements repeated at 3 different circumferential positions
- Tappings (Ø 0.5 mm) located in regions of lowest pressure gradient (< 20 mbar/mm)
- Measuring close to the stator throat is difficult due to the small dimensions and high pressure gradients



Future work

- Test runs with the new measurement system will be started at the end of 2020, installation work currently ongoing
- Turbine performance maps and better characterization of turbine efficiency
- More detailed information on the stator and rotor expansion at different conditions
- Experimental results will be used for validating numerical models and for generating updated loss correlations

Thank you for your attention!