OPTIMUM DESIGN OF THE AXIAL ORC TURBINES WITH SUPPORT OF THE ANSYS CFX FLOW SIMULATIONS

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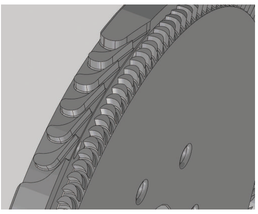
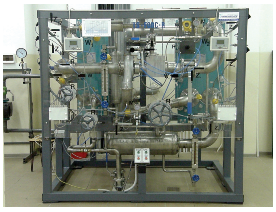
Abstract: The ORC power plants require essentially their turbines to be individually designed for each power plant case. This is due to the varying parameters (temperature, capacity) of the heat sources to be utilized by a prospective ORC power plant. Moreover, selected cycle working fluid and its critical parameters, as well as certain design constraints (like in the case of the hermetic turbogenerators), are all affecting the final design of the turbine that should yield the maximum power output. Occurrence of the transonic and supersonic flows in the turbine channels is another difficulty to reach the optimum turbine design. Several basic turbine designs will be discussed in this contribution. Their final form was achieved with support of the numerical 3D viscous flow simulations by using the ANSYS CFX code. The thermodynamic parameters of the organic fluids were taken from the REFPROP library. The discussed turbine solutions will refer mainly to application of HFC 227ea as the organic cycle fluid.

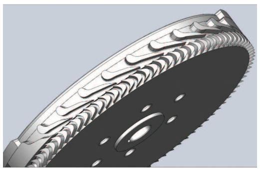
Assumptions:

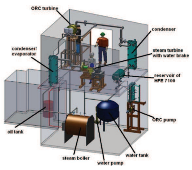
- Turbines of small to middle power output.
- Application of impulse stages which enable the use of small number of stages with untwisted blades. Simple construction (for example no relief pistons)
- Small number of stages induce applying the blade profiles which strictly fit given stage kinematics.



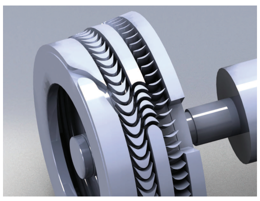


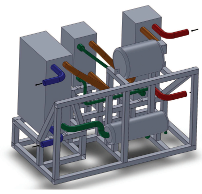
Supersonic, impulse, one stage turbine working with saturated vapour of the R227ea fluid(on the left). It operates in the test ORC cycle (on the right). Inlet pressure: 10.93 bar(a), inlet temperature: 57ºC, outlet pressure: 4.53 bar(a), mass flow rate: 1.66 kg/s, internal power: 13 kW, Mach number at the outlet of the nozzle: 1.26.





Supersonic, impulse, one stage turbine working with saturated vapour of the HFE7100 fluid (on the left). It operates in the test, hybrid ORC cycle (on the right). Inlet pressure: 2.42 bar(a), inlet temperature: 90ºC, outlet pressure: 0.34 bar(a), mass flow rate: 0.58 kg/s, internal power: 9 kW, Mach number at the outlet of the nozzle: 1.8

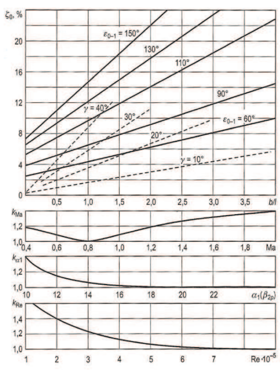




Supersonic, Curtis turbine working with supercritical vapour of the R227ea fluid (on theleft). It operates in the test, supercritical ORC cycle (on the right). Inlet pressure: 32.0bar(a), inlet temperature: 130ºC, outlet pressure: 4.93 bar(a), mass flow rate: 0.92 kg/s, internal power: 15 kW, Mach number at the outlet of the nozzle: 1.8.

One-dimensional design

Due to short blades of the turbines, one-dimensional theory seems to be a good design method. It can be used to optimize the kinematics of the stage.



Total pressure loss in the channels:

The basic loss is determined one the basis of the ratio between channel height and blade cord (picture on the left). Then, according to the flow properties correction factors are determined and the basic loss is multiplied by them.

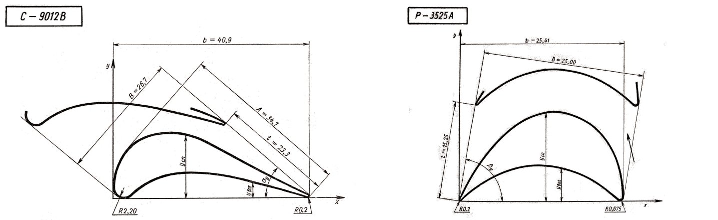
Other losses:

- tip clearance loss
- friction loss
- Sealing loss
- Partial arc supply loss

Blade geometry:

Traditional approach:

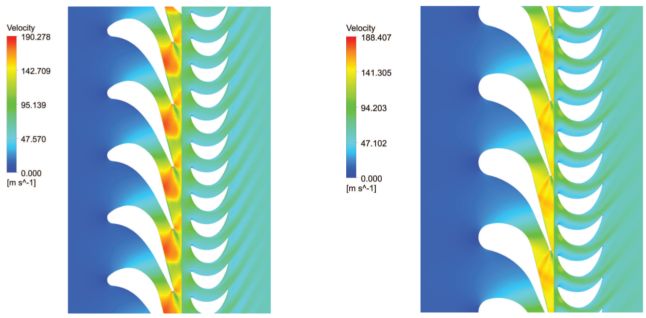
Selecting and setting the proper profile from atlas according to the kinematics and properties of the flow.



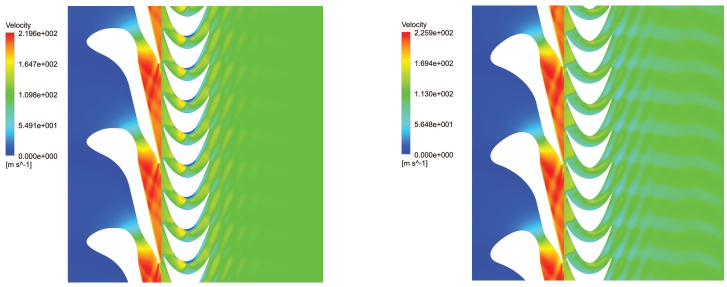
Supersonic nozzle (left) and rotor (right) profiles taken from the profile atlas.

Recommended approach:

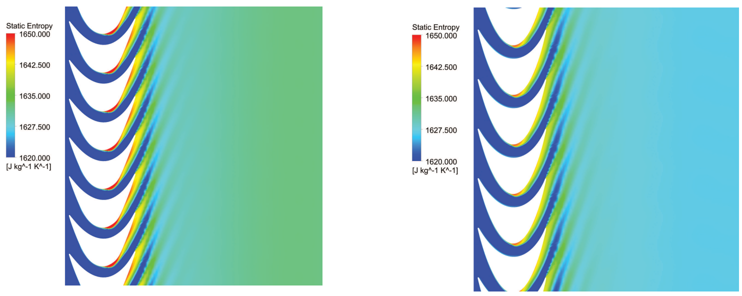
Shaping the blade according to the flow kinematics



For the impulse turbine operating with R227ea fluid the supersonic nozzle was redesigned and proper outflow angle and degree of divergence were set. The velocity field is more uniform and as a result the internal efficiency of the stage rised by 3%.



For the impulse turbine operating with HFE7100 fluid the rotor profile was redesigned according to the flow kinematics. The separation of the flow was significantly reducedand thus the internal efficiency rised by 4.5%.



For the Curtis turbine operating with R227ea fluid the rotor profile was redesigned according to the flow kinematics. Significant reduction of the entropy in the rotor can beobserved. The internal efficiency benefit is 3%.

Literature:

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