Design of a Turgo two-phase runner

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Introduction (1)

- Power loss in a classic expander in an Evans thermodynamic cycle due to an isenthalpic expansion

- A turbine can do a two-phase expansion and transform a part of the available energy to work

- The recovered energy is transformed to electric energy and the refrigeration capacity of the cycle is increased between 8 and 20%
A two phase turbine in parallel with an expansion valve

T-s diagram: Isenthalpic vs Isentropic expansion
Characteristics of two-phase flow: void fraction, flow regime and velocity

Void fraction is best calculated experimentally from X-ray images, gamma rays imaging

Flow regime maps were developed based on the vapor quality, void fraction and mass velocity

The maximum velocity of a two-phase flow corresponds to its sonic velocity. It depends on the flow regime
Two types of turbines are used as two-phase flow expanders

- **Hero Turbine:**
  - A reaction turbine
  - No need for a homogeneous two-phase flow

But:

- The centrifugal force has a pumping effect on the fluid inside the arms of the turbine
- The fluid is pushed against the walls of the canals, creating more friction
Background

- **Turgo Turbine:**
  - An impulse turbine
  - No pumping effect on the fluid
  - Simple mechanical design
  - Drag can be reduced

- The Turgo turbine was chosen as the two-phase expander to develop due to:
  - The counter intuitive design of a Hero turbine when used as a two-phase turbine
  - Disadvantages of Hero turbine
Bucket profile

- Low inflection point to favor the downward evacuation of the fluid

- The exit angle from the bottom is large enough to prevent the interference between the exiting flow and the adjacent bucket

- The height of the angle assures a constant contact between the buckets and all of the two-phase flow
Friction losses in the bucket

- The jet impingement is simulated with Fluent 13
- Three buckets are drawn and rotated around a virtual turbine axis at 3000 RPM
- Transient simulation, K-epsilon turbulence model
- Surface roughness, mass flow rate and the flow conditions are identical to their real values
- Most of the fluid evacuation is downward

- 83% of the flow theoretical force is transferred to the buckets (vs 93% for conventional hydraulic Turgo turbines)
Drag losses

- Drag is an important source of losses

- Density of the chosen refrigerant, R-134a, at 3.2 bar is 15.5 kg.m$^{-3}$ in its gas saturated form

- The drag losses were characterized for different turbine wheel diameters

- Fluent was used to measure the drag losses
Drag losses\textsuperscript{(2)}

- The wheel has a periodic geometry
- The wheel diameter was changed to measure the drag for different wheel sizes
- The real size of the turbine wheel enclosure was used to represent the space around the wheel
Drag losses (3)

- The single frame method is used

- The fluid domain is rotated at 3000 RPM in the direction of the wheel rotation

- The wheel is stationary relatively to the fluid domain

- The outer walls are fixed

- Standard K-omega turbulence. The y+ value was adapted to fit the k-omega requirements
Drag losses

- Drag losses results

\[ P = z \rho x b \omega^3 (R - x/2)^3 \]

*Diab et al. (2004)*

- \( P \) power (W)
- \( z = 0.06 \)
- \( \rho \) density \((\text{kg.s}^{-1})\)
- \( x \) exposed bucket length (m)
- \( b \) bucket height (m)
- \( \omega \) rotation speed \((\text{rad.s}^{-1})\)
- \( R \) wheel radius (m)
Designing the runner (1)

- The drag and bucket friction losses are used to design the runner

- Main design points:
  - Wheel diameter
  - Number of buckets
  - Top and bottom buckets angles
  - Drag and friction losses
  - Jet portion intercepted by the back of the bucket
  - Upward and downward evacuation of the intercepted flow
  - Constant interception of the whole flow by the runner
Designing the runner (2)
Conclusion

- By calculations, the turbine mechanical power is 4.5 kW

- Total power available from the expansion is 11 kW
  → Turbine isentropic efficiency = 41%

- A two-phase turbine is feasible

- The designed turbine would be built and tested to assess its performance