Numerical investigation of the flow in a swirl generator, using OpenFOAM

Oscar Bergman
Outline

• Introduction
• Purpose and goal
• Experimental rig and measurements
• Numerical setup
• Results
• Conclusions
• Future work
Introduction
Purpose and goal

• Conduct steady-state and unsteady 3D simulations on a swirl generator.

• Compare with measurements and theoretical design data from previous studies.

• Provide results for helping future studies in solving the problem with precessing vortex ropes in water turbines.
Experimental rig
Experimental rig

- Strout
  - Holds up the nozzle
Experimental rig

- Strout
- Guide vanes

- creates a swirling profile
Experimental rig

- Strout
- Guide vanes
- Free runner

- redistributes the total pressure
- rotates freely
Experimental rig

- Strout
- Guide vanes
- Free runner
- Draft tube

- plexiglass walls
- windows for LDV measurements
Experimental rig

- Strout
- Guide vanes
- Free runner
- Draft tube

- Theoretical design profile
  - Cross-section 1 & 2
Measurements

• Total volume flow: 30 l/s
Measurements

• Total volume flow: 30 l/s
• Runner rotating at 870 rpm
Measurements

• Total volume flow: 30 l/s
• Runner rotating at 870 rpm

• Laser Doppler Velocimetry
  - measuring the meridional and tangential velocities
Measurements

- Total volume flow: 30 l/s
- Runner rotating at 870 rpm

- Laser Doppler Velocimetry
- Pressure transducers
  - measuring the static pressure at the wall
Numerical setup
Numerical setup

• The grid
  - 2.3 million hexahedral cells
  - Coupled parts by General Grid interfaces (GGI)
Numerical setup

- The grid
- Solvers

  - For steady-state:
    » SIMPLE pressure corrector
    » Rotation through different frames of reference
Numerical setup

- The grid
- Solvers
  - For steady-state:
    » SIMPLE pressure corrector
    » Rotation through different frames of reference
  - For unsteady:
    » PISO pressure corrector
    » Real rotation with a sliding grid at the interface
Numerical setup

• The grid
• Solvers
  - For steady-state:
    » SIMPLE pressure corrector
    » Rotation through different frames of reference
  - For unsteady:
    » PISO pressure corrector
    » Real rotation with a sliding grid at the interface

Turbulence model: standard k-ε model with wall-functions
Numerical setup

- The grid
- Solvers
- Boundary conditions

- Velocities and turbulence: Homogenous Neumann at outlet
- Pressure: Zero mean at outlet and homogenous Neumann at all other boundaries
Numerical setup

• The grid
• Solvers
• Boundary conditions
• Convection scheme
  – 1\textsuperscript{st} order upwind at startup
  – 2\textsuperscript{nd} order linear upwind when stable
Unsteady results

• Rotational speeds
  - 870 rpm (runner rotates freely)
  - 920 rpm (runner rotates freely according to fluent simulations)
  - 890 rpm (linearly interpolated)
Unsteady results

- Rotational speeds
- Initial conditions
  - Results from the steady-state simulations
Design profiles

Meridional velocity

Tangential velocity

Unsteady results
Comparison with LDV at 870 rpm

Unsteady results

Survey axis 0

Survey axis 1

Survey axis 2
Comparison with LDV at 920 rpm

Unsteady results

**Survey axis 0**

- **Measured meridional velocity**
- **Measured tangential velocity**
- **Numerical meridional velocity**
- **Numerical tangential velocity**

**Survey axis 1**

- **Measured meridional velocity**
- **Measured tangential velocity**
- **Numerical meridional velocity**
- **Numerical tangential velocity**

**Survey axis 2**

- **Measured meridional velocity**
- **Measured tangential velocity**
- **Numerical meridional velocity**
- **Numerical tangential velocity**
Comparison with LDV at 890 rpm

Unsteady results

Survey axis 0

Survey axis 1

Survey axis 2
Moment acting on the runner

870 rpm

Unsteady results

920 rpm

890 rpm
SIMPLE based solver vs. PISO based solver

Unsteady results

Survey axis 0

Survey axis 1

Survey axis 2
SIMPLE based solver compared to measurements

Survey axis 0

Survey axis 1

Survey axis 2

Unsteady results
Pressure at MG0 (at the throat of the draft tube)

870 rpm

890 rpm

920 rpm
Fourier analysis of results from 920 rpm

- MG0
- MG1
- MG2
- MG3
870 rpm

920 rpm

Unsteady results
Conclusions

• Unsteady simulations accurately predicts the flow

• 920 rpm was corresponding most with the measurements

• 870 rpm was corresponding most with the theoretical design profiles

• The inclusion of all parts of the swirl generator have added more frequencies to the flow.

• Moment on the runner:

<table>
<thead>
<tr>
<th>Rotational speed</th>
<th>Moment on runner</th>
</tr>
</thead>
<tbody>
<tr>
<td>920 rpm</td>
<td>-0.55 Nm</td>
</tr>
<tr>
<td>870 rpm</td>
<td>0.23 Nm</td>
</tr>
<tr>
<td>890 rpm</td>
<td>0.08 Nm</td>
</tr>
</tbody>
</table>
Future work

• Further investigation of the SIMPLE based solver

• Other turbulence model such as LES or DES

• Customize a solver for adjusting the rotational speed in accordance to the moment acting on the runner
Acknowledgements

I would like to give my thanks to:

- Department of Applied Mechanics
- Supervisors Håkan Nilsson and Olivier Petit