Performance-based Tolerance Specification for a Centrifugal Pump Impeller

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GRUNDFOS PRODUCTS AND OFFERINGS
#1
Pump manufacturer in the world

74
Years old (founded in 1945)

83
Companies across the world

16
Million units produced every year

19
Thousand employees worldwide

3.6
Turnover (billion Euros) 2018

1
Owner
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1. Motivation

Development process

Hydraulic designer

Tolerance specialist

?
Tooling specialist
1. Motivation

Development process

Hydraulic designer

Tolerance specialist

Produced component with deviations
so how do we control them?
so how do we predict their impact?
so how can we reduce their impact?

Variations are unavoidable

Hypothesis Can be done by replacing traditional tolerances with tolerance zones based on sensitivity studies.
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Solution Robustness evaluation

Create mesh → Perturb/Deform geometry → Perform CFD → OptiSLang/DoE
2. Simulation set-up

Fluid domain

- Rotating domain
- Stationary domains
- Cavities
2. Simulation set-up

Mesh properties

- Structured hexahedral meshes

<table>
<thead>
<tr>
<th></th>
<th>Cell count</th>
<th>Min. orthogonal angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full domain</td>
<td>585,330</td>
<td>24.7</td>
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</tbody>
</table>
2. Simulation set-up

CFD simulation

- Convergence good, averaged result
2. Simulation set-up

CFD simulation

- Convergence good, averaged result
- Good match between CFD and test
3. Parametrization
Hydraulic design methods

Conventional hydraulic design method
- Direct specification of blade angle distribution
- No direct specification of loading or performance

Inverse hydraulic design method
- Specification of performance and blade loading (pressure difference across blade)
- No direct specification of blade angles
3. Parametrization

**Geometric parametrization**

- Metal sheet impeller
- 8x3 control points
- Displacement normal to the surface
- Constant blade thickness

**Advantages:**
- Parameters linked to geometry changes
- Easy to impose tolerances
- Easy to mimic specific production variations
4. Perturbation method
Mesh morphing
5. OptiSLang set-up

Parameters

- Robustness evaluation
- Advanced Latin Hypercube Sampling
- 100 samples (>2k)
- Responses
  - Head
  - Power consumption
  - Efficiency
  - Minimum pressure
  - Axial force
5. OptiSLang

Solver call

- Text-based solver (bash)
- Python

```
sources /home/72936/.bashrc
module load cfx
module load anaconda
python ~/../../SolverCall/SolverCall.py
module unload anaconda
while [ ! -f output.txt ];
do
sleep 1;
done
sleep 1;
```

Perturb geometry → Perform CFD

OptiSLang/DoE
6. Results

Visualization of the sensitivity

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Eta_mean</th>
<th>Fp_mean</th>
<th>Models</th>
<th>Head_mean</th>
<th>MinP_mean</th>
<th>P2_mean</th>
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<tbody>
<tr>
<td>Parameter_01</td>
<td>32.5 %</td>
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<td>36.8 %</td>
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<tr>
<td>Parameter_02</td>
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<td></td>
<td>24.7 %</td>
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<td>Parameter_03</td>
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<td>42.5 %</td>
<td>14.0 %</td>
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<td></td>
<td></td>
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<td>Parameter_22</td>
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<td>15.4 %</td>
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<td>Parameter_23</td>
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<td>36.9 %</td>
<td>45.9 %</td>
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<td>49.4 %</td>
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<tr>
<td>Parameter_24</td>
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<td>1.6 %</td>
<td>16.6 %</td>
<td></td>
<td>18.5 %</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>91.8 %</td>
<td>95.4 %</td>
<td>96.3 %</td>
<td>98.2 %</td>
<td>95.8 %</td>
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</tr>
</tbody>
</table>

- Head
- Power consumption
- Efficiency
- Minimum pressure
- Axial force
6. Results
Visualization of the sensitivity

- Head
- Power consumption
- Efficiency
- Minimum pressure
- Axial force

Combined sensitivity

Strict  Loose  Strict
6. Results

Adjusted tolerance zones

Power consumption, normalized [-]

Case 1: +/- 0.1 mm
Case 2: +/- 0.3 mm
Case 3: +/- 0.5 mm
6. Results

Adjusted tolerance zones

- Prediction of tolerance impact

---

**Head gain, normalized [-]**

- **Flow rate [m³/h]**

- **Nominel**
  - Case 1
  - Case 3

---

**Power consumption, normalized [-]**

- **Flow rate [m³/h]**

- **Case 1**
  - Case 3

Peak difference: 2.5 %-points
7. Conclusion

- **Sensitive regions identified**
  - Tighten tolerances in important regions
  - Loosen tolerances in less important regions
  - Reduce complexity and/or increase performance

- **Estimated performance variations**
  - Optimize tolerances and avoid over-engineering
  - Estimate required safety margins in design phase

- **New methodology**
  - Applicable to any geometry

**Next steps**
- Test on more geometries
- Include in design procedures