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Response surface optimization of a fluid regulating control valve

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Multi-Physics and Multi-Objective Response Surface Based Design Optimization of a Control Valve
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Introduction
A control valve is a flow control device typically used to regulate different types of flow. Currently, the design of control valves is primarily carried out using traditional methods which have been well developed over the years. Typical traditional valve design methodologies are based on existing specific valve design data with the assumption of geometry and flow characteristics similarities. These assumptions are the major limitations of traditional valve design methods; such that existing data cannot be accurately referenced in the case of different geometry profile trim being introduced into the valve.

Traditional approach of building few prototypes and measuring performance only assist in understanding a small fraction of the design space. One factor at a time (OFAT) experiments and simulations systematically vary one design variable at a time while holding the others constant and recording the impact on performance. The time required makes it practical only to cover a small fraction of the design space. This approach fails to account for the multiple factor interactions. These challenges have been addressed in this tool.

Hypothesis & Objectives
We hypothesize that the response surface artificial neural networks (ANN) paradigm model can be successfully implemented in the control valve design tool, and can accurately predict the multi-physics and multi-objective target function output values at low cost.

Objectives:
- Develop a robust universal and automated control valve design tool.
- Determine the accuracy of the response surface neural network model in predicting non-linear and discontinuous flow field, and resulting fluid structure interaction (FSI) stress and deformation response.

Methodology
The response surface optimization of the control valve is implemented in the computational fluid dynamics (CFD) platform of Ansys, the fluid simulation tool coupled with a finite element analysis tool (FEA) from which direct fluid structure interaction response is determined.

Valve baseline design concept (CFD) simplified.

- Top cage flow holes Diameter
- Top cage flow holes Diameter
- Pressure outlet
- Stem Outside diameter
- Vena contracta region
- Bottom cage flow holes

Control valve design tool update process strategy

- Process Requirements
- Design of experiments (DOE) Latin hypercube.
- Response surface Artificial neural networks (ANN)
- Multi-physics and multi-objective optimization
- Validate response surface model (ANN)

Optimization:
The Screening approach has been used in this tool to find the target output objective values. The screening approach is a non-iterative direct sampling method by a quasi-random number generator based on the Hammersley algorithm.

Objectives and constraints

- Pressure
- Type
- Target
- Laser Brand
- Laser Brand

Result
Detailed response surface plots at low cost giving insight into multiple factor interaction.

Table of (ANN) response surface design target predictions and verified results with % error

<table>
<thead>
<tr>
<th>Name</th>
<th>P1 [mm]</th>
<th>P2 [mm]</th>
<th>P3 [mm]</th>
<th>P4 [mm]</th>
<th>P5 [mm]</th>
<th>P6 [mm]</th>
<th>% Error</th>
<th>% Error</th>
<th>% Error</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Candidate Point 1</td>
<td>30.3</td>
<td>25.5</td>
<td>13.8</td>
<td>9.3</td>
<td>11.9</td>
<td>12.1</td>
<td>1.3</td>
<td>0.9</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
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<td>25.5</td>
<td>13.8</td>
<td>9.3</td>
<td>11.9</td>
<td>12.1</td>
<td>1.3</td>
<td>0.9</td>
<td>0.5</td>
<td>0.4</td>
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<tr>
<td>Candidate Point 3</td>
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<td>0.4</td>
</tr>
<tr>
<td>Candidate Point 4</td>
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<td>1.3</td>
<td>0.9</td>
<td>0.5</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Conclusion:
A multi-physics and multi-objective control valve design tool has been proposed. The artificial neural networks response model has accurately predicted the multiple objective and multi-physics target design outputs within a small % error with validation results. The proposed tool can be successfully used in the design and optimization of control valves at very low cost of computational analysis and time to results.