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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 assists 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 network (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 the non-linear and discontinuous flow field, and resulting fluid structure interaction (FSI) stress and deformation response.

Methodology

Design of Experiments (DOE)
The Latin Hypercube Sampling Design DOE type has been implemented in this tool. The DOE is generated by the LHS algorithm, an advanced form of the Monte Carlo sampling method that avoids clustering samples. The user-defined sampling type has been used in this tool with an initial 30 sample design points.

Response Surface: Artificial Neural Networks (ANN)
This mathematical technique is based on the natural neural network in the human brain. In order to interpolate a function, we build a network with three levels (Input, Hidden, Output) where the connections between them are weighted, like this:

![Diagram of Artificial Neural Networks](image)

Methodology

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 Hamersley algorithm.

Objectives and constraints

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Value 3</th>
<th>Value 4</th>
<th>Value 5</th>
<th>Value 6</th>
<th>Value 7</th>
<th>Value 8</th>
<th>Value 9</th>
<th>Value 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
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<td>4.0</td>
<td>5.0</td>
<td>6.0</td>
<td>7.0</td>
<td>8.0</td>
<td>9.0</td>
<td>10.0</td>
<td>11.0</td>
<td>12.0</td>
</tr>
<tr>
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<td>4.5</td>
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</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.