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COMPUTATIONAL FLUID DYNAMICS SIMULATION FOR IMPROVED TURBULENT FLOW PREDICTION

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ABSTRACT

In this paper, the flow of air through a Pressure Regulating and Shut-Off Valve (PRSOV) has been solved numerically with the objective of determining the pressure of the PRSOV pilot chamber. The flow through the valve is transient, compressible, and turbulent in nature. The flow has been solved using ANSYS FLUENT coupled with a special User Defined Function (UDF). The UDF is used for dynamic meshing, automatic data acquisition from the ANSYS FLUENT solver, and scheduling the numerical test procedure. Within the UDF, the valve inlet pressure is varied in a stepwise manner. For every value of inlet pressure, transient analysis leads to quasi-static flow through the valve. Spool forces are calculated based on different pressures at the inlet. From this information of spool forces, the pressure characteristic of thepilot chamber of the passive control circuit has been derived. The same characteristics have also been obtained after modeling the flow analytically. Both results have been compared. It is observed that CFD analysis of the flow has led to improved results.

KEYWORDS: *Fluid Dynamics*

Article History

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INTRODUCTION

The accurate prediction of turbulent flow behavior is crucial in various engineering applications, particularly in systems involving fluid control and regulation. In this context, this paper focuses on the computational fluid dynamics (CFD) simulation of turbulent airflow through a Pressure Regulating and Shut-Off Valve (PRSOV). The primary objective is to determine the pressure within the PRSOV pilot chamber, a critical parameter influencing valve performance.

The flow through the PRSOV exhibits transient, compressible, and turbulent characteristics, posing challenges for traditional analytical methods. To address this, advanced numerical techniques are employed, utilizing ANSYS FLUENT software augmented with a bespoke User Defined Function (UDF). This UDF facilitates dynamic meshing, automated data acquisition, and the scheduling of numerical experiments, enhancing the efficiency and accuracy of the simulation process.

Within this framework, the inlet pressure of the valve is systematically varied, enabling a comprehensive analysis of the flow dynamics. Each step in this variation is accompanied by transient analysis, yielding insights into the quasi-static behavior of the flow through the valve. Moreover, spool forces, critical for understanding valve operation, are computed based on the varying inlet pressures.

Utilizing the information obtained from spool forces, the pressure characteristics of the pilot chamber in the passive control circuit are derived. Additionally, analytical modeling of the flow is conducted to validate the numerical results. Comparative analysis of the two approaches provides valuable insights into the accuracy and efficacy of CFD simulations in predicting turbulent flow behavior.

The findings indicate that CFD analysis significantly improves the prediction of flow characteristics compared to traditional analytical methods. This underscores the importance and potential of computational techniques in enhancing our understanding and optimization of complex fluid systems.

RESEARCH METHODS

The research methodology employed in this study involves a computational fluid dynamics (CFD) approach to simulate and analyze turbulent airflow through a Pressure Regulating and Shut-Off Valve (PRSOV). The objective is to accurately predict the pressure within the PRSOV pilot chamber, a crucial parameter affecting valve performance.

Numerical Simulation

The flow through the PRSOV is simulated numerically using ANSYS FLUENT software. This computational approach allows for the modeling of transient, compressible, and turbulent flow behavior within the valve system.

User Defined Function (UDF)

A custom UDF is developed and implemented to enhance the capabilities of the simulation. This UDF is specifically designed for tasks such as dynamic meshing, automated data acquisition from the ANSYS FLUENT solver, and scheduling of numerical experiments. It plays a pivotal role in streamlining the simulation process and improving its efficiency.

Variable Inlet Pressure

Within the UDF framework, the inlet pressure of the valve is systematically varied in a stepwise manner. This variation enables the exploration of different operating conditions and their effects on flow behavior.

Transient Analysis

For each value of inlet pressure, transient analysis is performed to study the quasi-static flow through the valve. This approach allows for a detailed examination of flow dynamics and pressure variations over time.

Spool Force Calculation

Spool forces, critical for understanding valve operation, are computed based on the different inlet pressures. These forces provide valuable insights into the mechanical behavior of the valve system.

Derivation of Pressure Characteristics

Utilizing the information obtained from spool forces, the pressure characteristics of the pilot chamber in the passive control circuit are derived. This analysis helps in understanding the response of the valve system to varying operating conditions.

Analytical Modelling

Additionally, analytical modeling of the flow is conducted to validate the numerical results. This comparative analysis enables the assessment of the accuracy and reliability of the CFD simulations.

Comparison of Results

Both numerical and analytical results are compared to evaluate the performance of the CFD approach in predicting turbulent flow behavior within the PRSOV. This comparison highlights the advantages of CFD analysis in achieving improved results compared to traditional analytical methods.

Overall, the research methodology combines advanced numerical simulations with analytical techniques to gain a comprehensive understanding of turbulent flow behavior in PRSOV systems, with a focus on enhancing predictive accuracy and performance optimization.

RESULTS & DISCUSSION

The computational fluid dynamics (CFD) simulation conducted in this study yielded valuable insights into the turbulent flow behavior through the Pressure Regulating and Shut-Off Valve (PRSOV) and its impact on the pressure within the PRSOV pilot chamber. Here, we discuss the key findings and implications of the study:

Variation of Inlet Pressure

The systematic variation of the valve inlet pressure allowed for the exploration of a wide range of operating conditions. This approach facilitated a comprehensive analysis of flow characteristics under different pressure scenarios, enabling a detailed understanding of the valve's performance.

Transient Analysis and Quasi-Static Flow

Transient analysis revealed the dynamic nature of flow through the valve, highlighting the importance of considering time-dependent effects. Despite the transient nature of the flow, quasi-static conditions were observed, indicating a stable flow regime through the valve.

Calculation of Spool Forces

Spool forces, essential for assessing valve operation, were computed based on the varying inlet pressures. These forces provided valuable insights into the mechanical behavior of the valve system, aiding in the evaluation of its performance and reliability.

Derivation of Pressure Characteristics

By analyzing the spool forces, the pressure characteristics of the pilot chamber in the passive control circuit were derived. This analysis elucidated the relationship between inlet pressure variations and the resulting pressure within the pilot chamber, offering valuable information for optimizing valve design and operation.

Comparison with Analytical Modeling

The obtained pressure characteristics were compared with those derived from analytical modeling of the flow. This comparative analysis revealed discrepancies between the two approaches and underscored the advantages of CFD analysis in capturing the complex flow phenomena inherent in turbulent flows.

Improved Results with CFD Analysis

The comparison between CFD and analytical results demonstrated that CFD analysis led to improved accuracy in predicting flow behavior and pressure characteristics within the PRSOV system. This highlights the efficacy of CFD simulations in capturing the intricacies of turbulent flows and their influence on valve performance.

Overall, the results of this study underscore the importance of employing CFD simulations for predicting turbulent flow behavior in PRSOV systems. By leveraging advanced numerical techniques, such as transient analysis and spool force calculations, CFD enables a more comprehensive understanding of flow dynamics and facilitates the optimization of valve design and operation.

CONCLUSION

In conclusion, the computational fluid dynamics (CFD) simulation conducted in this study has provided valuable insights into the turbulent flow behavior through a Pressure Regulating and Shut-Off Valve (PRSOV) and its implications for the pressure within the PRSOV pilot chamber. By leveraging advanced numerical techniques and the capabilities of ANSYS FLUENT coupled with a customized User Defined Function (UDF), we have achieved significant progress in understanding and predicting the complex flow phenomena associated with the PRSOV system.

Through systematic variation of the valve inlet pressure and transient analysis, we have elucidated the quasi-static flow behavior through the valve under different operating conditions. Additionally, the computation of spool forces has allowed for a detailed assessment of the mechanical behaviorof the valve system, providing insights into its performance and reliability.

Furthermore, the derivation of pressure characteristics for the pilot chamber of the passive control circuit has shed light on the relationship between inlet pressure variations and the resulting pressure within the chamber. Comparative analysis with analytical modeling has highlighted the advantages of CFD analysis in capturing the intricacies of turbulent flows and predicting flow behavior more accurately.

Overall, the results of this study underscore the effectiveness of CFD simulations in improving the prediction of turbulent flow behavior in PRSOV systems. By enhancing our understanding of flow dynamics and pressure characteristics, these simulations offer valuable guidance for optimizing valve design and operation, ultimately leading to improved system performance and efficiency.

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