Engineering Analysis of Flow Characteristic Curve for Steam Turbine Control Valve

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1. Introduction

The steam turbine converts the kinetic energy of steam to mechanical energy of rotor blades in the power conversion system of fossil and nuclear power plants. The electric output from the generator of which the rotor is coupled with that of the steam turbine depends on the rotation velocity of the steam turbine bucket. The rotation velocity is proportional to the mass flow rate of steam entering the steam turbine through valves and nozzles. Thus, it is crucial to control the steam mass flow rate for the load following operation of power plants. Among various valves that control the steam flow to the turbine, the control valve is certainly the most significant. The steam flow rate is determined by the area formed by the stem disk and the seat of the control valve. While the ideal control valve linearly controls the steam mass flow rate with its stem lift, the real control valve has various flow characteristic curves pursuant to the stem lift. Thus, flow characteristic curves are needed to precisely design the control valves manufactured for the operating conditions of power plants. It has long been a practice to depend upon experimental means to obtain valve characteristic curves, due mostly to limited computational capability of computational fluid dynamics (CFD) codes. In this paper, a CFD code, FLUENT, was used to obtain the valve characteristic curve, whose results were validated against the data from the OMEGA (Optimized Multidimensional Experiment Geometric Apparatus) tests and operating plants. The Widow's Creek type control valve was the reference model. The computational and experimental results were translated to flow characteristic curve by rectifying the ratio of actual mass flow rate versus the theoretical mass flow rate. It is expected that future control valve design may well benefit from the multidimensional computational results spanning a wide spectrum of thermo hydrodynamic conditions involving the valve size and configuration as well as the inlet and outlet conditions supported by limited experiments for the software verification and validation.

2. Numerical Analysis

2.1 Modeling and Grid

The structured grid was used for numerical analysis. Using structured grid can reduce memory capacity, and can find results quickly. On the other hand, it is hard to obtain adequate results at tangled shape where has complicate flow characteristic. On account of this gird cell was set densely at stem disk and seat by unstructured gird. Fig. 1 shows typical configuration of a steam turbine control valve.

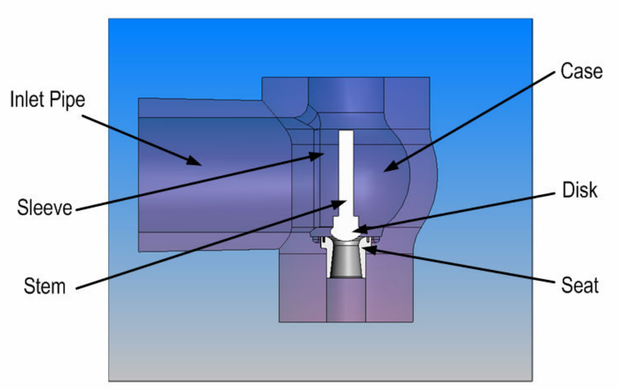

Fig 1. Typical configuration of steam turbine control valve.

So as to compare numerical analysis results with experimental results, the same design drawing, which was scaled to 2:1 for test valve model, was used to model three-dimensional figure of control valve. Fig. 2 is three-dimensional CAD modeling for numerical analysis. The inlet pipe shape was revised to have only one bend of pipe in order to set the fully develop flow in contrast to the prototype and test valves having two bends of pipe.

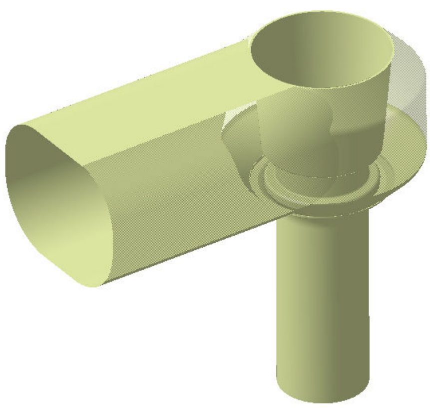

Fig 2. Three-dimensional CAD modeling for numerical analysis

2.2 Boundary Conditions

The outlet pressure was set at atmospheric and air was used as working fluid. The Navier-Stokes equation and the k-ε turbulent model were used for numerical analysis. The no-slip boundary condition was applied at the wall. Heat transfer was not considered.

To determine the flow coefficient, numerical results were used as actual mass flow rate. The theoretical mass flow rate was calculated by

$$\dot{m} = A_e \cdot \sqrt{2 \cdot \frac{\kappa}{\kappa - 1} \cdot \frac{p_o}{v_o} \cdot \left(\frac{p_e}{p_o}\right)^{\frac{2}{\kappa}} \cdot \left(1 - \left(\frac{p_e}{p_o}\right)^{\frac{\kappa-1}{\kappa}}\right)} \qquad (1)$$

The mass flow rate coefficient was defined as

$$FC = \frac{\dot{m}_{actual}}{\dot{m}_{theoretical}} \qquad (2)$$

3. Results

Fig. 3 presents the results of the control valve flow characteristic curves from the experimental and numerical analyses. The maximum flow coefficient around 0.72 at pressure ratio was 0.967. The stem lift ratio was 0.25. The maximum flow coefficient was 0.681.

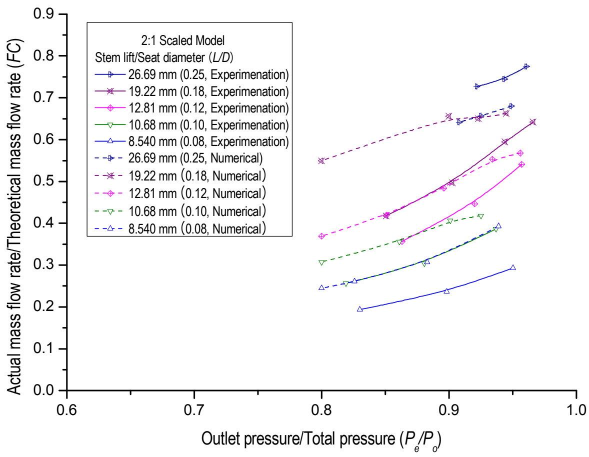

Fig3. Flow characteristic curve for 2:1 scaled model

ACKNOWLEDGMENTS

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