

Structural Design and FEM Analysis of Large Butterfly Valve: A Review

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Abstract— Valves for hydro power projects are installed for safety, maintenance, and shut-off, as well as for flow and pressure regulation.

A Butterfly valve is a type of flow control device, which is widely used to regulate a fluid flowing through a section of pipe. This type of valve is mainly used as safety valve, turbine inlet valve, and pump valve for low to medium design pressures.

They are operated by oil hydraulic systems for opening and closing or by closing weight and hydraulic pressure for opening. For turbine inlet valves, oil pressure can also be taken from the governor hydraulic oil system. The sealing system is of flexible, adjustable rubber/metal type to reduce leakage to a minimum. Water flow through the valve is possible in both directions.

The main objective of this work is to analyse the option of fabricated variant for door & body in place of casted, reduction in the material of valve body & door by structural design & FEM analysis & optimization in the material of valve component.

The 3D modeling to be performed for butterfly valve by using CAD software. Further the stress & displacement FEM analysis of the butterfly valve to be performed by using ANSYS tool to evaluate the optimized result.

Index Terms— Butterfly valves, body, door, FEM analysis, hydro power, Structural.

I. INTRODUCTION

Hydro power is considered as one of the most economical and non-polluting sources of energy. Power generation from the water is termed as Hydroelectricity. Hydroelectricity means electricity generated by hydro power or from the use of the gravitational force of falling water or flowing water. One of the most common forms of power generation since this form of energy neither produces direct waste matter nor it is subjected to exhaustion.

Now a day's more and more hydro electrical power plants being setup and renovated. But still the design and development of hydro electrical power plant is based on the traditional methods. Therefore there is a huge scope of utilization of modern day's technique like finite element method (FEM) for achieving maximum possible optimization.

In any power plant valves for different purposes are usually needed. Normally it is a shut-off valve just in front of the turbine. In this way the turbine may be emptied without emptying the shaft or penstock. In addition the guide vane cascade is depressurised so that leakage flow is avoided.

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II. BUTTERFLY VALVE

These specialized Butterfly valves are installed to protect hydro-electric installations against the possibility of penstock rupture. Valves are designed to close against turbine runaway during an emergency condition. These valves act as isolating devices for inspection of penstock without dewatering entire head race tunnel. Yet another important application is for large water supply schemes fed from reservoirs through long pipelines, failure of which can cause disastrous floods. Valves by virtue of their design and robust construction, close down automatically and instantaneously in the event of the downstream pipeline failure. These valves close during over velocity condition occurring due to turbine trip or runaway condition.

Butterfly valves are normally applied in front of low and medium head water turbines, i.e. heads up to 200 m. For high head power plants the butterfly valve is from time to time used as a closing device in inlet tunnels and alternatively as emergency closure valves.

Butterfly valves consist of mainly of ring shaped housing, the valve disc, operating mechanism and counter weight.

III. LITERATURE REVIEW

The study of butterfly valves has evolved over the years; most of the earlier studies were based on analytical and experimental approaches. Because of the notable influence of the butterfly valve on the fluid flowing through it, many researchers have done lots of work to study the fluid characteristics of the butterfly valve.

One of the earliest and most comprehensive pieces of research on the flow characteristics and performance of butterfly valves was performed by

Cohn [1]. Using data provided by previous authors, Cohn attempted to parameterize torque and flow coefficients based on thickness to diameter ratio for numerous butterfly valve geometries, most of which were symmetrical.

McPherson [2] studied various blade variations of single eccentric butterfly valves in incompressible turbulent flow subject to free, submerged, and continuous piping discharge arrangements. McPherson found that for a given type of installation, the flow characteristics were not significantly influenced by either the shape of the blade or by the closing angle except for the near-open and closed positions, respectively. Using a two dimensional setup of different symmetric butterfly valve blades, cavitation was also predicted.

Sarpkaya [3] also studied the torque and cavitation characteristics of idealized two-dimensional and axially symmetrical butterfly valves by considering an idealized case of laminar uniform flow through a symmetrical lamina (representing the butterfly valve) between two infinite walls. Using these assumptions, Sarpkaya was able to extend approximate solutions to hydrodynamic torque, cavitation,

and flow coefficients for three dimensional butterfly valves using semi-empirical equations.

Addy et al. [4] conducted several small-scale compressible flow experiments with sudden enlargement configurations for butterfly valve models to predict mass flowrate and overall pressure characteristics. In addition, a full size butterfly valve was built and tested.

The sudden enlargement configurations were classified as three different types of nozzles: contoured converging, conical converging and sharp-edge orifice. It was concluded that the performance characteristics of the valve can be predicted if the valve flow coefficient is known for a specified operating pressure ratio.

Eom [5] building off the work of Cohn [1] and McPherson [2], studied the performance of butterfly valves as a flow controller. Eom compared the flow characteristics of perforated and non-perforated butterfly valve discs and found their performance to be in good agreement with one another, except at low blade (opening) angle values of about 10 degrees. He also studied the effect that blockage ratios (area of disc to area of pipe or duct) had on butterfly valves as throttling devices. Furthermore, Eom was able to predict loss coefficients sufficiently well from blockage ratios at Reynolds numbers in the range of 104.

Morris and Dutton [6] experimentally investigated the aerodynamic torque characteristics of butterfly valves using two dimensional planar models and three dimensional prototype valves at choked and un-choked operating points, and the results revealed the significance of the flow separation and reattachment phenomena on the aerodynamic torque characteristics of butterfly valves.

Morris and Dutton [7] also investigated the operating characteristics of two similar butterfly valves mounted in series, and an experimental investigation concerning the operating characteristics of a butterfly valve downstream of a 90 degree mitered elbow.

Kimura et al. [8] and Ogawa and Kimura [9] used free-streamline and wing theory to model symmetric butterfly valves between infinite parallel walls in two dimensions and used correction equations to compensate for pipe wall conditions. The correction equations also required a corrected opening angle and thickness of the discs, and uniform velocity. Using the given two-dimensional models, torque characteristics, pressure loss, and cavitation of three-dimensional experiments were predicted and analyzed. While the general pattern of torque coefficients followed the experimental data, the differences between the predicted and actual values were large. In more recent years since Kimura and Ogawa, scientific and engineering communities in the field of fluid dynamics and valve research have placed more emphasis in Computational Fluid Dynamics (CFD), especially with the advent of commercial CFD software in the 1990s.

Huang and Kim [10] were some of the first to use commercial CFD software to investigate three dimensional flow visualization of a symmetric butterfly valve (modeled as a thin flap valve disc). Huang used CFD code FLUENT to simulate a steady incompressible flow with $k-\epsilon$ turbulence modeling. Valve positions were simulated at openings of 30, 45, 60, 70, and 90 degrees. Huang also investigated the length downstream of the valve in which flow would return to fully developed conditions. Due to computational restrictions, a relatively coarse mesh of a maximum of 25,000 cells was used

in the CFD calculations. Huang also compared his numerical results with the experiments carried out by Blevins [11]. The 45 degree case was found to be the most agreeable with the experimental data, while the rest lacked agreement.

Lin and Schohl [12] used commercial CFD software FLUENT to predict drag coefficients for a symmetric coin shaped butterfly valve at opening angles in an infinite flow field with results obtained experimentally by Hoerner [13]. Sensitivity of the results to turbulence model selection, accuracy of discretization schemes, grid quality, and grid dependence were studied as part of the validation. Lin compared $k-\epsilon$, $k-\omega$, and $k-\omega$ SST turbulence models and opined that the later model was preferred for resolving the Reynolds-averaged Navier-Stokes equations and that use of a 1st order discretization for the flow domain led to predictions significantly higher than those from the 2nd order schemes. Flow coefficients aligned well with experimental data overall, however it should be noted that exact modeling comparisons between the experimental setup and the numerical model were difficult to match. Lin also modeled a 3.66 meter diameter butterfly valve within a pipe at valve openings of 20, 40, 50, 60, 70, 80, and 90 degrees with cavitation free conditions and incompressible flow using CFD.

A computational mesh size included about 1.5 million tetra and hexa-elements. Pressure drop across the valve was calculated and predicted flow coefficients matched relatively well with experimental data provided by the United States Army Corps of Engineers (USACE) for a similarly shaped disc butterfly damper.

Song et al. [14] performed a structural analysis of large butterfly valves, in addition to validating three-dimensional experimental data of a butterfly valve's pressure drop, flow coefficient, and hydrodynamic torque coefficient using general purpose CFD code CFX [15]. The $k-\epsilon$ turbulence model was selected by Song since it does not involve the complex non-linear damping functions required by other models. A mesh of nearly one million cells was used with a domain extending eight pipe diameters upstream from the valve and approximately ten pipe diameters downstream. Cases were run for disc opening angles of 5 to 90degrees in increments of 5 degrees. Generally, good results were obtained except when the valve opening angle was less than 20 degrees. In the 20 degree case, differences between experimental and simulation data were found to be nearly 50%.

Leutwyler and Dalton [16, 17] performed a CFD study in two and three dimensions for symmetric butterfly valves in compressible fluids at various angles and over a range of pressure ratios. The general purpose CFD code FLUENT was used with the following turbulence models: Spalart-Allmaras, $k-\epsilon$, and $k-\omega$. Leutwyler favored the $k-\epsilon$ turbulence model for its well-rounded capabilities and moderate computational costs. In addition to examining grid refinement, coefficients for lift, drag and torque were validated against experimental values.

Cheiworapuek et al. [18] investigated incompressible turbulent flow past a butterfly valve at 15, 30, 45, 60 and 90 degree opening angles. The CFD code FLUENT was used to validate experimental data for butterfly valves having diameters of 150 and 300 mm. The number of elements used in the simulation ranged from 1.1 million to 1.4 million. The $k-\epsilon$ turbulent model was used. For the experiment, pressure taps were located 1D upstream and 14D downstream.

Cheiworapuek observed that vortices were found near the tips of the butterfly valve and became larger as the valve disc was oriented at more closed positions.

The loss coefficient was generally unaffected by a change in inlet velocity for a given disc orientation. Large differences between the experimental data and simulation results were on the order of 50% for loss coefficients and torque.

Feng et al. [19] used a general purpose CFD code with a $k-\epsilon$ turbulence model to study cavitation and flow characteristics of a 1.2 meter diameter double eccentric butterfly valve. A hybrid mesh of quadrilateral and triangular elements were used. The flow domain extended from five diameters upstream to about ten diameters downstream. Feng found that a double eccentric structure had improved dynamic response and self-sealing in comparison with a single or no offset butterfly valve.

Xue Guan Song, et al [20] studied the multidisciplinary optimization of a butterfly valve. The initial model of valve is made and then the initial analysis including fluid and structural analysis is carried out to predict the fluid and structure performance of the valve. Optimization is carried out in the form of mathematical functions and using with the trade-off method. Validation simulation shows that the orthogonal array experiments drastically reduced the numbers of the computer experiments, and trade-off method combined with response surface model can predict the optimum conditions accurately and effectively.

IV. DISCUSSION & FUTURE WORK SCOPES

While many have researched butterfly valves over the years, the following comparison study will seek to contribute insight into the use of CFD to predict butterfly valve performance factors, especially in specifying the level of agreement that can be expected at various valve opening angles, and discuss meshing methods to improve results.

However, only studying the fluid characteristics is not enough for the large diameter butterfly valve because the pressure produced by the fluid is too high, which has great effect on the stress distribution in valve.

Now a day's more and more hydro electrical power plants being setup and renovated. But still the design and development of hydro electrical power plant is based on the traditional methods. Therefore there is a huge scope of utilization of modern day's technique like finite element method (FEM) for achieving maximum possible optimization.

Valves are very widely used for hydro mechanical part which is used to control the flow of water under high heads.

This dissertation describes the design optimization of butterfly valves using CAD software and ANSYS. To structural design the butterfly valve for weight optimization the Principal stress first, second, von mises stress & maximum deformation value are find out by using ANSYS and compare stresses value for existing casted verses optimized fabricated design for door and body of butterfly valve.

Analysis of the butterfly valve is done to optimize the stresses and minimize the weight using ANSYS. The mathematical model of optimization is established firstly, and the FEA is carried out by using the ANSYS software. Based on the analysis of optimal result, the stress concentrates on the valve

has become evaluate, which provides a better reference for redesign of valve.

Advantages of fabricated Valve option over cast version:

- The casting is found to be economical when numbers of valves are found to be more in a project as the cost of pattern is distributed over numbers.
- Strength of casting is less as compared to high tensile plates, resulting in more material consumption.
- On many occasions, casting has to be imported. This leads to higher lead-time, at the same time transportation problems persist with casting.
- Fabricated valve allows smooth passage to water and hence allow to extract higher turbine efficiency
- Cast valves will have some casting defects but fabricated valves are free from such defects.
- Fabricated valve requires less inspection as compared to cast one, which requires full surface inspection.
- Precision machining increasing service life & reliability.

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