CFD Method of Prediction and Validation of Operating Torque for Butterfly Valves with Various Disc Profiles

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Abstract - Butterfly valves are commonly used in large municipal water supply schemes, industrial applications such as cooling water systems in thermal power stations, hydro-electric power stations etc. to control the internal flow of both compressible and incompressible fluids. A butterfly valve usually includes a metallic disc fashioned around a imperative shaft, which act as its axis of rotation. As the valve’s starting attitude, 0, is improved from 0 degrees (absolutely closed) to 90 degrees (completely open), fluid is able to more simply waft beyond the valve. Characterizing a valve’s overall performance elements, such as stress drop, hydrodynamic torque and hydrodynamic torque coefficient, is important for fluid system designers to account for system requirements to correctly operate the valve and save you everlasting harm from taking place. Another technique in which butterfly valve overall performance factors may be received is via the usage of Computational Fluid Dynamics (CFD) software to simulate the physics of fluid waft in a piping machine round a butterfly valve. This observe sought to evaluate experimental and simulated CFD overall performance elements of a 1400mm diameter butterfly valve for diverse valve openings and waft situations in an effort to decide the validity of using CFD to predict butterfly valve performance factors. For the assessment of the adequacy of valve operation capacity and the actuator sizing, the desired torque estimation is necessary. Since the major contributing issue of the specified torque within the mid-stroke position is hydrodynamic torque, it is necessary to expect the torque properly beneath the actual flow situations. During commencing of the butterfly valve, the fluid flows through the valve, a force is carried out to the disc through the fluid. In fashionable, as the drift charge will increase via the valve, greater force is exerted upon the disc through the fluid. These increased dynamic forces require extra torque to rotate the disc. The quantity of torque required to rotate the disc at some stage in operation varies relying on form of fluid flowing thru the valve, the velocity, the form of the disc and the position or orientation of the disc. It is high quality to lower the torque in given software. Lower torque requires a smaller actuator to operate the valve thereby saving physical size and further reducing cost. In this proposed work, the 3 important torques seating/unseating, bearing friction and hydrodynamic torque is found for disc with double offset by carrying out the experiment on a 150 NB Butterfly valve and the total torque obtained is compared using CFD simulation software and is validated. Further the double offset disc is changed to single, triple, bi-lattice and Tri-lattice and CFD analysis is carried out. Finally a correlation is established between the experimental value and the CFD values and based on this finally an empirical formula has to be arrived to find the total torque for different disc profile without carrying out experiment or CFD. Based on the correlations established between the experimental and CFD values, the Valve industry can make use of this Data for optimum selection of Gear box and Actuator.

Keywords: Pressure drop; Hydrodynamic torque; Hydrodynamic torque co-efficient; Seating/unseating; Bearing friction torque

1. INTRODUCTION

A butterfly valve is a form of drift control tool, commonly used to alter a fluid flowing via a section of pipe. A flat round disc (blade) is located in the Centre of the pipe. The disc (blade) has a shaft (rod) through which it connected to an actuator at the outside of the valve. Rotating the actuator turns the disc (blade) either parallel or perpendicular to the go with the flow. The valve disc (blade) while pivoted at the center and moved with the assist of an actuator resembles butterfly wings and consequently they're referred to as butterfly valves. A butterfly valve, Fig. 1 is from a circle of relatives of valves referred to as area flip valves. The butterfly is a steel disc established on a shaft (rod). When the valve is closed the disc is grew to become in order that it completely blocks off the passageway. When the valve is fully open, the disc is circled 1/4 flip in order that it allows unrestricted passage. The valve can also be opened incrementally to modify glide, thanks to the gradual interlocking notch. Large Butterfly Valves are commonly geared up with a gearbox (or tools operator). Gearbox output power which is mostly a hollow shaft or shaft with keyway or splines are used.
whereas the hand wheel by means of gears is attached to the shaft (rod).

2. LITERATURE REVIEW

One of the earliest and most comprehensive pieces of studies at the go with the flow characteristics and overall performance of butterfly valves turned into achieved [1]. Using records supplied via preceding authors, Cohn attempted to parameterize torque and glide coefficients primarily based on thickness to diameter ratio for sever butterfly valve geometries, maximum of which had been symmetrical. CFD software FLUENT is used [2] business to expect drag coefficients for a symmetric coin shaped butterfly valve at commencing angles in an countless glide field with consequences obtained experimentally [3]. The consequences confirmed that CFD modeling can provide a reasonable estimate of the force and discharge coefficients, as a contrast turned into made among CFD anticipated and experimental facts. A comparison is investigated [4] look at of forty eight inch butterfly valve’s experimental performance coefficients the use of CFD in an incompressible fluid at Reynolds numbers ranging about among 105 and 106. It is found that for mid-open disc angles (α = 300-600), CFD was able to approximately predict not unusual performance coefficients for butterfly valves. For decrease valve angles (α = 100-200), CFD simulations did not are expecting those same values, whilst higher valve angles (α = 700-900), gave combined consequences.

The turbulent glide of water thru a butterfly valve of two hundred mm diameter is studied [5]. The consequences confirmed that the go with the flow is smoother and freed from turbulence at small strain drop across the valve either at massive valve beginning attitude or small inlet speed. A numerical evaluation of butterfly valve and expected the flow coefficients and hydrodynamic torque coefficients are completed [6]. In this study, 3 dimensional numerical simulations by way of business code CFX had been carried out to look at the go with the flow coefficients and hydrodynamic torque coefficient when butterfly valve with various starting levels and uniform incoming pace had been used in the piping device.

A numerical simulation for go with the flow of water beyond over a butterfly valve the usage of industrial fluid dynamics software FLUENT is carried out [7]. It changed into observed that the glide has a small effect with growing closing angle till it reaches 550, wherein the go with the flow around the valve started out to grow to be noticeably turbulent. a CFD take a look at at in two and three dimensions for symmetric butterfly valves in compressible fluids at numerous angles and over quite number stress ratios is performed [8]. The fashionable motive CFD code FLUENT changed into used with the subsequent turbulence models are preferred the ok-ε turbulence version for its well-rounded abilities and moderate computational costs. In addition to inspecting grid refinement, coefficients for carry, drag and torque had been validated in opposition to experimental values.

ANSYS FLUENT code and the same old ok-ε version to assess the overall performance aspect consisting of flow coefficient for unique valve openings is used and shown in Fig. 1. The results confirmed properly settlement with experimental statistics. They concluded that CFD gives a means of gaining treasured insight into the go with the flow discipline of the valve, in which complex fluid structure and pace profile recovery may be located and studied.

Fig. 1 Butterfly Valve, shows closed and open position

To carry out the experiment for a scaled model of 150 NB butterfly valve (Manually operated with lever) and to find out the total torque required.

Based on the experiment, to find out the pressure drop across the valve and the three torque values (Seating/unseating, dynamic and bearing torque) at different opening/closing angle from 00-900 in increments of 100 each.

Based on the dynamic torque and pressure drop value obtained by the experiment, dynamic torque coefficient has to be found out which is very important parameter in deciding the total torque value [9].

Using Computational fluid dynamics (CFD) – Fluent software a 3D model and meshing of the disc has to be made. By giving proper boundary conditions and post processing (run), the torque and pressure drop values at different opening/closing angle from 00-900 in increments of 100 each can be obtained.

A comparison has to be made between the experiment and CFD simulation values for torque, pressure drop and dynamic torque co-efficient values and an estimation of error of uncertainty has to be arrived.

A correlation has to be established between the experiment and CFD simulation and based on this finally an empirical formula has to be arrived to find the total torque for different disc profile without carrying out experiment or CFD [10].

3. METHODOLOGY

The methodology given in this paper is a step-by-step procedure for predicting valve torque that represents the present method used by many Butterfly Valve manufactures.
By using the computational Fluid dynamics (CFD) software estimate the operating torque Values versus angle of opening/closing for various disc profiles i.e. symmetric (Zero offset) and non-symmetric (single offset, double offset and triple offset) from fully closed position 00 to fully opened position 900. It is proposed to include latest design styles of valve disc (blade) such as bi-lattice (bi-plane) and tri-lattice (bi-plane). These designs have evolved after extensive study on valves used in large pumping systems and hydro-electric power stations where the pressure drop is critical so also the weight of the disc. For handling high pressure, the thickness of disc (blade) for flat slab disc will have to be increased. This will increase the weight and pressure drop of the disc (blade) and hence the operating torque. Valve designers usually encounter this design conflicting requirements. Proposed study will address this aspect. Once the total torque is estimated, based on which the standard gear box (manual operator) can be selected.

These operating torque values or results are compared with the values from the experiment that will be carried out and also on the Published Experimental Data.

Based on the above study, it is proposed to establish correlations for hydrodynamic torque and pressure drop for a given valve size and disc profile.

Zero offset (concentric/symmetric) disc profile is not preferred and is not designed/built in large sizes and is not included in our study.

4. BUTTERFLY VALVE TORQUE REQUIREMENTS

The amount of total torque (TT) required to operate a butterfly valve disc is actually the sum of several torques which occur within the butterfly valve. Specifically

\[
TT = TSU + Td + Tbf + Tss + Te + Th
\]

where

\[
TSU = \text{Seating and unseating Torque, N.m}
\]

\[
Td = \text{Dynamic torque resulting from lift effect of the fluid flow on the disc, N.m}
\]

\[
Tbf = \text{Bearing friction torque, N.m}
\]

\[
Tss = \text{Shaft (stem) seal friction torque, N.m}
\]

\[
Te = \text{Eccentricity torque resulting from disc offset from centerline of shaft (stem) (either single, double or triple offset), N.m}
\]

\[
Th = \text{Hydrostatic torque, N.m}
\]

4.1 Seating and unseating Torque (TSU)

The magnitude of Seating and unseating Torque (TSU) is a function of the pressure differential across the valve, the seat material’s coefficient of friction, the finished surface of the disc edge, and the amount of interference between the seat ID and disc OD when flanged in the piping and the seat thickness and the type of service (media) for which the valve is being used. After the disc clears the seat material the value of Seating and unseating Torque (TSU) will drop to zero.

Seating and unseating torque is determined by the following equation,

\[
TSU = \mu_s D_2 \Delta P
\]

where,

\[
\mu_s = \text{Seat/Seal coefficient of friction, dimensionless}
\]

\[
D = \text{Disc diameter, m}
\]

\[
t = \text{Seal contact width, m}
\]

\[
\Delta P = \text{pressure differential across valve, N/m}^2
\]

If a butterfly valve sits in the closed position for an extended period of time (over 5 days) the seating material will take a compression set. The effect of compression set is to further increase the value of (TSU). The effect of compression set has to be considered in the actuator selection.

4.2 Dynamic Torque (Td)

Dynamic torque (Td) occurs when the position of the disc is between the closed position 00 and the wide open position 900. With the disc in the partially open position, velocity of the fluid passing the leading disc edge is less than the velocity passing the trailing edge. This variance in velocity past the leading disc edge and trailing disc edge results in an unbalanced distribution of forces across the face of the disc. The total forces acting perpendicular to the disc face on the leading edge half of the disc are greater than the total forces acting perpendicular on the trailing half of the disc. This uneven distribution of forces acting on the disc face results in a torsional moment which tries to turn the disc to the closed position. The magnitude of (Td) is greater when the disc is between 700 and 800 of rotation (disc opening angle).

To determine dynamic torque, the following equation is applied

\[
Td = C_{dt} D^3 \Delta P
\]

where

\[
C_{dt} = \text{Coefficient of dynamic torque, dimensionless}
\]

\[
D = \text{Diameter of Disc, m}
\]

\[
\Delta P = \text{Differential pressure across the valve, N/m}^2
\]

Both the C_{dt} (Coefficient of dynamic torque) and \Delta P (pressure drop at the valve) strongly depend on the disc shape. Calculating the C_{dt} (Coefficient of dynamic torque) for different valves and at different disc opening angles is a very difficult task, and therefore, for using the above equations, experimental data is necessary. However, by the implementation of the numerical methods, the dynamic torque can be calculated before the valve has been actually manufactured.
4.3 Bearing Friction Torque ($T_{bf}$)

The bearing friction torque ($T_{bf}$) in a butterfly valve is a function of the coefficient of friction between the bearing and the shaft, the shaft diameter, the disc diameter (area), and the pressure drop across the disc at each angle of rotation (Fig. 2)

$$T_{bf} = \frac{\pi}{4} D_d^2 \left(\frac{ds}{2}\right) C_f \Delta P$$  \hspace{1cm} (4)

where

- $T_{bf}$ = bearing torque, Nm
- $D_d$ = Disc diameter, m
- $ds$ = Shaft diameter, m
- $C_f$ = Static coefficient of friction between the bearing and the shaft, dimensionless
- $\Delta P$ = Pressure across the disc, N/m$^2$

![Fig. 2 Bearing friction torque](image)

5. RESULTS AND DISCUSSION

Butterfly valves are extensively used in numerous industries including water distribution, sewage, oil and gasoline plant life. The hydrodynamic torque implemented on the butterfly valve disc is one of the most vital elements which ought to be considered of their layout and alertness. Although numerous strategies were used to calculate the full torque of those valves, most of them are primarily based on hydrostatic analysis and forget about the hydrodynamic effect which has a first-rate position to decide the torque of the huge-size valves. For finding the dynamic-valve-torque, a few empirical formulation and methods were proposed; as an example in AWWA C504 preferred, a dating for calculating the dynamic torque has been given and its variation versus disc angle has been said. However, using those empirical relationships is limited due to the situations described inside the standards. In this paper, the dynamic-valve-torque has been calculated for a huge butterfly valve beneath one of kind situations and additionally on the unique starting angles of the valve disc. For this motive a computational fluid dynamics (CFD) method has been used.

An experiment is accomplished for a model butterfly valve of one hundred fifty NB diameter operated by hand by using lever. Refer Schematic diagram of the experimental set up is shown in Fig. 3. Experimental installation for checking out butterfly valve of a hundred and fifty NB incorporates of a centrifugal pump of capability 2800 lpm at 6 m head. Required quantity of water is pumped from water garage tank of 6000 litres capacity. The pump / motor is connected to the Motor starter for starting and preventing of the pump.

The outlet of the pump is connected by means of butterfly valve of one hundred fifty NB for controlling the go with the flow to the take a look at valve. The outlet of the upstream butterfly valve is hooked up to electromagnetic glide meter to measure the release or flow. In among the upstream butterfly valve and the flow meter a thermometer is hooked up for measuring the water temperature when you consider that density of water adjustments with alternation in temperature.

The downstream pipe of the flow meter is connected to test section where in at the inlet upstream pressure gauge is provided to measure the pressure P1 at the distance of 3D minimum (D is nominal diameter of the Valve) from the test valve Model of 150 NB size butterfly valve. A Strain Gauge is mounted in between the test valve shaft (under test section) and the lever from which the torque reading at different valve opening and closing angles can be obtained and readings are taken from the display unit.

The downstream end of the test valve is connected with the downstream pressure gauge similar to the upstream arrangement at a distance of 6D (D is nominal diameter of the Valve) to measure the pressure P2. After the downstream pressure gauge, a thermometer and butterfly valve is connected to get the reading at the downstream similar to the upstream reading. The other end of the throttle valve is connected with downstream pipe back to the storage tank.

![Fig. 3 Schematic diagram of experimental set up](image)

6. CONCLUSION

The Valve torque depends on fluid pressure and flow velocity besides valve disc profile.

Valve designers have adapted various styles for the valve disc with objective of reducing pressure drop in
the fully opened valve and optimum strength to weight ratio.

But for the improved valve disc profile they don’t really have correct procedure or estimation of operating torque. This is a major problem which requires an exhaustive study to come out with procedures for estimation of operating torque for various disc profiles.

Based on the correlations established between the Experimental and computational fluid dynamics (CFD) values, the Valve industry can make use of this data for optimum selection of Gear box and Actuator. This will avoid the risk of under sizing or over sizing the gear box and actuator for the given valve and flow parameters.

With this optimum design of Valve gear box and actuator it is expected to bring down the cost substantially.

REFERENCES


