ISA Transactions 63 (2016) 401–412

Contents lists available at ScienceDirect

ISA Transactions

journal homepage: www.elsevier.com/locate/isatrans

Multi-objective global optimization of a butterfly valve using genetic algorithms

Sergio Corbera [a], José Luis Olazagoitia [b,*], José Antonio Lozano [a]

[a] Universidad Politécnica de Madrid, Ronda de Valencia 3, 28012 Madrid, Spain
[b] Universidad Nebrija, Pirineos 55, Madrid 28040, Spain

ARTICLE INFO

Article history:
Received 13 July 2015
Received in revised form
15 February 2016
Accepted 13 March 2016
Available online 4 April 2016

Keywords:
Butterfly valve
Multidisciplinary optimization
Global optimization
Genetic algorithms
NSGA-II
FEM
CFD
DOE
Pareto

ABSTRACT

A butterfly valve is a type of valve typically used for isolating or regulating flow where the closing mechanism takes the form of a disc. For a long time, the attention of many researchers has focused on carrying out structural (FEM) and computational fluid dynamics (CFD) analysis in order to increase the performance of this type of flow-control device. This paper proposes a novel multi-objective approach for the design optimization of a butterfly valve using advanced genetic algorithms based on Pareto dominance. Firstly, after defining the need for this study and analyzing previous papers on the subject, the initial butterfly valve is presented and the initial fluid and structural analysis are carried out. Secondly, the optimization problem is defined and the optimization strategy is presented. The design variables are identified and a parameterization model of the valve is made. Thirdly, initial design candidates are generated by DOE and design optimization using genetic algorithms is performed. In this part of the process structural and CFD analysis are calculated for each candidate simultaneously. The optimization process involves various types of software and Python scripts are needed for their interaction and the connection of all steps. Finally, a set of optimal solutions is obtained and the optimum design that provides a 65.4% stress reduction, a 5% mass reduction and a 11.3% flow increase is selected in accordance with manufacturer preferences. Validation of the results is provided by comparing experimental test results with the values obtained for the initial design. The results demonstrate the capability and potential of the proposed methodology.

1. Introduction

Butterfly valves are low cost, lightweight and compact valves that can be operated easily giving a satisfactory performance. They are suitable for on–off service as well as throttling. Proper design of the shape of the disc-seat pair can control cavitation and flow torque. Besides, the adequate selection of materials in valve components can make them suitable for use with any fluid and very different applications.

A butterfly valve is usually comprised of a disc that can be rotated a quarter of a turn by a shaft running through it. The relative position between the geometric center of the disc and the shaft determines if the valve is symmetrical, eccentric or double eccentric. The rotation of the disc determines the flow that is allowed through the valve, that is to say, maximum when the disc is positioned parallel to the flow (in the most open position), or minimum when perpendicular to it (closed).

Butterfly valves have been used for many years and extensive research on them exists. First studies on butterfly valves were based on experimental investigation. For example in [1] the performance of a butterfly valve downstream of an elbow is analyzed. The most famous works were published by Ogawa and Kimura [2,3], which covered the study of the torque characteristics and pressure drop in a butterfly valve. Once computational simulation became faster and affordable, the hydrodynamic characteristics of butterfly valves at different disc angles have been extensively researched using CFD software [4,5]. Cavitation is one of the most important concerns due to noise, malfunctioning and unplanned maintenance on the product [6–8]. These studies focused mainly on the hydrodynamic characteristics of the butterfly valves. However, the structural analysis of these valves is also important, as different studies have demonstrated [9–11].

If both fluid dynamics and structural analysis on butterfly valves are considered together, it is possible to obtain multi-objective optimum valves. There have not yet been many studies in this field addressing at the same time their fluid and structural characteristics. However, it is important to mention works by Song

* Corresponding author. Tel.: +34 914521100x2863.
E-mail address: jolazago@nebrija.es (J.L. Olazagoitia).

http://dx.doi.org/10.1016/j.isatra.2016.03.008
0019-0578/

et al. [12], Yi et al. [13], Kim et at. [14] and Yang et al. [15]. These works focus on different aspects of the structural optimization of butterfly valves through different techniques such as Design of Experiments (DOE), Taguchi, topological optimization, and so on. In [12] the initial shape of the valve is defined by means of an initial topology optimization. Based on this, design variables for the valve shape are selected. Using an orthogonal array DOE, a family of possible designs is analyzed (via a 2D CFD and a 2D FEM). The results from the DOE designs are used to construct some mathematical models (surrogate models). The surrogated models are interrogated (CFD and FEM) for their ability to provide a trade off between multiobjective optimization and the provided solution if checked against the simulation of the optimal design. In [13] an eccentric butterfly valve is optimized for a waterhammer scenario acting on the valve. The pressure exerted by the waterhammer effect on the valve is used in the FEM analysis. The optimization is focused on determining the height of the rotating axis subjected to the pressure drop between the inlet and the outlet and the total moment on the axis. In this case the structural optimization is prioritized. A 2D topology optimization is first run, followed by a finer shape optimization allowing for a stress and a mass reduction of 3.5% and 9.88%. The optimum model is then compared with the initial one both in FEM and CFD analysis. In [14,15] an initial 2D topology optimization is run in the conceptual design stage for a double eccentric butterfly valve for a given position. From this point, using a Taguchi DOE a design space is defined and CFD analysis using orthogonal arrays are run. The 2D topology optimization is improved in relation to the hydrodynamic performance and disc structure. The sensitivity of the analysis is explored using an analysis of the variance. The verification of the optimal shape is validated using CFD analysis.

In this paper an alternative methodology using genetic algorithms based on Pareto dominance is presented for the optimization of a double eccentric disc of a butterfly valve, where, in contrast to previous studies, both structural analysis and flow capacity are considered simultaneously, without needing to rank objectives in order of importance, or sequentially. In addition, a totally new parametric approach based on control points is proposed for managing the design of the butterfly valve. This is an important point to underline since it allows for a broader range of possible final designs to be feasible, and explored, for the global optimization. Another difference with regard to previous optimization studies is that the proposed methodology includes three-dimensional computational studies for both CFD and FEM.

As a global optimization is considered for the valve design for minimum tension, maximum flow through the valve and minimum weight, a powerful search algorithm is needed. In this case a genetic algorithm-based optimization is used. As a result, after the optimization is run and the design space is fully explored, the optimal Pareto fronts are available to the designer. This is an important advantage, since the decision about the preferences of the objectives can be taken a posteriori and the optimization does not need to be rerun. As all the data is available in Pareto fronts, the designer can change his/her mind at any point of the design procedure and choose another optimal design prioritizing different solutions for different applications.

This paper is structured as follows: Section 2 presents a brief description of the butterfly valve which is the object of this study; Section 3 describes the structural and CFD analysis of the initial model; Section 4 explains the model variables, restrictions and design space to be explored, the optimization strategy together with the interactions between different software and programming in Python; Section 5 focuses on the results of optimization presenting some optimum disks; and finally, Section 6 draws some conclusions.

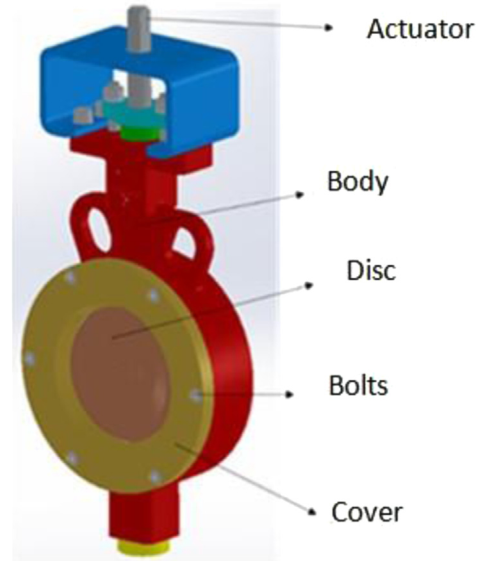

Fig. 1. CAD assembly of original butterfly valve.

Table 1
Main specifications of butterfly valve.

Operation conditions	
Valve size	Diameter:100 mm
Design pressure (N/mm^2)	5.5
Operating temperature (°C)	20
Operating fluid	Water
Material properties	
Disc	Steel

2. Initial butterfly valve: description and specifications

The butterfly valve object under research in this paper is used as a flow control device for industrial applications. Its initial design belongs to a high performance valve manufacturer. As shown in Fig. 1, the overall structure of the butterfly valve consists of an actuator, a valve body, a butterfly disc, a cover and a shaft (hidden). In order to rotate the disc from 0° (fully closed) to 90° (fully opened), both actuator and disc are connected through a shaft. On the shaft, at both sides of the disc, there are two fixed bearings inside the valve body. The cover is bolted to the body, and in order to provide an adequate shutoff, an interference fitting between disc edge and seat exists assuring proper sealing.

According to the information provided by the manufacturer, the main specifications of the butterfly valve are described in Table 1.

3. Analysis of initial model

In order to evaluate the performance of a specific valve model successfully, structural and fluid field analyses are needed, as mentioned above. For this study, ANSYS Workbench and FLUENT are used for both static structural and computational fluid dynamics analysis respectively.

3.1. Fluid field analysis and flow coefficient K_v

Flow performance in a butterfly valve can be measured by different coefficients such as: pressure loss coefficient, flow