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Offset Disc Butterfly Valve Design

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Abstract: *Butterfly valves are used for controlling or regulating the flow through pipes in wide variety of applications such as in fire protection, HVAC, Plumbing services, marine, oil and gas field etc. This paper describes about designing a grooved type 6-inch offset disc butterfly valve which can withstand 300psi pressure and adhere to UL and FM guidelines. Initially benchmarking process was carried out to analyze the performance of the competitor's valve. Reverse engineering of benchmarked valve was carried out using 3D software Creo2.0 for future modeling and analysis purposes. Keeping the benchmarked valve as reference different product concepts was generated on valve features and sealing. Among these concepts the best concept was developed by using concept scoring technique. The best concept was then evaluated by carrying out FEA and CFD analysis to analyze the UL and FM pressure rating guidelines. Based on the developed concept of valve, 2D draft drawings are generated using Creo 2.0*

Keywords - Butterfly valve, Benchmarking, Reverse Engineering, FEA and CFD Analysis, UL and FM guidelines.

I. INTRODUCTION

Butterfly valves are used for controlling or regulating the flow through pipes. It contains a metal disc which is mounted at the centre of the pipe and can shut off and shut on to regulate the flow. The actuator is connected to the disc through shaft, turns the disc in the direction perpendicular and parallel to the flow. The disc is said to be in opened condition when it is parallel to the flow and closed condition when it is perpendicular to the flow.

In any of the product development process there will be many objectives which have to be improved in order to gain the market competitiveness. The objective of the product development process and the key factors affecting the objective was systematically analyzed and improvement steps were established based on benchmarking process [1]. The idea of benchmarking enables the decision makers to understand exactly how much improvement to be carried out in order to achieve superior performance [2]. Reverse engineering process involves measuring an object and constructing its 3D model, which is used for future modelling of parts. It is used in the situations where functional CAD models are unavailable. Different product concepts are generated and the best concept is selected by concept scoring technique. Structural analysis helps in determination of different stresses acting on the valve [3-4]. The flow behaviour across the flow regulating butterfly valve is predicted using CFD simulation [5]. Thereby using simulation tool it becomes easy to optimise the product behaviour and validate the design [6-8].

In this paper a 6-inch offset disc butterfly valve is designed that meets UL and FM guidelines to withstand 300psi pressure. The best in class competitor's valve is benchmarked and reverse engineering process is done for the future modelling and analysis purposes. Keeping the benchmarked valve as a reference various concepts are generated with respect to its features and functionality. To reduce the number of parts body and end face is integrated into a single part. To achieve efficient sealing between the disc and body, slot is provided in the body to accommodate the seat by press fit. FEA is carried out on the body and disc by applying 1500psi pressure with FOS 5 times the actual pressure (300psi). CFD analysis is carried out in order to study the flow behaviour across the valve.

II. BENCHMARKING PROCESS

The main objective was to develop a competitive design of offset disc butterfly valve with efficient valve sealing and thereby to upgrade the valve to the current requirement. Benchmarking is simply a process of comparing one's business processes and performance against those of best practices of other industries.

2.1. Best in class benchmarking

Best in class benchmarking is carried out to study and analyze the best competitor who has gained the market competitiveness. The butterfly valve developed by the Competitor 1 as shown in figure 1 holds the highest market share and is the global leader in the field of HVAC and plumbing. Competitive advantage gained by the competitor 1 was studied by considering its products performance in terms of strengths and weaknesses.

Figure 1 Butterfly valve of competitor 1.

Table 1: Strengths and weaknesses of competitor 1's butterfly valve

STRENGTHS	WEAKNESSES
It is approved by UL and FM	Limited warranty period
Unique design of offset disc	The external thread provided in the end face might lead to leakage during operation
Increase in the flow and operating torque is reduced up to 35%	The seat provides sealing for both thread and disc of the valve which is not so efficient.
Stem bearings maintain constant low torque values	Number of parts more
Seal has unique registered name as Master Seal	

This valve has gained the market competitiveness based on its strengths and hence fast reaches to the customer. This unique design and highest distribution channel has led the competitor 1's butterfly valve to gain the highest market share. Hence this product was analyzed and then taken as a reference to generate different concepts in order to develop competitive butterfly valve with improved performance.

III. REVERSE ENGINEERING

The main parts of butterfly valve are body, end face, disc, seat and stem. The shape of each part was captured by laser scanning method. The pre-processing activities were carried out using the software Creo 2.0 REX module which includes data reduction, noise filtering, hole filling etc. Then the 3D model of butterfly valve parts was generated as shown in figure 2 (a) Body (b) End face (c) Disc (d) Seat (e) Stem. Once the parts are modeled it is then assembled which is shown in figure 3(a).
The material specifications of butterfly valve parts are valve body - ductile iron with black alkyd enamel coating, disc - ductile iron with electro less nickel coating, Seat - EPDM, stem - stainless steel, stem bearing - brass.

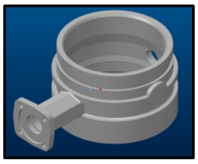

Figure 2(a) Body

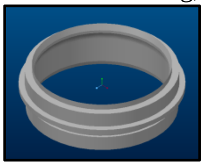

Figure 2(b) End face

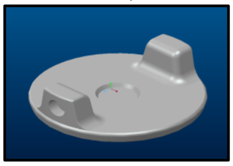

Figure 2(c) Disc

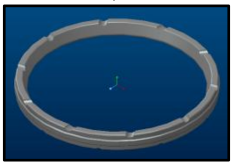

Figure 2(d) Seat

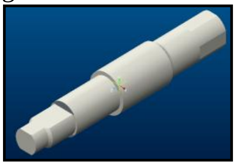

Figure 2(e) Stem

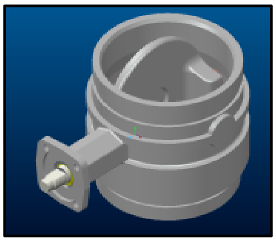

Figure 3(a) Standard view of butterfly valve.

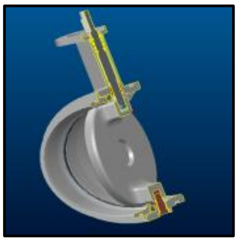

Figure 3(b) Sectional view of butterfly valve.

IV. CONCEPT GENERATION

Concept generation involves the identification of requirements and new concepts are generated based on requirements.

Four new concepts on valve features and valve sealing were generated, the generated concepts are explained below:

4.1. Concept 1

In this concept to reduce the number of parts, valve body and end face is integrated into a single part. The seat is designed to match the disc profile for efficient sealing. The disc is designed for two piece stem to reduce the operating torque. To achieve sealing the seat is molded to the disc directly which is shown in the figure 4(a). It is then assembled with the body of butterfly valve for efficient sealing which represents concept 1. A 3D model of concept 1 is shown in the below figure 4(b) with disc in closed position.

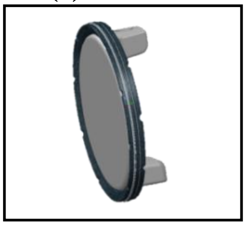

Figure 4(a) Seat molded to disc

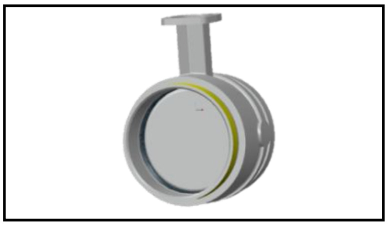

Figure 4(b) Concept 1

4.2. Concept 2

In this concept to reduce the number of parts, valve body and end face is integrated into a single part. The seat is designed to match the body and disc profile for efficient sealing. The disc is designed for two piece stem to reduce the operating torque. To achieve sealing the seat is molded to the body of the valve directly which is shown in the figure 5(a). The disc is then assembled with the body of butterfly valve for efficient sealing which represents concept 2. A 3D model of concept 2 is shown in the below figure 5(b) with disc in closed position.

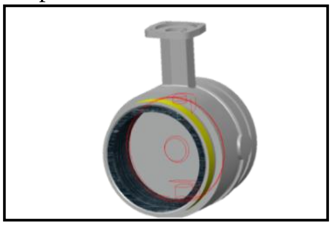

Figure 5(a) Seat molded to valve body

Figure 5(b) Concept 2

4.3. Concept 3

In this concept to reduce the number of parts, valve body and end face is integrated into a single part. The seat is designed to match the body and disc profile for efficient sealing. The disc is designed for two piece stem to reduce the operating torque. The neck design of valve body is made hexagonal in shape and flange design is made circular in shape. To achieve sealing the seat is designed to accommodate in the body by press fit as shown in figure 6(a). The profile of the seat is matched with that of the body. The disc is then assembled with the body of butterfly valve for efficient sealing which represents concept 3. A 3D model of concept 3 is shown in the figure 6(b) with disc in closed position.

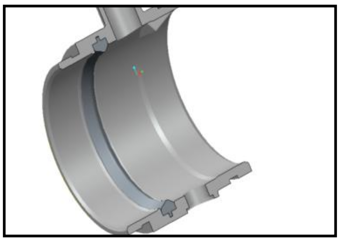

Figure 6(a) Seat assembly in body

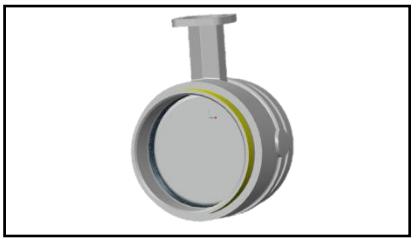

Figure 6(b) Concept 3

4.4. Concept 4

In this concept to reduce the number of parts, valve body and end face is integrated into a single part. The disc is designed for two piece stem to reduce the operating torque. The profile of the seat is matched with that of the disc. To achieve sealing the seat is designed to accommodate on the disc by press fit. A metallic plate is used to lock the seat by fastening it on the disc as shown in the figure 7(a). The disc is then assembled with the body of butterfly valve for efficient sealing which represents concept 4. A 3D model of concept 4 is shown in the below figure 7(b) with disc in closed position.

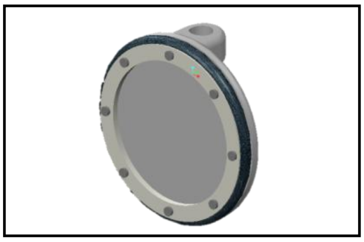

Figure 7(a) Seat assembly on disc.

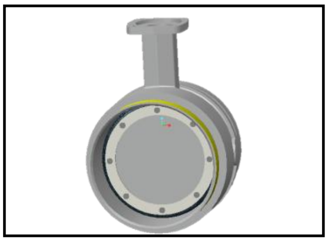

Figure 7(b) Concept 4

V. CONCEPT SELECTION

Once the concepts are generated, the best concept was selected in concept selection stage. Concept selection process is carried out by concept scoring matrix. The steps in concept scoring involve: Preparing the selection matrix. Next step is to rate and rank the concepts. Combine and improve the rated concepts. Finally, Select one or more concepts. Reflect on the results and the process.

Concept scoring process is shown in Table 2. The strengths and weaknesses of concepts were evaluated with respect to criteria's such as ease of manufacturing, assembly, maintenance, sealing efficiency, durability and operating torque. The concepts were rated against each of the selection criteria.
Using the concept scoring matrix the best concept for valve sealing is selected. Concept 3 is the best concept as it is rated highest score in the matrix and hence it is used for further testing and development.

Table 2: Concept Scoring Matrix for Concept 1, 2, 3 and 4

		Concept 1		Concept 2		Concept 3		Concept 4	
Selection Criteria	Weightage	Rating	W.S	Rating	W.S	Rating	W.S	Rating	W.S
Ease of Manufacturing	20%	4	0.8	3	0.6	3	0.6	2	0.4
Ease of Assembly	30%	2	0.6	2	0.6	4	1.2	2	0.6
Sealing Efficiency	25%	2	0.5	2	0.5	4	1	2	0.5
Durability	10%	1	0.1	1	0.1	2	0.2	1	0.1
Ease of Maintenance	5%	1	0.05	1	0.05	3	0.15	2	0.1
Operating Torque	10%	2	0.2	2	0.2	3	0.3	2	0.2
	Total score	2.25		2.05		3.45		1.9	
	Rank	2		3		1		4	
	Continue?	No		No		Yes		No	

VI. FINITE ELEMENT ANALYSIS (FEA)

Finite element analysis was carried to evaluate the selected concept by using Creo simulate software. Static analysis was carried out on butterfly valve body and disc to determine the impact of different stresses acting on it. The material used is ductile iron confirming to ASTM A-536 grade 65-45-12. The material properties are Ultimate tensile strength - 448 MPa, Yield tensile strength - 310 MPa, Poisson's ratio - 0.12. Tetrahedron elemental mesh is used with tetra - 6563, edge - 10667 and face - 15106. The valve body is constrained in all the degrees of freedom as shown in figure 8(a). The pressure of 1500 psi with FOS 5 times the actual pressure i.e. 300psi is applied on the circumference of the valve body as shown in figure 8(b).

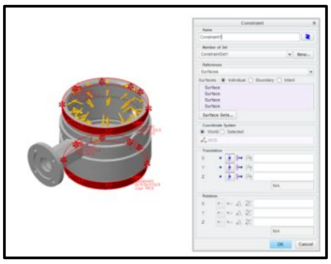

Figure 8(a) Body is constrained in all DOF

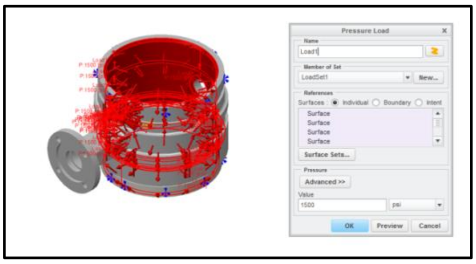

Figure 8(b) Pressure applied on valve body

From the analysis results, hoop stress acting on the valve body as shown in figure 8(c) is 189 MPa which is less than the yield stress of the material i.e. 310 MPa. Therefore the valve is safe under working condition.

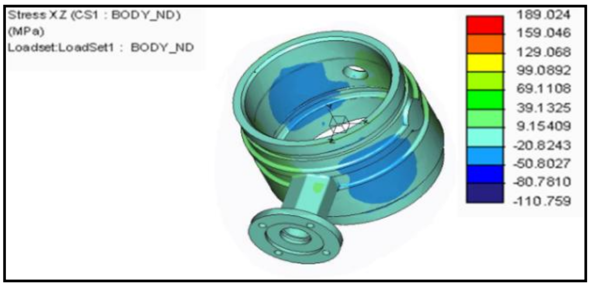

Figure 8(c) Hoop stress acting on valve body

Static analysis was carried out on the valve disc with same material as stated above. Tetrahedron elemental mesh is used with tetra - 1388, edge - 2194 and face - 3140.
The valve disc is constrained in all the degrees of freedom as shown in figure 9(a). The pressure of 1500 psi with FOS 5 times the actual pressure i.e. 300psi is applied on both the sides of valve disc as shown in figure 9(b).

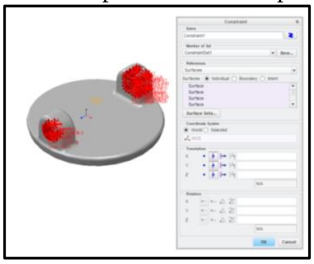

Figure 9(a) Disc is constrained in all DOF

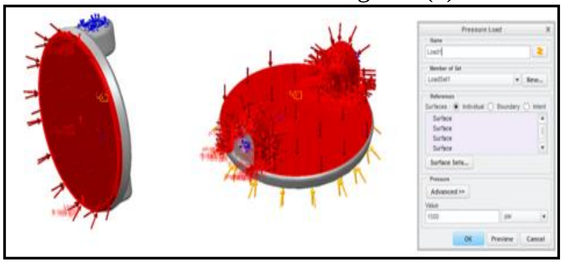

Figure 9(b) Pressure applied on one side of disc

From the analysis results, von mises stress acting on the valve disc as shown in figure 9(c) is 38.89 MPa which is less than the yield stress of material i.e. 310 MPa So the valve disc is very safe under working condition.

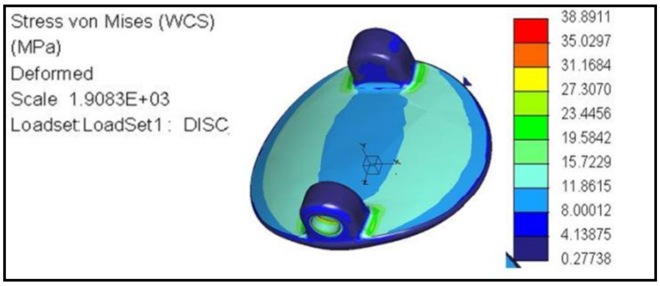

Figure 9(c) Von mises stress acting on valve disc

VII. CFD ANALYSIS

CFD analysis was carried out on the developed butterfly valve in order to determine the pressure drop, flow co efficient and flow behaviour across the valve for various angles of disc opening. The flow analysis was carried out using Autodesk CFD simulation software.
As per the FM guidelines with the disc in the full open position, the loss of pressure through the valve should not exceed 5.0 psi or 35 kPa at a flow producing a velocity of 20 ft/sec or 6.1 m/sec in schedule 40 steel pipe of the same nominal

diameter as the valve. The 3D model of butterfly valve was created using Creo 2.0 software with disc in full opened condition. The cross sectional view of butterfly valve with pipe extension on both the sides is shown in the figure 10(a).

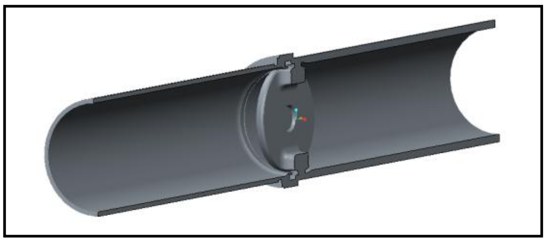

Figure 10(a) Cross sectional view of butterfly valve for flow simulation

Fluid medium used is water to flow across the valve. The material used is ductile iron conforming to ASTM A-536, grade 65-45-12. Material properties include Young's Modulus - 169 GPa, Poisons Ratio - 0.12, Density - 7.1 g/cm^3. Here the objective is to find the pressure loss across the valve with a pressure deviation from inlet to outlet. Inlet boundary condition - Velocity = 6.1 m/sec, Outlet boundary condition - Pressure = 0
From the analysis results the differential pressure between upstream and downstream δP across the valve is 15300 MPa or 2.21 psi as shown in figure 10(b).
Therefore flow coefficient of a newly developed butterfly valve design with disc in full opened condition is 1210. Since the pressure drop through the valve is less than 5psi it obeys the requirement as per FM guidelines.

Flow coefficient with different angles of disc opening was found in a similar way for both the benchmarked valve and newly developed butterfly valve. Figure 10(c) Graph represents the flow co efficient for different angles of disc opening of both benchmarked and newly developed valve.

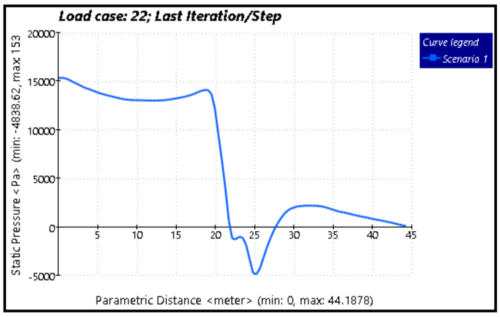

Figure 10(b) Differential pressure.

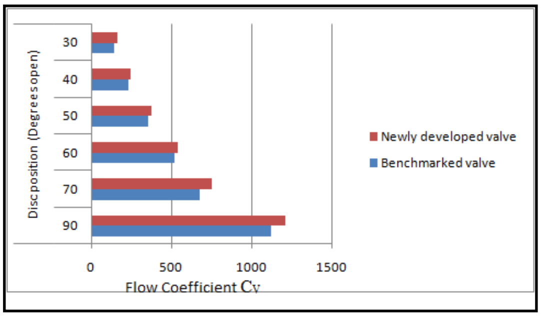

Figure 10(c) Flow co efficient at different angles of disc opening

VIII. CONCLUSION

A 6-inch grooved type offset disc butterfly valve was developed, with better flow characteristics and it can withstand 300 psi of pressure to adhere UL and FM guidelines. Various stresses acting on the valve body and disc due to a pressure of 300 psi was determined. Flow simulation was carried out to determine the pressure loss across the valve and flow co efficient at different angles of disc opening.

By implementing the above butterfly valve design the seat is made press fit into the body which eliminates the need of end face thereby number of parts have been reduced. From the analysis results the hoop stress acting on the valve body is 189 MPa and von mises stress acting on the valve disc is 38 MPa which is less than the yield stress of the material. Therefore the valve is safe under working condition. The pressure drop across the benchmarked valve is 2.6 psi where as the pressure drop across the developed valve is 2.2 psi with disc in full opened position which does not exceed 5 psi as stated by the FM guidelines.

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