

**Torque Optimization In Triple Offset Butterfly Valve**Pramod Gite<sup>1</sup>, Pramod Kalyani<sup>2</sup>, Nitin Jadhav<sup>3</sup>, Arun Bhosale<sup>4</sup><sup>1</sup> Mechanical Engg Department, Alard College of Engineering, Marunje, Pune<sup>2</sup> Kalson Engineering Solutions, Akurdi, Chinchwad, Pune<sup>3</sup> Mechanical Engg Department, Alard College of Engineering, Marunje, Pune<sup>4</sup> Sinhgad College Of Engineering, Kondhava, Pune

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**Abstract-** Butterfly valves are versatile components widely used in hydraulic systems as shutoff and throttling valves. Butterfly valve components must be able to withstand the forces and torques that are generated with use. These are commonly used as control valves in applications where the pressure drops required of the valves are relatively low. Butterfly valves can be used in applications as either shutoff valves or as throttling valves. As shutoff valves, butterfly valves offer excellent performance within the range of their pressure rating. Typical uses would include isolation of equipment, fill/drain systems, bypass systems and other like applications where the only criteria for control of the flow/pressure is that it be on or off. Although butterfly valves have only a limited ability to control pressure or flow, they have been widely used as control valves because of the economics involved. Butterfly valves allow high flows with relatively low pressure loss from the valves, and are typically used for flow control for valve openings from 30 to 70 degrees of full open. The objective of the work is to design and optimize torque of triple offset butterfly valve. It includes a plan to perform design calculation, modelling, and stress analysis on components worked out with the Finite element software. Additionally, experimental testing of valve with the help of suitable testing set up for validation of result.

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**Keyword-:** Butterfly Valve, Shaft dia., Disc weight, Torque Optimization, Stress Analysis.

**I. INTRODUCTION**

Selecting the proper valve for piping systems plays an important role in reducing the energy requirement and thus the operating cost. Various valves are used for on off control, modulation of the flow rate through the system, prevention of back flow and pressure relief as safety devices. One of the most widely used valves is butterfly valve. The primary aim of butterfly valve is to regulate the flow rate. The flow characteristics inside and downstream of the butterfly valves behave differently in different angle of valve disk and different inlet velocities.

The valves are machine structures consisting of the housing and the sealing parts which are movable linearly or rotationally, perpendicular to the direction of fluid flow. They are used to regulate or to prevent fluid flow. Besides that, the contact area between the housing and the packing ring is too small and it leads to poor contact and fluid leakage.

Numerous solutions are used nowadays to prevent leaking problem. The most common solution is to perform analysis and to improve the existing design. According to their function, the valves can be divided into: valves for regulation of flow or pressure, valves to block or redirect flow and the valves for load balancing. The valves can be made of carbon and alloyed steel, grey or alloyed cast iron and of other plastic or rubber materials. Butterfly housing has complex geometry with axial symmetry and they used to be manufactured by gravity casting. Gravity casting enables better surface quality and material properties and narrower tolerances than sand casting. This method is the best method for valve housing manufacturing.

A low torque quarter turn, rotary action valve with a straight through flow configuration in which the disk is turned in axial trunnion bearings. The disk is exposed to the flow in open position. Butterfly valves can be obtained with flanges weld ends or in wafer pattern, the latter being very economical of expensive material. Seating arrangement may be soft (use of body lining elastomer or polymer inserts etc.) or metal to metal.

Valve an actuator position stops should be set with care. Since butterfly valves are torque seated they are very sensitive to errors/variations in setting of actuator end stops, air supplies etc. if actuator stops are fully backed off, the maximum actuator output torque is applied at every closure.

Butterfly valves should not be specified in small sizes or for high pressures. The increasing instruction of the disc in the flow path as size reduces or pressure increases results in high pressure drop. Application requirements should be made clear when ordering since, although butterfly valves are generally suitable for bi-directional sealing, they always have a preferred sealing direction.

Butterfly valves have the following disadvantages:

- The line cannot be pigged.
- They create higher pressure drop than full bore gate or ball valves.
- They have to be withdrawn from the line for maintenance.

## **II. LITERATURE REVIEW**

Farid Vakili-Tahami [5] discussed about Analysis of the hydrodynamic torque effects on large size butterfly valves and comparing results with AWWA C504 standard recommendations. Piyush P. Nagpurkar [6] discussed about design and development of double offset butterfly valve. M. S. Kalsi [7] discussed about effect of butterfly valve disc shape variations on torque requirements for power plant applications. Sachin K. Pisal [8] discussed about testing and performance evaluation of butterfly valve. This paper presents testing of butterfly valve for change in across pressure. C. K. Kim [9] discussed about experimental study for flow characteristics and performance evaluation of butterfly valves. Xue guan Song [10] This paper describes about numerical analysis of butterfly valve-prediction of flow coefficient and hydrodynamic torque coefficient. Yogesh Gawas [11] discussed about modeling and simulation of valve coefficients and cavitation characteristics in a ball valve. Kenny Eon [12] discussed about performance of butterfly valves as a flow controller. Butterfly valves.

## **III. PROBLEM STATEMENT**

Kalson Engineering Solutions is design maker and developer of Butterfly valve , Ball valve and Actuators. In case of Butterfly valve series for specified range of valves, its design were made at earlier stage. Hence there was scope of optimization of butterfly valve parameters. Out of that range 14" #150 Lug Type valve is a common (mid range), so we have selected 14" size first for its design optimization. The proposed work involves taking all the parameters into consideration to design and optimize valve. It includes a plan to perform design calculation, modelling, and stress analysis on components worked out with the Finite element software. Additionally, experimental testing of valve with the help of suitable testing set up for validation of result.

## **IV. METHODOLOGY**

Butterfly valve components have been studied from geometry point of view and meshed with fine elements to capture all details and critical areas. Static analysis has been carried out in Solid edge ST7 simulate to determine the stresses and displacements. In this project, methodology followed is as follows:

1. Study the existing design of Butterfly valve.
2. Existing model is drawn in Solid edge ST7 CAD Software.
3. By using Solid edge ST7 simulation express software preprocessing is done which includes geometry corrections if any then followed by FEA, boundary conditions and loads follow the iterations for optimization of weight of Butterfly valve components.

## **V. OBJECTIVES**

The basic objective of this project work is to optimize torque of existing Butterfly valve. Along with this overall objectives of this project work are as follows:

1. Study and stress analysis of the existing Butterfly valve.
2. Modeling of the modified BFV components with Solid edge ST7
3. Stress analysis of the optimized BFV components using Solid edge ST7 simulate
4. Optimization of disc for achieving leakage class-VI (as per API 598)
5. Weight Reduction of Disc, Shaft and cone angle selection for torque optimization.
6. Optimisation of butterfly valve components (body, disc, shaft) for weight reduction.
7. Comparison of the results.

## **V. FINITE ELEMENT ANALYSIS**

### **5.1 Introduction**

Finite Element Analysis consists of obtaining the effect of actions on all or part of the structure in order to check the ultimate limit states. Structural analysis is the determination of the effects of loads on physical structures and their components. A structure refers to a body or system of connected parts used to support a load. It is common practice to use approximate solutions of differential equations as the basis for structural analysis. This is usually done using numerical approximation techniques. The most commonly used numerical approximation in structural analysis is the Finite Element Method.

The finite element method approximates a structure as an assembly of elements or components with various forms of connection between them. Thus, a continuous system such as a plate or shell is modeled as a discrete system with a finite number of elements interconnected at finite number of nodes. The behavior of individual elements is characterized by the element's stiffness or flexibility relation, which altogether leads to the system's stiffness or flexibility relation. Early applications of matrix methods were for articulated frameworks with truss, beam and column elements; later and more advanced matrix methods, referred to as "finite element analysis", model an entire structure with one-, two-, and three-dimensional elements. Commercial computer software for structural analysis typically uses matrix finite-element analysis, which can be further classified into two main approaches: the displacement or stiffness method and the force or flexibility method.

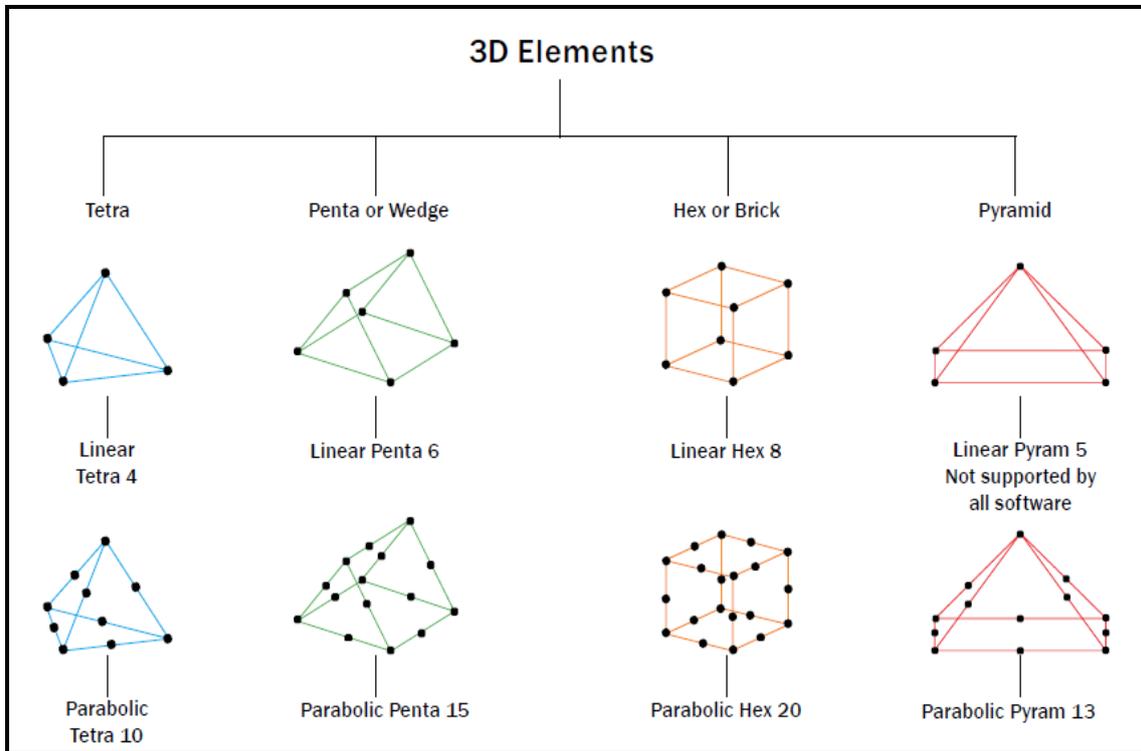


Fig. 3.1 Types of elements

Generally 3D elements are used when all dimensions are comparable. ( $x \sim y \sim z$ ) there are basically various types of element shape like tetra, penta, hex, pyramid shown in above fig. 3.1. All these element types comes under the group of solids whose practical applications are in Gear box, engine block, crankshaft, etc

### 5.2 Choice of mesh criteria

Basically for 2-D thin shell and 1-D beam element supports 6 dofs, but all solid elements have only 3 translational dofs (no rotational dof) i.e. a 10 noded tetra element has total of  $10 \times 3 = 30$  dofs. To understand choice mesh criteria let us consider a piece of paper (2-D geometry) or long steel scale (1-D geometry). It could be easily bent and twisted (rotational dof). But now consider a solid object like a duster or a paper weight. It could not be subjected to very high bending or torsion stiffness. Hence, solid elements have been formulated with 3 translational dofs and no rotational dofs.

### 5.3 Precautions during meshing

- 1) Mid nodes should lie exactly on the geometry
- 2) The element length and over all mesh pattern should be consistent
- 3) Minimum 2 elements on the fillets for tetra meshing
- 4) For brick meshing, a minimum of 2 elements across the thickness should be used
- 5) Modeling a sheet metal part with 3-D elements
- 6) Limitation of 1-D element and advantage of 3-D meshing

Hexa and Penta Elements(Brick mesh)

Hexahedral (hexa or brick) elements are solid elements which have been extracted from 2-D quad elements. Pentahedral (penta) elements are solid elements which have been extracted from 2-D triaelements. Their shapes are shown below:

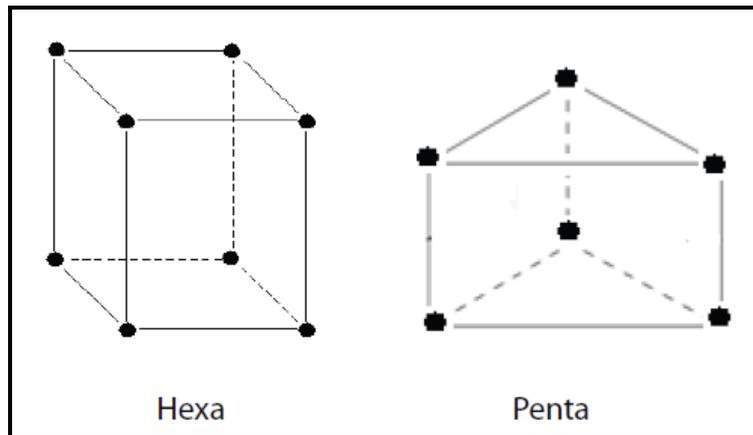


Fig. 3.2 Element types structure

As stated above, pentas and hexas can be created in the solid map panel. Below is a detailed description of this panel. Solid Map Meshing: In the Solid Map panel, solid elements are created. These solid elements can be created from solid geometry as well as from nodes, lines, and surfaces. In solid meshing, the ability to be meshed is referred to as mappability. Mappability is directional and can be likened to putting a surface mesh on one face of the solid, then extending that mesh along a vector through the solid volume. The Solid Map panel is used for solid-map meshing, and this panel includes several sub-panels. The general, line drag, linear solid, and ends only sub-panels all draw from the same set of input controls (the more specialized panels simply filter out the controls that do not apply to their mapping techniques). Note that all of these sub-panels depend on an existing 2-D mesh, which is then extrapolated into a 3-D mesh based on the parameters you input. The one volume and multisolids sub-panels, however, can automatically create 3-D mesh directly on solids as long as the solids you select are already mappable.

Solid map panel:

- General: Use the general sub-panel to access all of the possible entry controls for maximum flexibility.
- Line drag: Use the line drag sub-panel to select a 2-D mesh, and then select a line from the model geometry to use as the mapping direction.
- Linear solid: Use the linear solid sub-panel to select two existing 2-D meshes and extrapolate a 3-D mesh that connects them.
- Ends only: Use the ends only sub-panel to select two opposing surfaces and one 2-D mesh, then extrapolate the mesh between the surfaces
- One volume: Use the one volume sub-panel to select a single mappable solid volume and create a new 3-D mesh for it.

Multi solids: Use the multi solids sub-panel to select multiple mappable solids and create 3-D meshes for them.

## VI. BASELINE DESIGN CALCULATIONS

### 6.1 Analytical calculation:

Design of butterfly valve Body:

#### Summary of Wall Thickness of All Calculated Standards

Standard	Shell Thickness ( in mm )
	Body
ASME B 16.34 : 2009	10.20
ASME Section VIII, Div 1	3.77
BS EN 12516-1 : 2004	8.90
BS EN 12516-2 : 2005	6.01

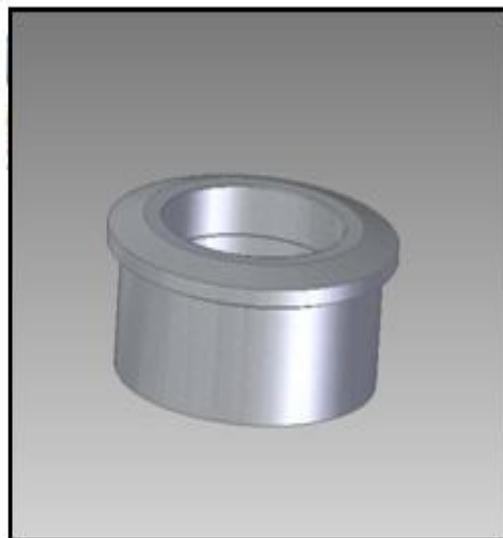
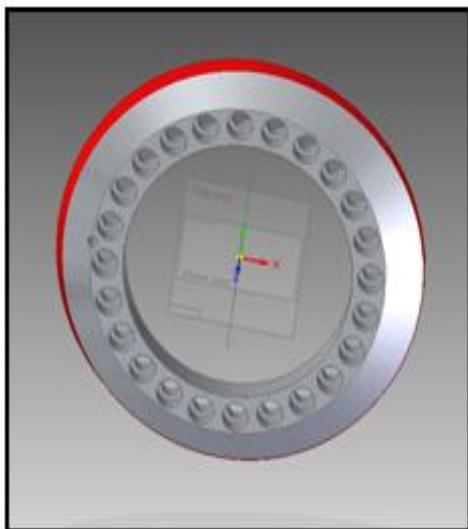


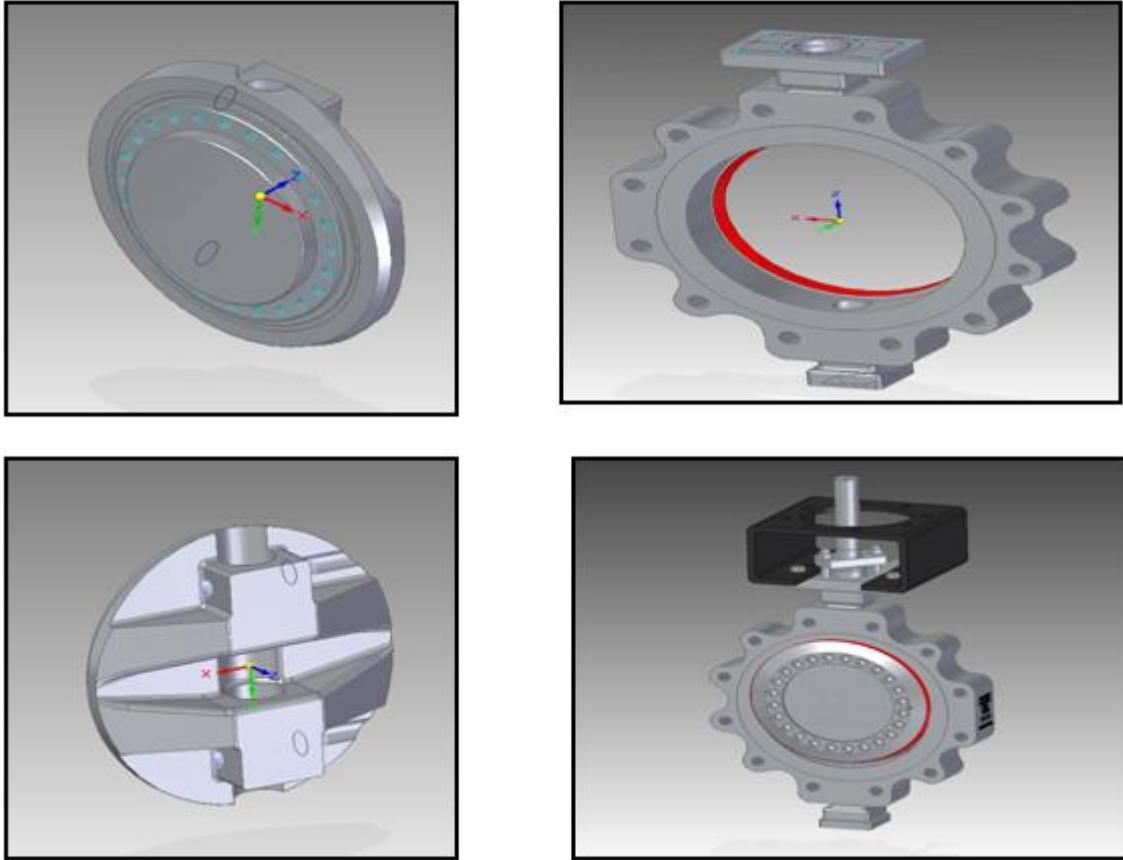
**Torque Calculations:**

		Input Data :		
Type	Size in (mm)	Class	End connection	
TOBV	DN350/14"	150	LUG	
Inputs				
1	Working pressure	P	2.0	Mpa
2	2nd Stem Offset from body centre	b	3	mm
3	Disc Dia.	L=D	330	mm
	Radius of disc	r	165	
4	Disc area of A1 side	A1	$(\pi r^2/2) + (bxD)$	43755.03 mm <sup>2</sup>
5	Disc area of A2 side	A2	$(\pi r^2/2) - (bxD)$	41775.03 mm <sup>2</sup>
6	Force acting on A1 side	F1	P x A1	87510.06 N
7	Force acting on A2 Side	F2	P x A2	83550.06 N
8	Unseating Torque	Tu	$F1\left(\frac{L+2b}{4}\right) - F2\left(\frac{L-2b}{4}\right)$	583 N-m
Bearing Torque				
9	Stem dia	ds	45	mm
10	Coefficient of friction	$\mu$	0.1	
11	Weight of disc & shaft	W	36.28	Kg
12	Bearing torque due to pressure & Wt.	Tb	$\frac{\mu \times ds}{2} \left( \left( \frac{\pi}{4} \right) D^2 \times P + W \right)$	385.7 N-m
Dynamic Torque				
13	Coefficient of dynamic torq	$\mu_d$	0.001	
14	Dynamic torque	Td	$\mu_d \times D^3 \times P$	71.874 N-m
Packing & Hub torque				
15	Packing & Hub torque	Tp	Negligible	23 N-m
Seating Torque				
16	Coefficient of seating torque	$\mu_s$	0.1	

17	Seating Torque	$T_s$	$\mu_s \times D^2$	10.89	N-m
Center of Gravity Torque					
18	Weight of disc	$W_c$		26.76	Kg
19	1st offset	$b_2$		46	mm
20	Angle opening	$\emptyset$		90	Deg
21	Center of gravity torque	$T_{cg}$	$W_c \times b_2 \times \sin \emptyset$	1.934	N-m
Total Torque					
22	Flow Stem side (UN SEATING TRQ.)	$T_{Sus}$	$(T_b + T_d + T_p + T_s + T_{cg}) + T_u$	1076.7	N-m
23	Flow Stem side (SEATING TRQ.)	$T_{Sse}$	$(T_b + T_d + T_p + T_s + T_{cg}) - T_u$	-89.9	N-m
24	Flow disc flat side (UN SEATING TRQ.)	$T_{Dus}$	$(T_b + T_d + T_p + T_s + T_{cg}) - T_u$	-89.9	N-m
25	Flow disc flat side (SEATING TRQ.)	$T_{Dse}$	$(T_b + T_d + T_p + T_s + T_{cg}) + T_u$	1076.7	N-m

## 6.2 Modelling of Butterfly Valve Components:





### 6.3 Valve Testing as per Standard:

There are six seat leakage classifications defined by ANSI/FCI 70-2-1976 (supersedes ANSI B16.104). The six valve leakage classifications are as follows:

Class I.

Identical to Class II, III, and IV in construction and design intent, but no actual shop test is made.

Class II.

Intended for double-port or balanced single-port valves with a metal piston ring seal and metal-to-metal seats. Air or water at 45 to 60 psig is the test fluid. Allowable leakage is 0.5% of the rated full open capacity.

Class III.

Intended for the same type of valves as in Class II. Allowable leakage is limited to 0.1% of rated valve capacity.

Class IV.

Intended for single-port and balanced single-port valves with extra-tight piston seals and metal-to-metal seats. Leakage rate is limited to 0.01% of rated valve capacity (known as metal to metal). Test fluid is air or water, pressure 45 and 50 psig or the operating pressure if lower.

Class V.

Intended for the same types of valves as Class IV. The test fluid is water at 100 psig or operating pressure. Leakage allowed is limited to  $5 \times 10^{-4}$  ml (= .0005ml) per minute per inch of orifice diameter per psi differential.

Class VI.

Intended for resilient-seating valves. The test fluid is air or nitrogen. Pressure is the lesser of 50 psig or operating pressure. The leakage limit depends on valve size and range from 0.15 to 11.5 ml per minute for valve sizes 1 through to 12 inches (known as soft seat classification). Class VI is also frequently used as a leakage bench mark for metal seated control and isolation valves where a tight degree of shut off is required.

## VII. OPTIMIZATION

### 7.1 Introduction:

Optimization is the act of obtaining the best result under given circumstances. The word 'optimum' is taken to mean 'maximum' or 'minimum' depending on the circumstances. In design, construction, and maintenance of any engineering system, engineers have to take many technological and managerial decisions at several stages. The ultimate goal of all such decisions is either to minimize the effort required or to maximize the desired benefit. Since the effort required or the

benefit desired in any practical situation can be expressed as a function of certain decision variables, so optimization can be defined as the process of finding the conditions that give the maximum or minimum value of a function. In mathematics, computer science and economics, optimization, or mathematical programming, refers to choosing the best element from some set of available alternatives.

**7.2 Importance of Optimization:**

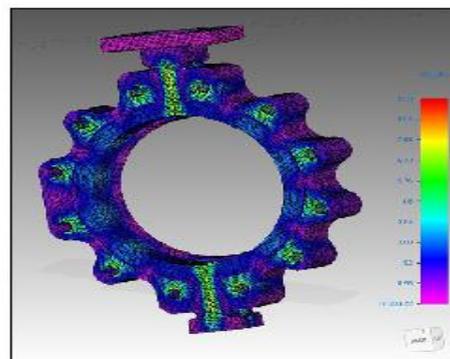
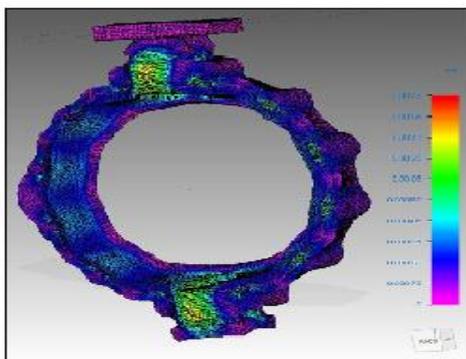
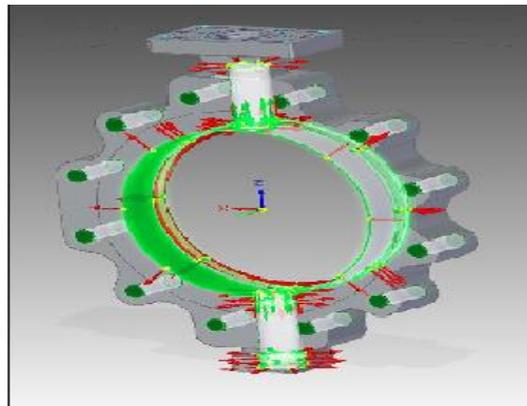
Typical engineering systems are described by very large numbers of variables, and it is the designer's task to specify appropriate values for these variables. Skilled designers utilize their knowledge, experience, and judgment to specify these variables and design effective engineering systems. Because of the size and complexity of the typical design task, however, even the most skilled designers are unable to take into account all of the variables simultaneously. Design optimization is the application of numerical algorithms and techniques to engineering systems to assist the designers in improving the system's performance, weight, reliability, and/or cost. Optimization methodologies can be applied during the product development stage to ensure that the finished design will have the high performance, high reliability, low weight, and/or low cost.

**7.3 Optimization of Butterfly Valve Parameters/Components:**

The stress analysis can be linear/elastic or nonlinear/plastic depending on the addressed failure mode and on the applied code rule. In this analysis, the scope is concerned with the calculation of Displacement and Von Mises Stress using FEA numerical solver. Finite element analysis was carried to evaluate the selected concept by using Solid edge ST7 simulate software. Static analysis was carried out on butterfly valve body, disc and shaft to determine the impact of different stresses acting on it. The material used is WCB, CF8M and 17-4PH. The material properties are Ultimate tensile strength - 482 MPa, Yield tensile strength - 310 MPa, Poisson's ratio - 0.12. Tetrahedron elemental mesh is used with tetra - 13758, edge - 22604 and face - 31710. The valve body is constrained in all the degrees of freedom as shown in figure. 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.

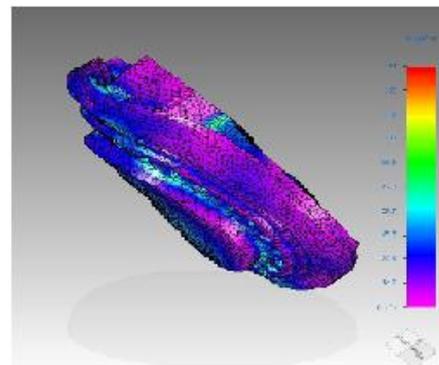
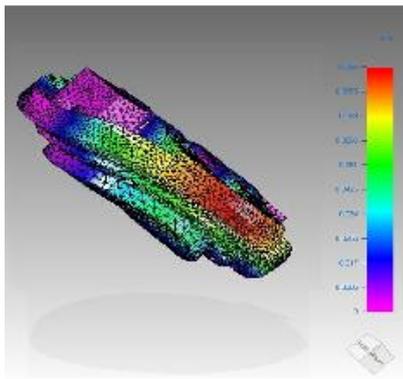
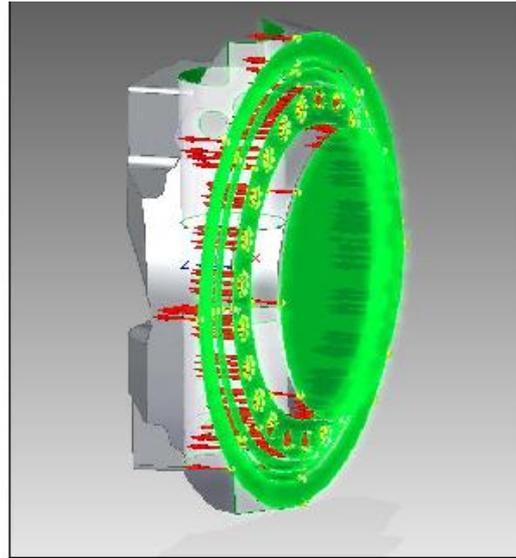
The parts are listed as given below,

- 1) Body :



Summary of Von Mises Stress and Displacement vector sum of Body		
Material	Maximum Von Mises Stress (MPa)	Maximum Displacement (mm)
WCB	9.59	0.00176

2) Disc:



**Summary of Von Mises Stress and Displacement vector sum of Disc – Trial 2**

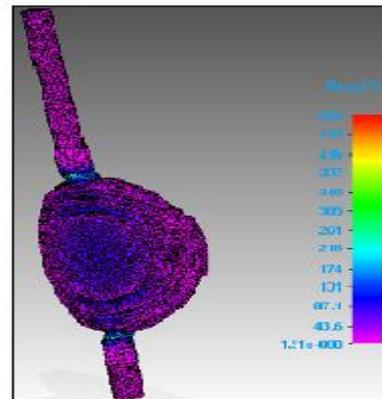
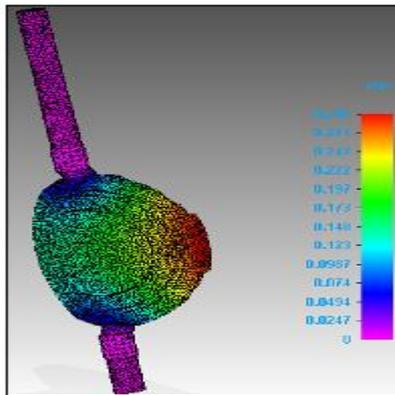
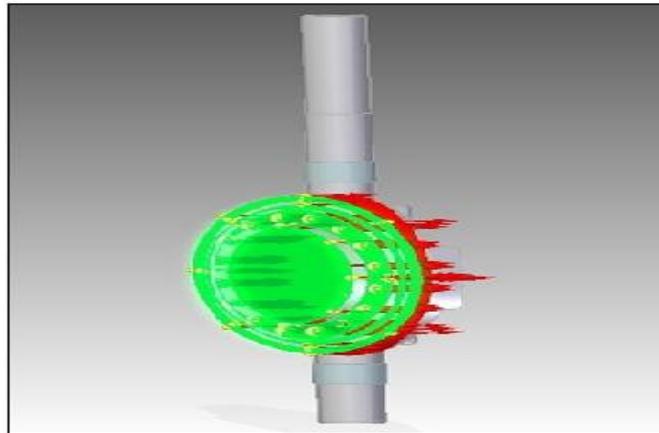
Material	Maximum Von Mises Stress (MPa)	Maximum Displacement (mm)	Maximum Weight
ASTM A351 Gr CF8M	144	0.085	26.8

We taken Tree trials. First trial is oversafe; Hence it is not accepted. Third trial is undersafe; Hence it is not accepted. Second trial is niether oversafe nor undersafe that is optemized; Hence it is accepted. The same disc is used for not only class-150 (line press -20 bar; testing press – 23.5 bar) but also class-300 (line press -51 bar; testing press – 61.5 bar) as it is able to sustain at pressure of this class also.

**Summary of three trials:**

Trial 1	Oversafe	Not Accepted
Trial 2	Optimized	Accepted
Trial 3	Undersafe	Not Accepted

3) Shaft:



Summary of Von Mises Stress and Displacement vector sum of Shaft		
Material	Maximum Von Mises Stress (MPa)	Maximum Displacement (mm)
17-4PH	523	0.296

**Comparison between existing and modified design:**

Sr No			Values of Existing Design	Values of Optimized Design	Reduction
1	Body	Weight in (Kg)	110	96	6
2	Disc	Weight in (Kg)	32	26.8	7
3	Shaft	Dia. (mm)	48	45	3
4	Valve	Torque (Nm)	1284	1076	208

**VIII. EXPERIMENTAL TESTING**

Experimental testing is carried out on Butterfly valve to validate results obtained through Numerical analysis using FEA software. In this case suitable testing set up for testing of 14” butterfly valve is arranged. Standard testing procedure to be followed for Torque testing , Leakage testing at different pressure conditions is given API-598 standard. Valve  
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validation and testing is carried as per standard to measure / observe the performance of valve at different conditions. Observed testing results is given below in tabulated form.

**8.1 Torque testing:**

Magnitude of torque required to open or close the valve under different pressure condition is identified during torque testing. Required torque to open or close the valve should be less than design torque. Torque wrenches use to measure the torque values.

Validation Testing Report					
Series / Size :	14" #150 Lug Type BFV				
MOC	WCB/CF8M/17-4PH/SS316+Graphite	Required Torque :1076 NM			
			Result		Remark
Sr No	Cycles	Torque Pressure Rating in Bar	Hydro Seat Test	Pneumatic Seat Test	
		20 Bar	22 Bar	6 Bar	Valve Both Side Testing OK
1	0	1050	OK	OK	
2	1000	1020	OK	OK	
3	2000	1000	OK	OK	
4	3000	900	OK	OK	
5	4000	890	OK	OK	



**8.2 Leakage testing:**

Butterfly valve leakage performance evaluation is found out in leakage testing.

- a) Hydro dynamic seat test ,
- b) Hydro dynamic shell test
- c) Pneumatic seat test is conducted in leakage testing.

In hydro seat test testing pressure is 1.1 times of design pressure. In hydro shell test, testing pressure is 1.5 times of design pressure. In pneumatic test for #150 butterfly valve is carried out at pressure 5-7 bar.



## IX. RESULT

Experimental testing performed on butterfly valve to validate the results obtained through Numerical analysis. Satisfactory results found after its performance testing. torque values are less and leakage rates are within limit with these new value of optimized design.

Sr No	Description	Body	Disc
1	Weight of existing design (kg)	110	32
2	Weight of optimised design (kg)	96	26.8
3	Reduction in weight (kg)	14	5.2
4	% Reduction in weight (kg)	12.7%	16.2%
5	Total weight reduction ( Body+Disc) (Kg)	13	
6	Reduction in Dia. of shaft (mm)	(48-45) = 3	
6	Torque of existing design (Nm)	1284	
7	Torque of optimized design (Nm)	1076	
8	Reduction in Torque (Nm)	208	
9	% Reduction in Torque (Nm)	16.2	

## **X. CONCLUSION**

Optimization of the complex shape constructions, of the butterfly valve can be successfully performed using CAE techniques. In this case, the valve body, shaft and disc was optimized by reduction of the weight and better design than previous one. New construction will requires less torque, higher leakage class (class VI) and more competitive at the market. In order to confirm these results, experimental testing is performed with these new values of torque and thickness. Experimental results found satisfactory.

We find that, the Von Mises Stress induced in the parts of Butterfly Valve because of applied pressure are less than the yield strength of the material. Hence we conclude that, Design of Butterfly Valve for chosen material is safe. % Reduction in Torque (Nm) for 14" Butterfly valve will be around 16.2. Similar methodology can be applied for other sizes as well depending on customer requirement and market demand.

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