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CONCEPTUAL DESIGN AND ANALYSIS OF HIGH PRESSURE BALL VALVE

Mahesh Kamkar[1],Prof.S.R.Basavaraddi[2]

[1]*M.Tech Student (Design Engineering), KLE Dr. M S Sheshgiri College of Engineering and Technology, Belagavi, Karnataka, India*

[2]*Associate Professor, Department of Mechanical Engineering, KLE Dr. M S Sheshgiri College of Engineering and Technology, Belagavi, Karnataka, India*

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Abstract - ***A valve is a mechanical device which regulates either the flow or pressure of the fluid. Among the different types of valves, high pressure ball valve finds use in certain application like industrial hydraulics and marine hydraulics. The present study involves designing the high pressure valve of nominal diameter 25mm (DN 25 and PN 350). When the flow line exceeds 150bar, the valves are known as high pressure valves. With the increasing the pressure, the design of various components of the valve become critical. The designing of high pressure ball valve components depends on pressure, temperature ratings and also other factors. The design calculation is done for sealing cup, ball, connection adaptor, valve housing and operating lever. The maximum stress and deflection is calculated for different sealing cup materials under high pressure. The torque required to operate the valve, which includes breaking torque, running torque and ending torque are calculated and compared with technical information from research case study.***

Key Words: *PTFE, Delrin-100, Acetal, High pressure ball valve, F.O.S, strength.*

1. INTRODUCTION

A valve is a mechanical device which regulates either the flow or the pressure of the fluid. Its function can be stopping or starting the flow, controlling flow rate, diverting flow, preventing back flow, controlling pressure, or relieving pressure[9].

Valves are mainly classified by following methods: Type of operation, The Nature and Physical condition of the flow, leakages and flow control types, operating method, functionality, etc. Most of the valves have two port, named inlet and outlet port. But for same applications there are multi-port configured valves. They can be three-way and four-way valves.

1.1. The Operative of the Valve Closure Member:

The kind of closure member movement defines both the geometry and operative of the valve.

- **Multi valve (linear motion valves):** The closure member has a linear displacement generally by turning its threaded stem several times. Valves: Diaphragm valve, Gate valve, Needle valve.
- **Quarter-turn valve (rotary valves):** The closure member as well its shaft turn 00 -900; from the fully-open position to the fully-closed position. Andquick opening/closure.
- **Valves:** Ball valve, Butterfly valve, Plug valve.

2.1Design Description:

The present study deals with the design of a high pressure ball valve. The designing of valve depends upon the pressure and temperature ratings and also other factors. The critical components are analyzed using the finite element analysis. Thus obtained engineering analyses are compared with the theoretical calculations. The pressure acting inside the valve will be calculated and analyzed using the ANSYS software.

2.2 Objective:

The high pressure ball valve will be designed for a working pressure of 350bars and a temperature range of 0 to 60 0C. The objectives of the project are listed as follows,

1. Customer specification and need for ball valve.
2. Designing of various components of the high pressure ball valve.
3. Modeling the components using SOLID WORKS2014.
4. Meshing the components using Hypermesh 9.0
5. Analyzing each components as follows -(ANSYS15.0)
   - Determining the compressive strength of the sealing cups for each material by applying compressive force on the sealing cups.
   - Torque required to operate the valve also calculated with considering the fluid factor and service factor. And comparison with the ISLIP FLOW CONTROLS Inc(IFC) technical information.
   - Then finding the frictional effect between ball and the sealing cups.
   - Determination of deflection occurred in the sealing cups.
   - Determination of maximum torque sustained by control spindle.

6. Comparing the finite element analysis result with theoretical calculations.

3. DEATALING DESIGN OF A HIGH PRESSURE VALVE

Design of high pressure valve will be mainly preceded based on the rating i.e, working pressure of the valve and operating temperature for particular applications. Based on theses aspects the material selection will be made and theoretical calculations will be done.

Product Description:

• Size: DN 25 PN 350

• Port: Full Bore Type

• Ends: SAE Flanged Ends

• Drill/Thrd: SAE Standards/BSP Threading

• Material Housing: Mild Steel and Trims-Stainless steel

• Inspection: Our QCD

• Additional requirement identified: -Ball - Chrome Plating Housing and Connection Adaptor - Zinc Plated Lever Type - Cranked lever with coating.

Based on the above data the following designing is been done.

3.1 Design of Ball:

Considering the nominal diameter and pressure ratings of the valve. Thus deciding the ball bore size and using Birnies equation outside diameter of the ball can be determined.

Design Pressure or Test Pressure = Nominal PressureX Factor of Safety

P = 350 x1.5 = 525 Bar

P= 52.5 N/mm^2

DN = 25mm.Which specifies the bore size of a valve and also the valve size.

Ball bore size d=25mm

Design Pressure P = 52.5 N/mm^2

Assuming Factor of Safety F. O.S =1.5

Ball Material - Stainless steel (SS304)

Yield Stress of material Yc= 205 N/mm^2.

To determine the outside diameter of the ball, assuming that it acts as a Thick Open cylinder.

Applying Birnies equation for thickness of open cylinders [8], we have, Thickness of cylinder,

$$t = \frac{d}{2} * \{\left[\frac{St+(1-\mu)P}{St-(1+\mu)}\right]^{\frac{1}{2}} - 1\}\text{-----}(1)$$

Where, d= Bore diameter of ball

St= Design stress
P= Test Pressure
μ= coefficient of Friction.
Stress St= (Ys /F.O.S)
St= 137.0 N/mm^2
Substituting all above values in eqs (1),

$$t = \frac{25}{2} * \{\left[\frac{137 + (1-0.3)52.5}{137-(1+0.3)52.5}\right]^{\frac{1}{2}} - 1\}$$

t= 7.34mm
Hence, t≈8.0 mm.
Thus outside Diameter, D= d + (2 x t) =41mm.

Hence the slot depth size is 5.5 mm and hence the diameter of the ball D≈ 42mm.
Table shows the calculated results for different components and material.

Table -1: Theoretical results for other components

Design	Pr bar	FOS	P*FOS N/mm^2	YsN/mm^2	Matl	t (mm)	D (mm)
Ball	P = 350	1.5	P= 52.5	Yc= 205	S.S (SS304)	8	42
Connection Adaptor	P = 350	2.0	P = 52.5	Yc= 250	Mild steel	9	45

3.4 Design of Sealing Cups:

Design of sealing cups will be based on the compressive strength of the material, which sustains the required pressure. With different materials are tested calculated and compared for selection in safe design.

Figure.4shows the cross sectional view of Sealing Cup.

• **Poly Tetra Fluoro Ethylene (PTFE):**

Compressive Strength of material Sc= 41.40 N/mm^2 [12]

Force acting on the Sealing cup,

F= P x A

A=490.94mm2

Thus,

Force, F= 25,775 N

Mean circumference of sealing cup,

b = π d

Here, d= mean diameter of sealing cup

Mean radius = (16.5+12.5)72 = 14.5 mm

Thus mean diameter d= 29.0mm

Therefore force, b= π x 29

b= 91.2 ≈92mm.

Arc Length, l= r x μ

Where r = 21mm referring Fig.3.3 & Fig.3.4.

Φ = ϕ2 – ϕ1

Φ =52-370=15^{o}= π/12

Arc length, l= 5.5mm.

Crushing Area can be calculated as, Ac=b x l

Ac=506mm2.

Crushing Strength or Compressive Strength on sealing Cups is given by,

$$\sigma c = \frac{F}{Ac}$$

σ c = 50.90N/mm2.

σ c ≈51.0N/mm2.

Factor of safety F.O.S = $\frac{Sc}{\sigma c}$

F.O.S = 0.8

Since the F.O.S = 0.8 for PTFE material, thus it cannot be used for high pressure valves.

3.5 Deflection in Sealing Cups:

Table -2: Deflection results of sealing materials

	deflectio n	Area (mm^2)	Thickness (mm)	E (N/mm^2)
PTFE	0.14 mm	921.20	7.0	1400
Delrin -100	0.08 mm	921.20	7.0	2480
Acetal	0.06 mm	921.20	7.0	3400

Table -3: Design results and acceptance of sealing cup materials

Sealing Cups	Sc= 41.40 N/mm2	2.5	PTFE	No
	Sc = 96.50 N/mm2	1.90	DELRIN - 100	No
	Sc= 124.10 N/mm2	2.50	Acetal	Yes

Table -4: Deflections of sealing cup

	deflectio n	Area (mm2)	Thickness (mm)	E (N/mm2)
PTFE	0.14 mm	921.20	7.0	1400
Delri n-100	0.08 mm	921.20	7.0	2480
Aceta l	0.06 mm	921.20	7.0	3400

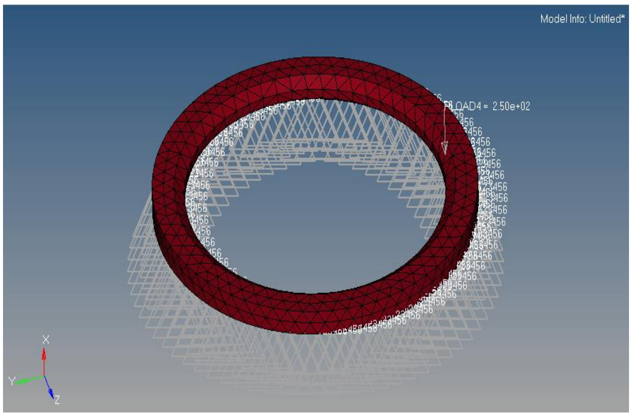

Figure.5 Constrained model of sealing cup-PTFE.

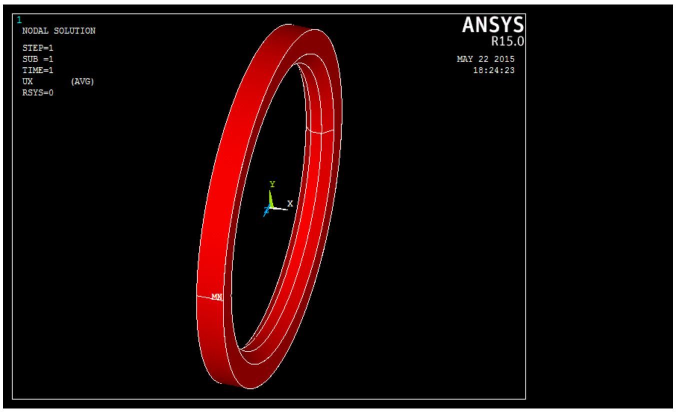

Figure.6 Stress Distribution in sealing cup-Delrin-100

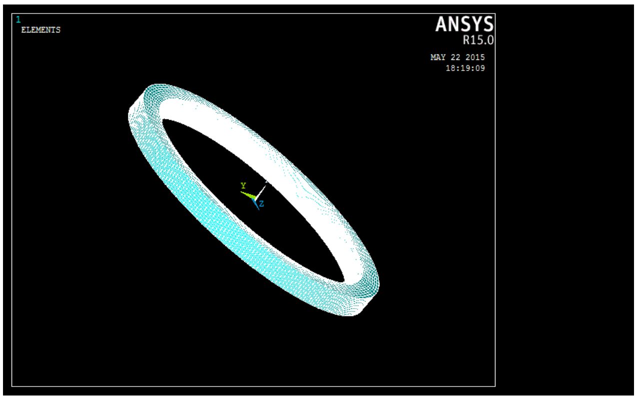

Figure.7 Deformed shape of sealing cup-PTFE

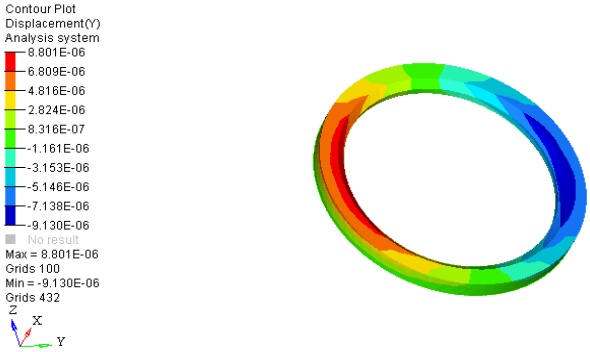

Figure.8 Deflection in the sealing cup-Acetal material

Table -5: Deformation results for different materials

Mtl	Theoretical Calculations			
	S_c in N/mm²	σ_c in N/mm²	F.O.S	δ in mm
PTFE	41.40	51.0	0.80	0.14
Delrin-100	96.50	51.0	1.90	0.08
Acetal (POM)	124.10	51.0	2.45	0.06
	Ansys Results			
	σ_c in N/mm²	F.O.S	δ in mm	
PTFE	55.0	0.75	0.293x1E-3	
Delrin-100	58.35	1.70	0.124x1E-3	
Acetal (POM)	58.35	2.20	0.113x1E-3	

4. CONCLUSIONS

The present study involves the design of high pressure ball valve to the requirements. The pressure and temperature involves in the designing are 525 bar and 60 ^{0}C respectively. The design is done for sealing cup, ball, connection adaptor, valve housing and operating lever. The following conclusion can be derived.

1.Design calculation for valve components like, ball,sealing cups, connection adaptor, valve housing ,operating lever etc. are done.

2.Sealing Cups of material Acetal (Poly Oxy Methylene) is able to sustain the test pressure of 525 bar under maximum working conditions compared to other sealing materials like Poly Tetra Fluoro Ethylene, Delrin-100 etc.

3.The minimum deflection in the sealing cup for material Acetal is 0.113 x 10-3mm as compare to other sealing cup materials.

4.The various torque for operation are as below, Operating torque-99 N-m Breaking torque-66 N-m Running torque-46 N-m and Ending torque-53N-m respectively.

5.The above calculated torque values are compared with Inc.Flow Controls technical information's.

6.Designed control spindle for high pressure valve is suitable for taking the operating torque.

7.Sealing Cups (Poly Tetra Fluoro Ethylene, Delrin-100, and Acetal) and control spindle are analyzed for test pressure of 525bar and operating torque of 99 N-m respectively using ANSYS software. Obtained ANSYS results are compared with theoretical calculations and are found nearer to calculated values.

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