

Design of M-Type Gate Valve

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Abstract: A pressure valve is the device that is used to channel high pressure fluid and to control the flow of the fluid through a pipe. The size of the valve varies according to the internal pressure. The use of pressure valve considered in the paper is during the extraction of petroleum. During the extraction of fluid from earth's crust, the flow is under high pressure and needs to be channeled. This channeling is done through a Christmas tree structure made up of number of pressure valves. Thus the requirement of the gate valves in petroleum industry is high thus the reduction of the thickness of the valve to an optimum thickness will reduce the weight and cost of the valve. This paper deals with the optimum thickness design required for the Gate valve for functioning smoothly under high pressure. The Gate valve considered in the paper for design is M-Type gate valve.

Keywords: Valve, M-Type Gate Valve, Pressure Vessel, Thickness, Stress

1. Introduction

In this modern world with the betterment of technology and with increase in our standard of living the one thing that always fears us is that we will run out of resources some time in future. So we always try to optimize the existing design and technologies by improving it. So we constantly strive to reduce the raw material usage in production or decreasing the size of the basic design by maintaining the productivity of the designed component intact.

Valves are used basically in every industry for various purposes. Thus an optimized design of a valve can reduce the weight of the component and also the cost of the valve. Thus the basic aim of this paper is to propose a design method that can be used to find the minimum required thickness for the functioning of a valve.

The M-Type gate valve design that is considered in this paper is a high pressure valve that is used under pressure of 5000 psi and tested under pressure of 7500 psi. And the cross section of the inlet and outlet of the gate valve is also according to the company standards. Thus the intent of the paper is to validate the design of M-Type gate valve and to calculate the optimum thickness of the valve to function under high pressure.

2. Basic Component Details

1. Valves

A Valve is that which either allows or prohibits the flow of hydraulic fluid by opening or partially obstructing various passage ways. Valves are found in every industrial process, including water and sewage processing, mining, power generation, processing of oil, gas and petroleum, food manufacturing, chemical and plastic manufacturing and many other fluids. The common types of valves are globe valve, gate valve, ball valve, plug valve, butterfly valve, diaphragm valve, check valve, pinch valve, and safety valve. Some valves are capable of throttling flow, other valve types can only stop flow, others work well in corrosive systems, and others handle high pressure fluids.

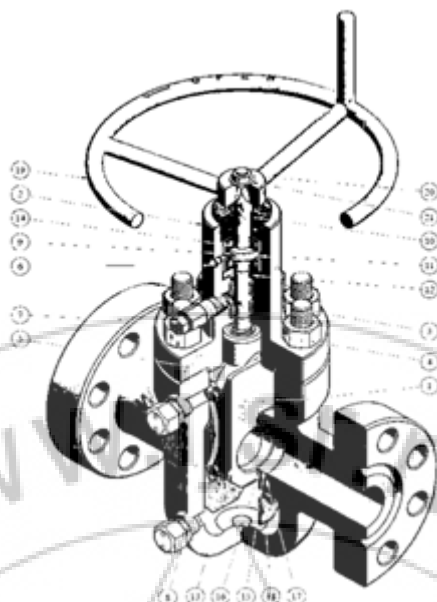
2. Gate Valves

A gate valve is a linear motion valve used to start or stop fluid flow however it does not regulate or throttle flow. The name gate is derived from the appearance of the disk in the flow stream. The gate valve consists of a plate like obstruction that is raised and lowered into place to control the flow of hydraulic fluid. The gate valve also known as a sluice valve, opens by lifting a round or rectangular gate/wedge out of the path of the fluid. The distinct feature of the gate valve is the sealing surfaces between the gate and the seats are planar, so gate valves are often used when a straight line flow of fluid and minimum restriction is desired. The gate faces can form a wedge shape or they can be parallel. Gate valves are primarily used to permit or prevent the flow of liquids and where it is important that pressure drop through the valve is minimal.

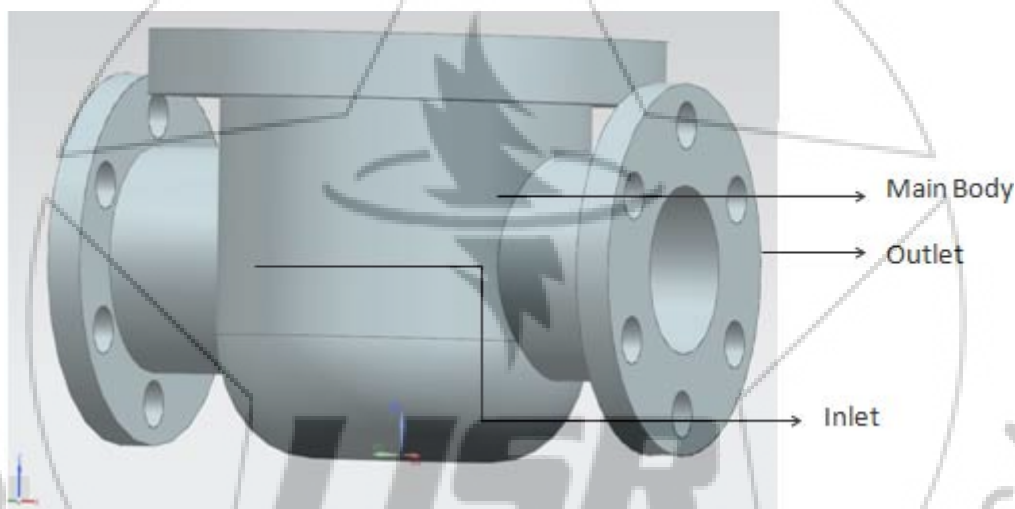
3. M-Type Gate Valve

The Model M series gate valve is a cast body line. The Model MEG is the Model M series of gate valves utilizing the expanding gate (hence EG). The expanding gate is a mechanical open and close wedge gate action, closing the gate against the seat on the upstream and downstream achieving a seal on both the upstream and downstream seat. This is advantageous when trying to accomplish a positive seal under low pressure and high pressure situations. This model is considered a directional valve since the segment (minor) side of the two pieces expanding wedge gate faces the upstream side and the gate (major) with the threaded neck and stem interface the downstream side.

1	Body, Flanged	12	Packing Retainer Bushing
2	Bonnet	13	Gate And Segment Assembly
3	Stud	14	Thrust Bearing
4	Hex Nut	15	Seat
5	Bonnet Seal Ring	16	Teflon Insert
6	Grease Alemite Filling	17	O-Ring, Back Seal
7	Packing Injection Fitting	18	Gate Guide
8	Body Grease Fitting	19	Hand Wheel
9	Stem	20	Hand Wheel Nut
10	Bearing Retainer Nut/Locknut	21	Hand Wheel Washer
11	Bearing Spacer Sleeve	22	Name Plate



M-Type Gate Valve Assembly



M-Type Gate valve Body

4. Pressure Vessel

Pressure vessels are the containers which are used for carrying fluid under pressure. Pressure vessels are designed to operate safely at a specific pressure and temperature technically referred to as the “Design Pressure” and “Design Temperature”. A pressure vessel that is inadequately designed to handle high pressure constitutes a very significant safety hazard. Pressure vessels with higher pressure than atmospheric pressure are called Unfired Pressure vessel. As our valve is operating under high pressure we use unfired pressure vessel.

Material used for pressure vessel must withstand high pressure, high temperature, high flow rates and sometime corrosive fluids. The severe operating condition intensifies the corrosion. Hence the selection of the material for pressure vessels is based on the required mechanical strength and anti-corrosive properties. Generally pressure vessels are of brittle material. Example: Cast iron, plain carbon steel, alloy steel, aluminum alloys, etc. for our valve we are using AISI 4130.

Pressure vessels are theoretically of almost any shape, but shapes made of sections of spheres, cylinders, and cones are

usually employed. A common design is a cylinder with end caps called heads. Head shapes are frequently either hemispherical or dished (torispherical). Depending upon the cylinder wall thickness is appreciable or not in relation to the inner diameter of the cylinder, cylinder can be classified into two categories

- I. Thin Cylinder.
- II. Thick Cylinder.

I. Thin Cylinder: If the ratio of inner diameter to its wall thickness is greater than 20, the cylinder is called as thin cylinder.

$$D_i/t > 20$$

II. Thick cylinder: If the ratio of inner diameter to its wall thickness is less than 20 then the cylinder is a thick cylinder.

$$D_i/t < 20$$

As per the specified measurement of M-type gate valve we found that the D_i/t ratio is less than 20 thus it is a thick cylinder. Hence while calculation we will use thick cylinder theory.

3. Design

The M-Type gate valve is a pressure vessel in itself. Observing from the design of the valve we can say that it comprises of one side closed cylinder in the middle and two both side open ended cylinder as inlets and outlets. So Design of M-Type gate valve is done here by using pressure vessel theory.

The basic information about the M-Type gate valve that is currently used in various industries is,

- Material: AISI 4130 Low Alloy Steel.
- Material Properties:
 - a) Tensile strength(S_{ut}) : 655Mpa
 - b) Yield strength(S_{yt}) : 517Mpa
 - c) Modulus of Elasticity (E) : 205×10^3 MPa
 - d) Poisson's ratio (μ) : 0.29
- Actual internal pressure : 5000 PSI (i.e.34.4735 MPa)
- Test Internal Pressure (Pi) : 7500PSI (i.e.51. 71025 MPa)
- M-Type gate valve is considered as a thick valve with,
 - i. Inner Diameter
 $D_i = 15.0114$ cm
 - ii. The inlet/s / outlet's inner diameter of the valve is,
 $d_i = 7.0248$ cm.
- For design safety purpose a factor of safety is considered to be 2. Thus the allowable stress is calculated by,
 $\sigma = S_{yt} / FOS$
 $\sigma = 517/2$
Thus $\sigma = 258.5$ MPa

- For determining the thickness of the cylinder the Clavarind's Equation is used.
i.e.

$$t = \frac{D_i}{2} \left[\frac{\sigma + (1 - 2\mu) P_i}{\sigma + (1 + \mu) P_i} - 1 \right]$$

$$t = \frac{15.0114}{2} \left[\frac{258.5 + (1 - 2 \times 0.29) \times 51.71025}{258.5 - (1 + 0.29) \times 51.71025} - 1 \right]$$

Thus $t = 1.5667$ cm

- Therefore the outer diameter of the valve will be
 $D_o = D_i + 2 \times t$
 $D_o = 15.0114 + 2 \times 1.5667$
 $= 18.1448$ cm
- Considering the inlet and outlet of M-Type Gate Valve as nozzles of Cylinder thus we use area compensation method for designing the inlet and outlet.
- The total width of the valve remains constant while the value of H1 and H2 can be calculated directly from the given design.
Thus $H_1 = 9.012428$ cm
 $H_2 = 3.7211$ cm
- The inner diameter of both the inlet and outlet from the actual design, $d_i = 7.9248$ cm
- The minimum required thickness of the cylinder for area compensation method is

$$t_{rs} = \frac{P_i \times D_i}{(2 \times \sigma \times \eta - P_i)}$$

$$t_{rs} = \frac{51.71025 \times 15.0114}{(2 \times 258.5 \times 0.85 - 51.71025)}$$

$$t_{rs} = 2.001969 \text{ cm}$$

- The value of minimum required thickness of the cylinder according to this is 2.001969 cm which is more than 1.5667 cm as earlier thus the thickness of the valve should be greater than 2.001969cm. The minimum thickness of nozzle will be

$$t_{rs} = \frac{P_i \times d_i}{(2 \times \sigma \times \eta - P_i)}$$

$$t_{rs} = \frac{51.71025 \times 7.9248}{(2 \times 258.5 \times 0.85 - 51.71025)}$$

$$t_{rs} = 1.0568 \text{ cm}$$

- Some corrosion allowance is added to the inner side of the valve so as to compensate for the losses due to corrosion thus $CA = 1.5$ mm.
- The area of opening in corroded condition for which compensation is required
 $A_r = d_{i_o} \times t_{rs}$
Thus $A_r = (7.9248 + 2 \times 0.15) \times 2.001969$
 $= 16.4658 \text{ cm}^2$

Area available for compensation:

1. The area of excess thickness in the portion of vessel shell is
 $A_1 = d_{ic} (t_s - t_{rs} - CA)$
Thus the thickness of the valve should be such that the area of excess thickness should be positive thus the thickness of the valve will be considered as
 $t_s = 2.2$ cm
Thus $A_1 = 8.2248 \times (2.2 - 2.001969 - 0.15)$
 $= 0.395 \text{ cm}^2$
2. The area of excess thickness in portion of the inlet / outlet wall outside the valve is,
 $A_2 = 2 \times H_1 (t_n - t_{rs} - CA)$
The value of t_n i.e thickness of the inlet / outlet wall of the valve should be such that the value of A_2 should be positive. Thus the value of t_n should be greater than the minimum required thickness of the inlet / outlet wall. Thus consider the value of $t_n = 2.5$ cm, this will give value of A_2 positive.
 $A_2 = 2 \times 9.012428 \times (2.5 - 1.0568 - 0.15)$
 $= 23.3097 \text{ cm}^2$
3. The area of excess thickness is portion of inlet / outlet wall inside the valve is,
 $A_3 = 2 \times H_2 (t_n - 2 \times CA)$
 $A_3 = 2 \times 3.7211 \times (2.5 - 2 \times 0.15)$
 $= 16.37 \text{ cm}^2$

4. The total area available for compensation is,

$$A_a = A_1 + A_2 + A_3$$

$$A_a = 0.395 + 23.3097 + 16.37$$

$$A_a = 40.0747 \text{ cm}^2$$

Thus the value of A_a is greater than A_r

Thus the outer diameter of inlet / outlet is

$$D_o = D_i + 2 \cdot t_n$$

$$= 15.0114 + 2 \cdot 2.5$$

$$= 20.0114 \text{ cm}$$

Stress Calculations:

• Stress on the inner surface of the valve:

1. Radial Stress;

$$\sigma_r = -P_i$$

$$\sigma_r = -51.71025 \text{ MPa}$$

• Circumferential Stresses:

$$\sigma_t = \frac{P_i(D_o^2 + D_i^2)}{(D_o^2 - D_i^2)}$$

$$\sigma_t = \frac{51.71025(20.0114^2 + 15.0114^2)}{(20.0114^2 - 15.0114^2)}$$

$$\sigma_t = 184.7949 \text{ MPa}$$

• Stress on the outer surface of the valve:

1. Radial stresses:

$$\sigma_r = 0 \text{ MPa}$$

2. Circumferential stresses:

$$\sigma_t = \frac{2 \cdot P_i \cdot D_i^2}{(D_o^2 - D_i^2)}$$

$$\sigma_t = \frac{2 \cdot 51.71025 \cdot 15.0114^2}{(20.0114^2 - 15.0114^2)}$$

$$\sigma_t = 60.4626 \text{ MPa}$$

• Axial stresses in the valve:

$$\sigma_t = \frac{P_i \cdot D_i^2}{(D_o^2 - D_i^2)}$$

$$\sigma_t = \frac{51.71025 \cdot 15.0114^2}{(20.0114^2 - 15.0114^2)}$$

$$\sigma_t = 66.54 \text{ MPa}$$

Thus from the stress calculations we can say that $\sigma = 258$ MPa (allowable stress) is more than all the stresses acting on the inner and outer surface of the valve.

4. Conclusion

- From the above process we can see that the design dimension (thickness) of the gate valve is within the safe limits.

- The thickness of the gate valve from calculations is less than the actual design in use. Thus the weight and material requirements is reduced.
- The paper shows a design process for M-Type gate valve but this process can be generalized and used for different gate valves also.

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Author Profile

Shashank S. Jadhav has recently completed his Bachelors of Engineering in Mechanical Engineering from Sinhadgad college of Engineering (affiliated to Pune University) with distinction.