Conceptual Structure Design Through Thickness Optimization Of High Pressure And High Temperature Self Regulated Pressure Valve Using Non-Linear Transient Finite Element Method

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Abstract

The primary purpose of a flow control valve is protection of life and property by venting fluid from an over pressurized vessel. Proper sizing, selection, manufacture, assembly, test, installation and maintenance of a flow control valve are all critical to obtaining maximum protection. A flow control valve is a safety device designed to protect a pressurized vessel or system during an overpressure event. An overpressure event refers to any condition which would cause pressure in a vessel or system to increase beyond the specified design pressure or maximum allowable working pressure (MAWP). Since flow control valves are safety devices, there are many Codes and Standards written to control their design and application. Many electronic, pneumatic and hydraulic systems exist today to control fluid system variables, such as pressure, temperature and flow. Each of these systems requires a power source of some type, such as electricity or compressed air in order to operate. A flow control valve must be capable of operating at all times, especially during a period of power failure when system controls are nonfunctional. The sole source of power for the flow control valve, therefore, is the process fluid. Once a condition occurs that causes the pressure in a system or vessel to increase to a dangerous level, the flow control valve may be the only device remaining to prevent a catastrophic failure. Since reliability is directly related to the complexity of the device, it is important that the design of the flow control valve be as simple as possible. In most of the studies, the gradually flow reducer valve has been focused mainly for high pressure and temperature application such as fertilizer industries, process industries, boilers etc. and utilization of these valves for given applications. However, a very few studies have been carried out and reported in literature, which address the effect of severity of high pressure and high temperature on the failure of this valve and components. This valve is having great advantages over all remaining valve types. It is possible to design a self regulated valve named gradually flow reducer valve.

In this paper the optimization of thickness of valve plate, material selection, design of various components of valve and analysis of gradual flow reducing valves for both axial and bending has been discussed.

Keywords – *Design of components, Gradual flow reducer valve, Thickness optimization.*

1. Introduction

AOMI has developed effective valves to control flow in pressure operations as the one illustrated in the fig.1.

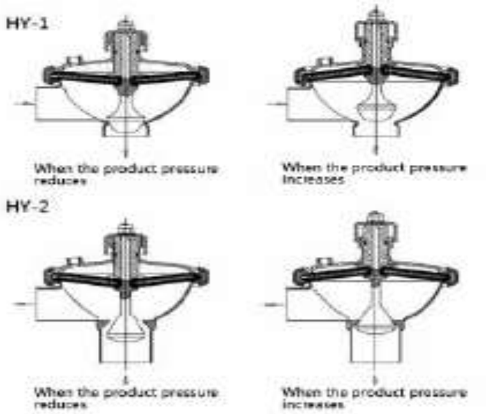


Fig.1 Flow control valve operation

However currently the valves are design for smaller applications. Its usage for large scale applications is being explored. With the development of self-regulated bi- metallic valve [1] the next focus has been to develop a pressure valve which is equally robust. The main idea remains same, safety of the system, and prevention of vessel bursting due to pressure overload. Traditional safety valves work on the outlet side, wherein if a particular pressure is reached the valves burst open resulting in a pressure relief and prevention of bursting. However if the gas is toxic, release should be the last option. The idea is then to regulate inflow into the vessel, once a critical pressure is reached. This valve will be an additional fail safe, in case the electronics fail.

2. Problem statement

"Gradual flow reducer valve" has been selected for design approach. In gradual flow reducer valve, the obstructer will have a combined load of bending due to the flow, plus the load of the springs and pressure. This will be a transient phenomenon and will need careful FEA for determining life of the valve determining life of the valve. Valve is used for such high pressure and high temperature applications.

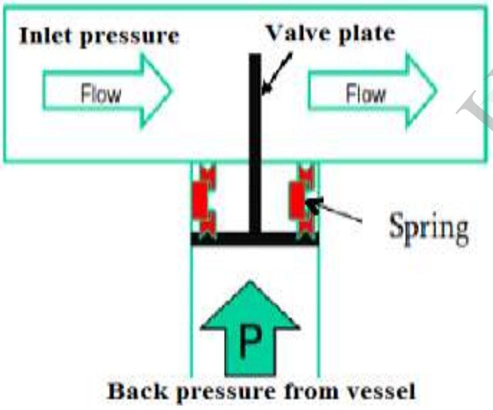


Fig. 2 Vital Aspect of Design

In this valve, a spring loaded obstruction will be used (Fig. 2). It will be so calibrated that it will connected to that it will connected to the vessel where pressure is to be regulated. The pressure P, inside the vessel will push the obstruction against the spring load.

3. Valve design

Outlier objective is to finalize dimensionality for pressure vessel valve, multiple objectives include, material finalization, thickness requirement, and stiffness finalization, Demonstration of feasibility of feedback loop (Pipe) and execution of loop (Pipe), and the characteristics of the loop.

Input data

The available data on field is provided by the client. Depending upon these data design of valve has to be made. Inlet loop has been finalized as per the detail dimensions given in following table no.1 and Feedback loop has been finalized as per the detail dimensions given in following table no.2.

Table 1 Design Inputs of Inlet Loop (Pipe)

Sr. No.	Description	Value	Unit
1	Inlet Radius	20 mm	mm
2	Inlet Pressure	Max 0.32	MPa
3	Inlet error	N.A	-
4	Inlet sensitivity	± 0.01	MPa
5	Operational Temperatures	70 - 350	°C

Table 2 Design Inputs of Feedback Loop (Pipe)

Sr. No.	Description	Value	Unit
1	Feedback inlet Radius	15	mm
2	Feedback Pressure	Max 0.32	MPa
3	Feedback error	less than 3%	-
4	Feedback Sensitivity	± 0.01	MPa
5	Operational Temperatures	70 - 350	°C

Valve Components and their design

For fitting the valve for the pressure vessel in the inlet pipe, different components of the valve are designed for dimension. The names of the component are as follows.

a) Valve plate
b) Spring
c) Valve casing
d) Inlet and feedback pipe
e) Flanges

The valve plate and spring dimensions for the accurate fitting of valve with given input data as shown in fig. 3.

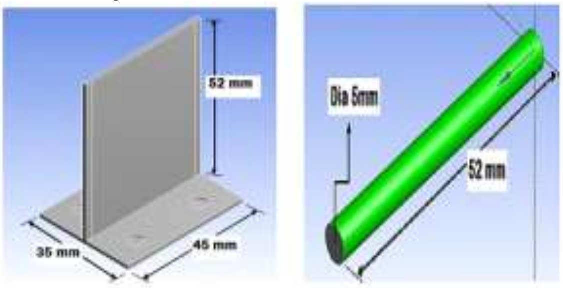


Fig. 3 Vital Aspect of Design

The inlet pipe and feedback design are provided by the client. The radius of inlet pipe is 20 mm and the feedback pipe radius is 15 mm. the details of the pipe and flanges are as shown in fig. 5.

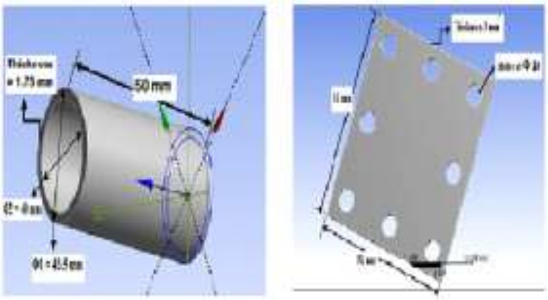


Fig. 4 Vital Aspect of Design

Casing is designed in such way that there is a full closing of valve along with the required opening and closing operations of the valve without any leakage. Casing is shown in full model of valve fig. 4.

After designing all the components, the gradual flow reducer valve gets assembled. The assembly of the gradual flow reducer valve is shown in fig 5.

Construction of gradual flow reducer valve

Valve plate is placed at the centre as shown in fig 5. The casing is made around the valve plate so as to there is no any leakage of valve during operation and also it allows the up and down motion of the valve plate along with compression and expansion of the springs. Inlet pipes are connected at the top to the casing. Feedback pipe is connected to the lower flange. Upper flange is connected to the casing. The two flanges are connected with each other with help of nuts and bolts in provided holes.

Working of gradual flow reducer valve

Initially the fluid with a pressure about 0.32 MPa is coming from the inlet loop (pipe) and straightly going into the pressure vessel or tank. As the pressure vessel is filling with the fluid with the same pressure as like inlet loop (0.32MPa) is start to push the valve plate in upward direction against the four springs, the fluid is pushing the plate in upward direction there is axial load on the valve plate. Since valve plate is coming up the bending load due to fluid pressure in inlet loop acting on a plate.

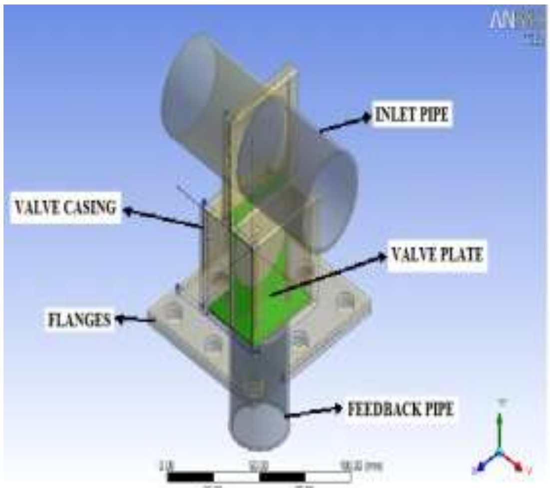


Fig. 5 Assembled full model of gradual flow reducer valve

Table 3 Dimensions of valve components

Sr. No.	Component name	Quantity	Final Dimensions
1	Valve plate	-	-
	Vertical valve plate	01	45 mm X 52 mm X 2 mm
	Horizontal valve plate	01	35 mm X 45 mm X 2 mm
2	Pipe	-	-
	Inlet pipe	02	R=20 mm, L=50 mm, t=3mm
	Feedback pipe	01	R=15 mm, L=50 mm, t=3mm
3	Valve casing	01	As per valve plate
4	Springs	04	Φ=5 mm, L=55 mm
5	Flanges	02	81 mm X 91 mm X 3 mm

Table 4 List Materials used

Sr. No.	Component name	Material used
1	Valve plate	Titanium
2	Pipe	Structural steel
3	Valve casing	Structural steel
4	Springs	Structural steel
5	Flanges	Structural steel

Material properties

Usually material in flow control valve is titanium. Titanium is used in process equipment (heat exchangers, tanks, process vessels, valves) also titanium used in the chemical and petrochemical industries primarily for corrosion resistance.

Titanium metal is used in automotive applications, particularly in automobile or motorcycle racing, where weight reduction is critical while maintaining high strength and rigidity. The metal is generally too expensive to make it marketable to the general consumer market, other than high-end products, particularly for the racing/performance market. Late model Corvettes have been available with titanium exhausts. Titanium is used in many sporting goods, tennis rackets, golf clubs, lacrosse stick shafts, cricket, hockey, lacrosse, and football helmet grills and bicycle frames and components. Although not a mainstream material for bicycle production, titanium bikes have been used by race teams and adventure cyclists. Titanium alloys are also used in spectacle frames. This results in a rather expensive, but highly durable and long lasting frame which is light in weight and causes no skin allergies. Many backpackers use titanium equipment, including cookware, eating utensils, lanterns, and tent stakes. Though slightly more expensive than traditional steel or aluminum alternatives, these titanium products can be significantly lighter without compromising strength. Because of its superior strength and light weight when compared to other metals traditionally used in flow control valves (steel, stainless steel, and aluminum), and advances in metalworking techniques, the use of titanium has become more widespread in the manufacture of flow control valves. For the valve casing, pipes and flanges structural steel is used.

Table 5 Materials Properties

Material	Density (Kg/m^3)	Tensile yield strength (MPa)	Compressive yield strength (MPa)	Tensile ultimate strength (MPa)
Structural steel	7850	250	250	460
Titanium	4620	9330	930	10700

Nominal Composition of titanium alloy used

The nominal composition of the titanium alloy which is used for the valve plate is given in following table 6.

Table 6 Dimensions of valve components

C	Fe	H	N	O	Al	Nb	Ta	Ti
0.08	0.5	0.15	0.05	0.4	6.0	7.0	0.5	Rem

4. Analysis approach

The complex dynamic plate, jacket and pipe stresses created during fluid flow under 0.32 MPa pressure are not well understood, even though the fluid flow under 0.32 MPa pressure transients causing the stresses may be approximated using various techniques, as discussed by Wiley and Streeter [23]. The dynamic stresses are investigated herein using finite element techniques.

The designed valve is analyzed by using ANSYS 12 Tool. While doing analysis firstly the thickness of the valve plate is finalized by varying the thickness in each analysis. After these analyses the optimum thickness gets finalized. The details of these analyses are as follows.

Model Geometry

Model of the selected valve was done using ANSYS Workbench V12 the details of which are as,

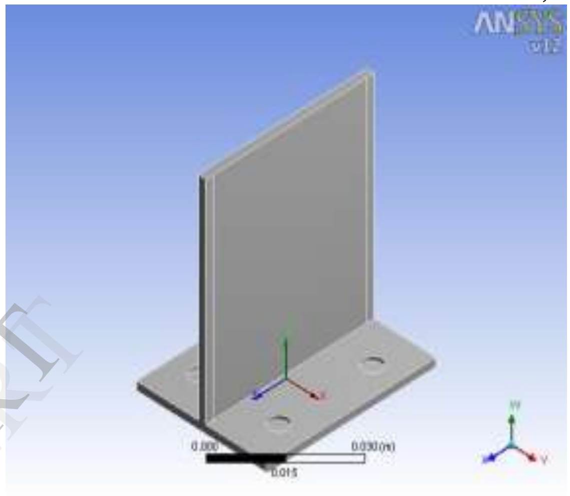
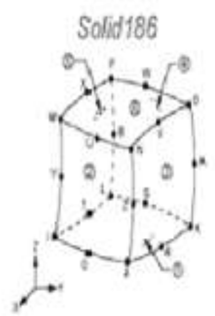


Fig. 6 plate geometry

FEA Element selection and meshing

For this non linear transient stress analysis, the body elements used in Workbench is SOLID186, a three dimensional (3D) 20-node hexahedral structural element. This type of elements promise a well-shaped mesh on even the most complicated geometries.



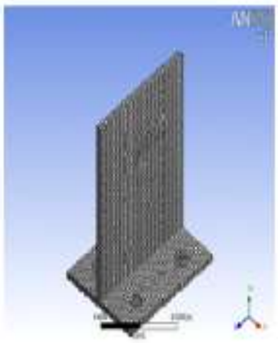


Fig. 7 Element and Meshing

Boundary Conditions

For all the analyses valve spring seat and contact area with casing is kept fixed, which is the first boundary condition for all analyses. Second boundary condition it that to apply the load in X-direction on vertical plate of 0.32 MPa. The mesh size is kept default for all configurations. Here six different thicknesses configurations of the valve plate have analyzed and stress and deformation of these six different thickness configurations are compared. Depending upon the values of stress and strain the optimum thickness gets finalized.

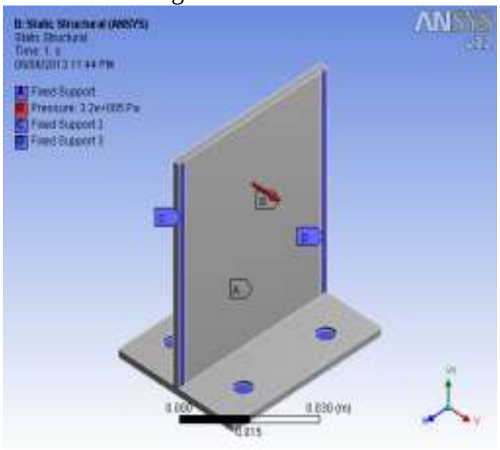


Fig. 8 Boundary conditions

Finite Analysis Results

Six different thicknesses configurations of the valve plate have analyzed and stress and deformation of these six different thickness configurations are tabulated in following table 7.

Table 6 Finite Analysis Results for thickness optimization

Analysis type & thickness of plate	Volume (m^3) 10^-6	Mass (Kg) 10^-2	Nodes	Elements	Total deformation (mm)	Eq. Stress (MPa)
0.5 mm	1.9379	0.79452	33720	6560	0.91308	240.08
1 mm	5.8136	2.3836	48253	9977	0.095237	29.858
1.5 mm	5.8136	2.3836	48253	9977	0.095237	111.1
2 mm	7.7515	3.1781	49165	10358	0.0436	66.433
2.5 mm	9.6893	7.6061	52597	11253	0.02485	15.437
3 mm	11.627	14.7671	64698	14046	0.016132	13.048

From above result table it is finalized that thickness of valve has to be kept 2mm, because at 2mm thickness we are getting considerable stress and deformation also we are achieving optimum weight and volume. Out of these six analysis the here results of only one case (0.5 mm plate thickness) has been shown below fig 8.

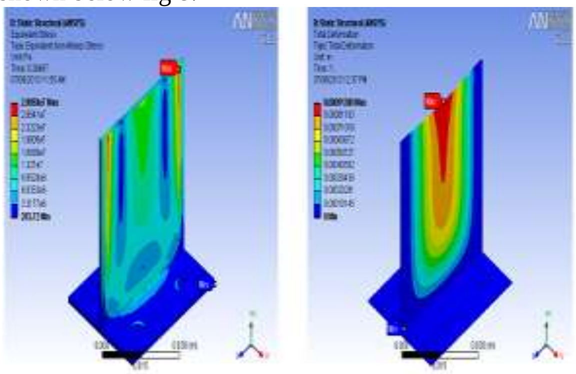


Fig. 9 Stress and deformation for 0.5 mm thick plate

Full model analysis

After optimizing the valve thickness the further analysis has been done for the full geometry of the valve. The full model of the valve with all the components has taken from fig. 5.

Following table 7 is the results table for different analysis done in ANSYS 12.

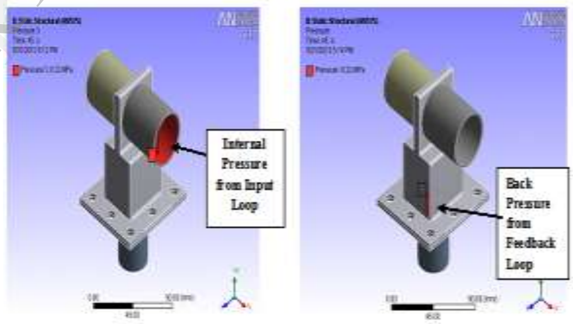


Fig. 10 Boundary Conditions for full model

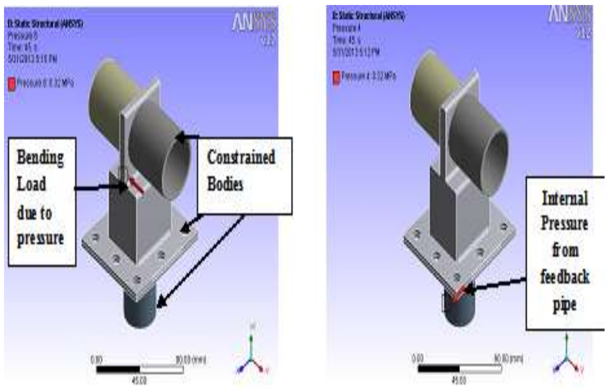


Fig. 11 Boundary Conditions for full model

Table 6 Finite Analysis Results for full model

Analysis type	Equivalent stress (…..x 10^7Pa)	Total Deformation (m)	Nodes	Mass (Kg)
Plate in bending	0.66433	4.36 x 10^{-5}	49165	3.1781 x 10^{-2}
Plate in axial loads	3.8726	0.04172	14976	3.1781 x 10^{-2}
Combined bending & axial load	4.7947	0.039444	14937	3.1781 x 10^{-2}
Jacket stresses	2.6989	1.2851x10^{-4}	104276	0.15885
Valve with pipe	5.0514	0.042066	154075	0.80513
Non linear Transient Analysis	6.25	0.042096	156095	0.80513

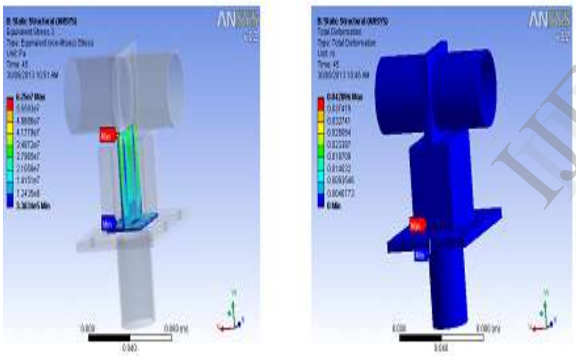


Fig. 12 Stress and Deformation in plate for Non linear Transient Analysis

5. Conclusion

A fresh self regulated pressure valve fully mechanically operated on/off valve designed for control of hydraulic flow has been offered. The design of this "gradual floe reducer valve" has been designed with available data on field. The thickness optimization of this gradual flow reducer valve has been done by using finite element analysis. The optimum thickness of the valve is finalized as 2mm. After finalizing the optimum design, same design has been taken for the further analysis. All further analysis has done for analyzing stress levels and maximum deformation. A prototype valve based on the proposed design has simultaneously achieved high flow, low full open pressure drop (0.32 MPa), and no extra actuation power system. A basic model of the valve suitable for design purposes and optimization has been developed. Proper design can improve efficiency. Future work will focus on certify the design with experimental results.

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