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DESIGN AND ANALYSIS OF DISC PLATE IN HOT BLAST VALVE#DN1800

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ABSTRACT: *Valve is a mechanical component that regulates the flow of fluids by opening, closing or partially obstructing various passage ways. Gate valve is one of the type of flow control valve, which controls the flow of fluid in the form of a wedge or disc. The hot blast valve which is the modified form of a gate valve of DN1800, with the gate in fully closed condition. The Effect of pressure locking is an important phenomenon for the design of a hot blast valve. Due to this effect the most critical components of the hot blast valve gets effected like the valve body, bonnet, disc, etc. In this paper investigation is done on the disc plate which has the major effect by the pressure locking. In order to make the design safe from the pressure locking phenomena a static analysis is done on the disc both theoretically and numerically. In theoretical analysis the disc plate was designed using the plate theory and the stresses and strains were calculated. In numerical analysis the model is generated in CREO3.0 and analysis done in ANSYS Workbench. The results obtained from the theoretical and numerical analysis were compared and the redesign of the disc plate at different thickness is done. The results obtained were compared to select the best thickness of the disc plate, which tries to reduce the effect of pressure locking phenomena caused by the closing of the valve while operating.*

Keywords: *Hot Blast Valve, Disc Plate, stress, ANSYS.*

1. INTRODUCTION

Valves can be classified based on Mechanical motion, valve size, pressure – temperature rating and function. Gate valves are isolated valves which gives a linear motion that is used to start or stop the fluid flow. When the valve is in fully open position the disc is completely removed for the flow of stream. The major parts of the gate valve are the body, bonnet, disc, which retain the pressure applied. The pressure drop in a gate valve is minimal and it has good shut off characteristics. The gate valve can be operated by manual, hydraulic, electrical, pneumatic, motor and solenoid. The valves can be manufactured by casting and forging. The most common material used for a Gate valve is structural steel. The various end connections of a Gate valve are butt weld, flanged, socket and threaded ends. For the design of a valve it is crucial to have the various stress and deflections acting on the parts of the valve within the yield strength.

2. LITERATURE REVIEW

Pradip Bhaskar et. Al. [1] in their paper discussed about the structural analysis of the gate valve body using FEA. It was shown that the maximum principal stress was found at the inner wall of end line flow connection at operating as well as testing pressure. While the minimum principal stress found at outer surface i.e. connection between bowl and flow connector at operating as well as testing pressure. Due to the internal pressure acting on the valve body which results in the expanding of the valve body. Also it is seen that as the internal pressure increases the stresses in the valve body Increases linearly and the resulting von mises stress plot gives maximum stress which are found within yield strength limit.

S. Satish Kumar et.Al. [2] In his study a stress analysis and temperature distribution of valve body of the Gate Valve is carried out. In this paper the seat ring is welded with the valve body by using gas tungsten arc welding and a model of body and seat ring of Gate Valve was developed in SOLID WORKS 2014, and analyzed in ANSYS 15. Gate valve stress analysis and temperature distribution is done by Finite Element Method using ANSYS15. The main purpose is to create a model of the gate valve body and analysis the load deformation, stress concentration, temperature distribution and directional heat flow in the valve body at the place where the seat ring is welded.

K.H.Jatkar et.Al. [3] In his paper he performed a stress analysis of the critical components of Gate Valve, which are the Body, Gate Stem, and slab gate. Stress analysis is done by FEM using ANSYS 11 and validation is supported by stress analysis using classical theory of mechanics. The result obtained from FEM software and classical analytical theory are compared. These results can be used in further development of Gate Valve.

ThankGod E. Boye et.Al. [4] In this work, computer aided design method was utilized to design and perform stress analysis of a high pressure gate valve used on a typical oil and gas wellhead of working pressure up to 15,000 psi. (103.4 MPa). The results obtained from the two methods indicated reasonable convergence after validation. The stress analysis conducted was based on von mises failure criterion which is most suitable for ductile materials. The results obtained from both analytical design calculation and that of finite element analysis indicates reasonable agreements by measuring their percentage performance variance. Therefore, the findings of this research work attests to reliability of the designed HPGV valves in meeting engineering design assessments, and in turn can be optimally advanced in the manufacture of high pressure gate valves.

Shashank S. Jadhav [5] in his paper the use of pressure valve considered for 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. See that the design dimension (thickness) of the gate valve is within the safe limits.

3. THE HOT BLAST VALVE

Hot blast valves (HBV) are critical equipment in ironmaking plants. In an ironmaking plant, an HBV is located between the stove (blast furnace air preheater) and the blast furnace. Effectively used to isolate the blast furnace from hot blast stove in integrated steel plants and pig iron making facilities using stoves. Also are used as a stove shut-off valve and back draughting valve. For a burner shut-off valve the same design is adopted with wedge arrangements to achieve isolation of gas lines from stoves.

These valves have the following features:

1. Disk, flow section of the body and the inner surface of the cover have the refractory coating which considerably reduce heat loss in the valve;
2. Design features of the disk provide high density of locking of the valve;
3. The most heat-loaded elements of the valve construction have minimum quantity of welds in the zone of high temperatures in order to provide high operate reliability of the valve;
4. The gland seal of ducts which supply and discharge cooling agent to the valve disk is manufactured from an ecological clean graphite which ensures its advantages under service condition;
5. Advanced technological equipment of valve production provides their high quality.

The following table 1 gives the technical information about the hot blast valve;

Table 1: Features of Hot Blast Valve

Sizes	500mm to 3000mm
Temperature	up to 1500C
Pressure	Up to 600 KPa
Media	Hot Air

MAIN COMPONENTS IN A HBV:

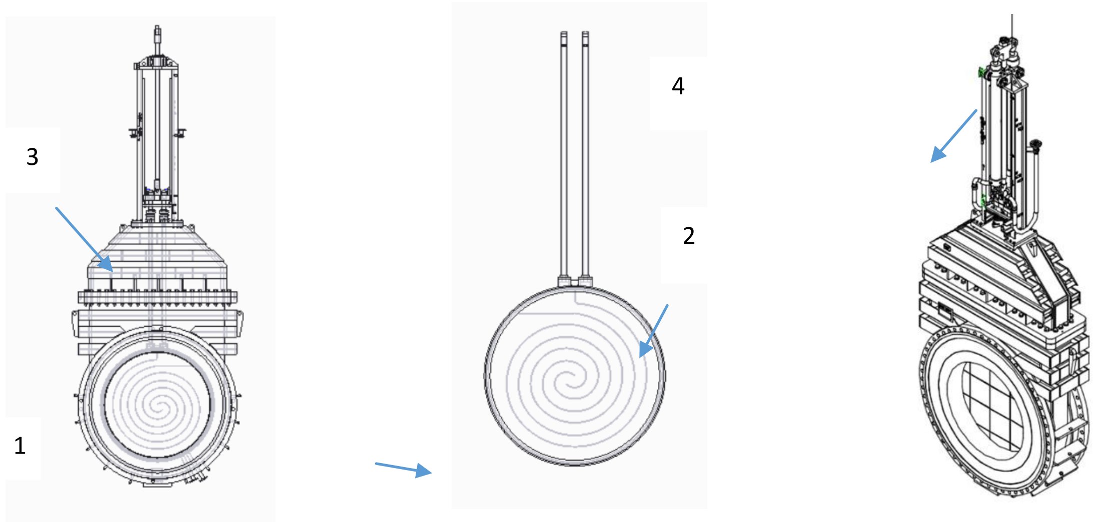
The various components of the gate valve are shown in figure 1 and their description is given as follows: -

1. Body:

Most of the time, a body of a knife gate valve is made from industrial grade stainless steel since this mechanism receives a lot of beating and has to withstand the elements, especially if it is exposed outside. Stainless steel also takes a long time before it could experience corrosion and fatigue. Also, it makes the device lighter than brass or steel valves.

2. Gate:

This is one of the main parts of this type of gate valve. This is responsible for stopping any fluids or gasses from flowing through once the valve is closed and generally, this is the part that receives the most battering and stress, apart from the exposed parts. The gate is almost always made of cast stainless steel to withstand corrosion and prolong the life of the valve.



a) Hot Blast Valve b) Gate c) Isometric View

Figure 1 Schematic View of the Hot Blast Valve

3. Valve Bonnet:
It is the top cover of the valve and it is bolted to the valve body. It also acts as a casing which contains all the other internal parts of the valve.

4. Stem:
This is basically the shaft of the mechanism. This is where the gate is attached and in turn, connected to the hand wheel. The stem is threaded so when the wheel is turned, it will enable the gate to raise or lower. This is also made of stainless steel to save weight and to also resist and withstand corrosion.

5. Valve packing:
Most valves use some form of packing to prevent leakage from the space between the stem and the bonnet. It is commonly a fibrous material (eg. flax) or other compound (eg. Teflon) that forms a seal between the internal parts of a valve and the outside, from where the stem extends through the body.

4. THEORETICAL APPROACH TO DISC PLATE DESIGN

CLASSICAL PLATE THEORY:
In continuum mechanics, plate theories are mathematical descriptions of the mechanics of flat plates that draws on the theory of beams. Plates are defined as plane structural elements with a small thickness compared to the planar dimensions. The typical thickness to width ratio of a plate structure is less than 0.1. A plate theory takes advantage of this disparity in length scale to reduce the full three-dimensional solid mechanics problem to a two-dimensional problem. The aim of plate theory is to calculate the deformation and stresses in a plate subjected to loads.
Of the numerous plate theories that have been developed since the late 19th century, two are widely accepted and used in engineering. These are

- classical plate theory
- first-order shear plate theory

For the design of the disc plate the calculation is based on the classical plate theory and the required material properties are taken from table2.

Material Properties:
The material of the disc plate for the hot blast valve is given in the table 2
The material used for the disc plate as per IS 6911: 1992 is STAINLESS STEEL - IS: X04Crl9Ni9.

Table 2 Material Properties of the disc plate

MATERIAL	QUANTITY
Working Temperature	<425C
Tensile Strength	400MPa
Yield Strength	200MPa
Hardness Number	HBS 192
Density	7850 Kg/m3
Young's Modulus	210GPa
Poisson's Ratio	0.3

3.1 Valve Disc Plate Design:

A theoretical approach is made to calculate the disc plate thickness and the stresses acting on it.

3.1.1 Disc plate stress calculation:

As per the circular plate theory-
The stress acting on the plate is given by the following formula,

$$y = \frac{pr_o^4}{64D}[1-[\frac{r}{r_o}]^2]^2$$

Where, D is the flexural rigidity,

$$D = \frac{Et^3}{12(1-\vartheta^2)}$$

Where,

P = uniform load = 0.25 N
r_o = Inside diameter = 1800 mm
E= Young's modulus, 210 GPa
t = thickness of the disc plate, 20 mm
ϑ = Poisson's ratio, 0.31

Deflection, y_{max} at, r = 0 i.e.; at the center of the plate

$$y_{max} = \frac{pr_o^4}{64D} = \frac{0.25*900^4}{64*D} = 16.5\text{mm}$$

The maximum stress is given by,

$$\sigma_{max} = \frac{6}{t^2} M_{max}$$

Where, M_{max} is the maximum bending moment.

$$M_{max} = \frac{pr_o^2}{16}(1+\vartheta)$$

$$\sigma_{max} = 249 \text{ MPa}$$

5. STATIC ANALYSIS ON THE DISC PLATE

Modelling: modelling of Hot blast valve is done in CREO Parametric software which is most popular and easy in modelling in present days. The dimensions of each component took from the blue prints in the industry. It is having more than 25 subassemblies with more number components. Some of major components of the major components of hot blast valve are presented below figures like bonnet, Valve body, Disc, Hydraulic drive and stuffing box etc. which are subassemblies.

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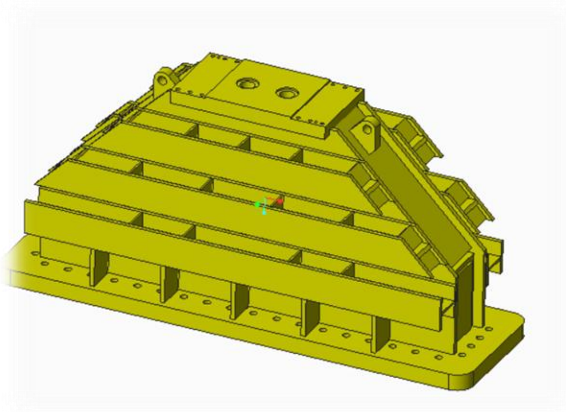

Figure 2 Bonnet

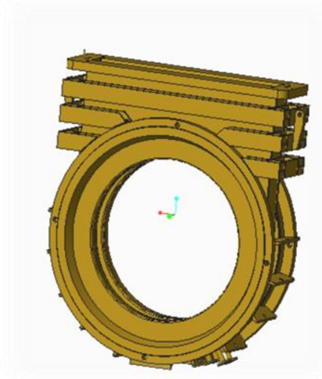

Figure 3 Valve Body

Figure 4 Disc

Figure 5 Hydraulic Drive Frame

Figure 6 Stuffing Box

When the Hot Blast Valve is connected in line, the various components are subjected to cyclic loads due to gas pressure. The effect of these forces and their moments cause considerable stresses of bending, shear and tension compression in the Hot Blast Valve material. Joints and fillets are critical location of body and slab gate that endure the highest level of stress under service loading. The static structural analysis is done in ANSYS Workbench.

Meshing:

In this module of analysis, the geometric model created in CAD is meshed. Meshing is converting a whole geometry into number of elements and these elements are connected by nodes**.** Meshing is carried out to convert the body into infinite DOF to finite DOF by nodes and connected by elements. Results will appear at nodes and interpolate on the elements.in this meshing, Coarse grain structure gives best results for our model are presented below in the figure.

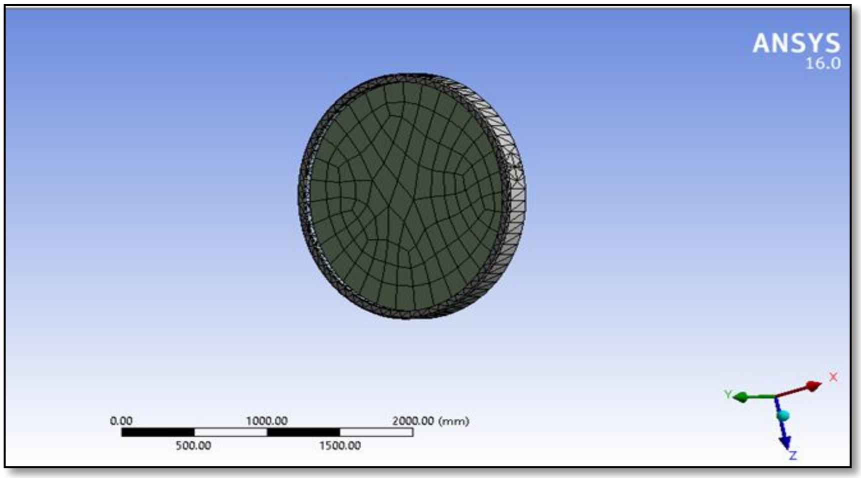

Figure 7 Meshing of the Disc

MATERIAL PROPERTIES, BOUNDARY CONDITIONS:

Material properties: Stresses and strains of the valve disc plate are essentially depending of the properties of the material of the disc has been made. The material specification for disc plate used is STAINLESS STEEL - IS: X04Crl9Ni9 with reference to IS 6911: 1992 Modulus of elasticity E = 210GPa, Poisson ratio μ = 0.3, density =7850 Kg/m3and yield strength 200Mpa.

Boundary conditions**:** Pressure is uniformly distributed all over the disc plate. The model is fixed by the restraints to prevent all possible motions to the system of reference as shown in the figure. 0.25 MPa test pressure is applied on the valve disc plate.

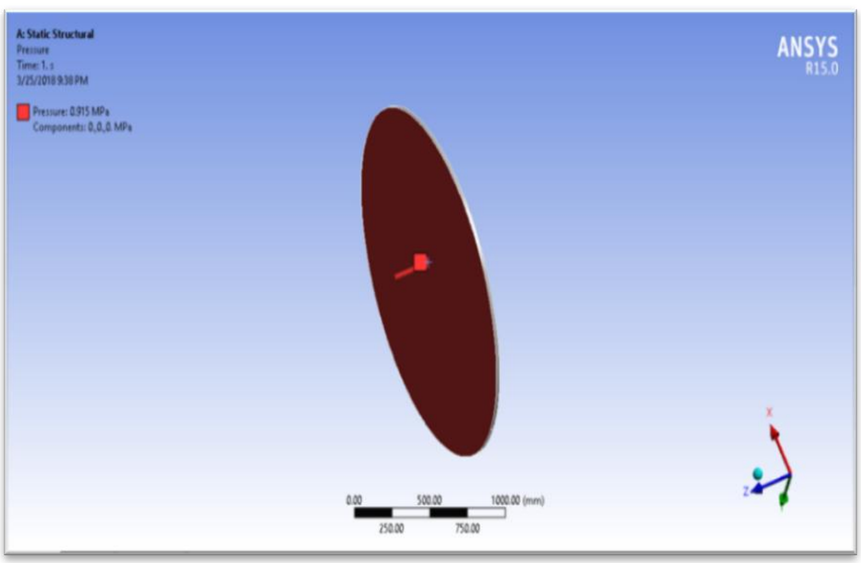

Figure 8 Load of 0.25Mpa is applied on the disc plate.

RESULTS OF DISC PLATE WITH 20 mm THICKNESS:

For above boundary conditions and load on the disc plate with 20 mm thickness have developed stresses are presented below. Von Mises stress condition taken as the maximum stress condition for the given model. The results obtained in ANSYS workbench are presented below in the figures. The results obtained in ANSYS are similar to the Classical plate theory but in both the cases the design exceeds the yield strength criteria. Hence, a redesign of the disc plate with various thickness required which could withstand the operating pressure of 2.5bar (0.25 MPa).

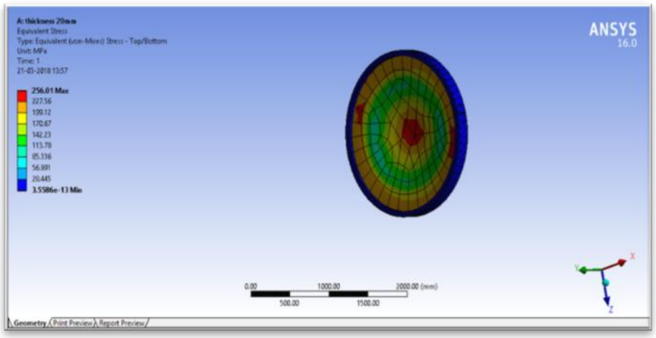

Figure 9 maximum stress = 256.01 N/mm2 @ t=20 mm

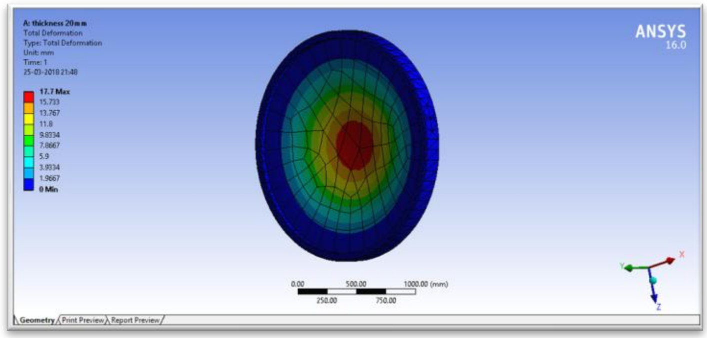

Figure 10 maximum deflection = 17.7 mm @ t=20 mm

6.REDESIGN OF THE DISC PLATE

The redesign of disc plate with various thickness are carried out on the basic of standard plate thickness. In order satisfy the design limits of the hot blast valve, the disc plate thickness should be compatible with the hydraulic system. If thickness of the disc plate is increased, the capacity of lifting up the hydraulic device should be increase otherwise it may fail due to heavy load of disc weight. Hence, we take 18,22,25 and 28 as thicknesses for the redesign.

ANALYTICAL APPROACH:
In analytical approach, for the above mentioned methodology of classical plate theory the same equations used for the calculation of the stresses on the disc plate. The results are presented in the below table

Table 3 Stress values for various thickness based on plate theory

S.No	Thickness, mm	Max. Stress,N/mm2
1	18	307
2	22	206
3	25	159
4	28	127

NUMERICAL APPROACH:
In numerical approach, modelling of disc plate with various thickness is done in CREO parametric software. The figures are as shown in below.

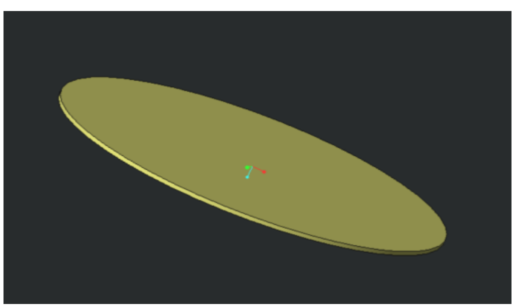

Figure 11 Disc at t=18mm

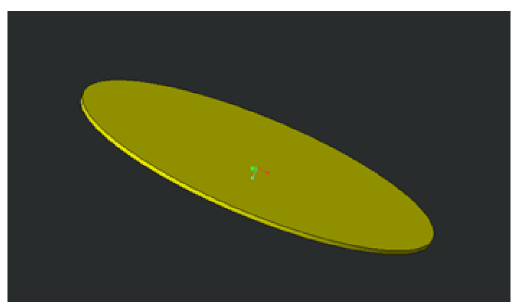

Figure 12 Disc at t=22mm

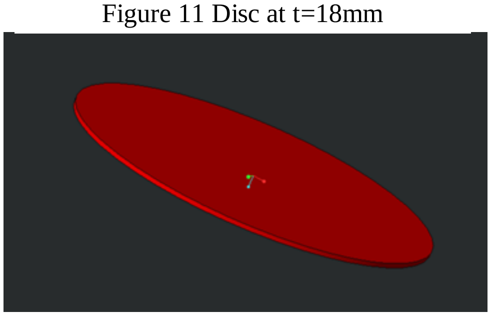

Figure 13 Disc at t=25mm

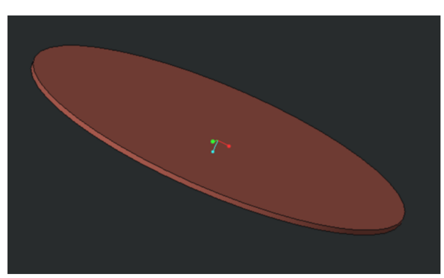

Figure 14 Disc at t=28mm

The meshing and boundary conditions are similar to the existing design as mentioned in the section above section.

STATIC STRESS ANALYSIS -REDESIGN

After meshing and boundary conditions, the post processing for the maximum stress on the disc plate are obtained for different thicknesses of 18,22,25 and 28 are 315.17, 219.24, 180.14 and 119.42 N/mm2 are respectively. The plots of maximum stress are presented below in the figures.

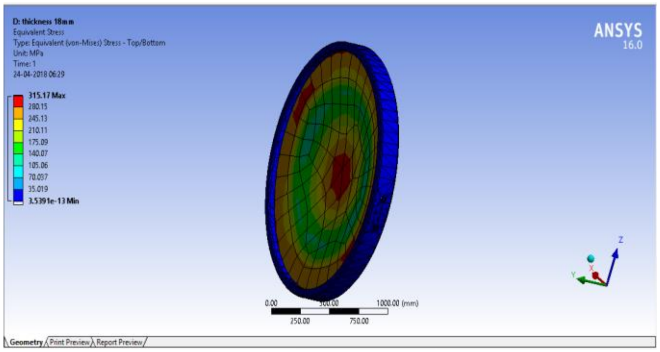

Figure 15 maximum stress = 315.17 N/mm2 @ t=18 mm

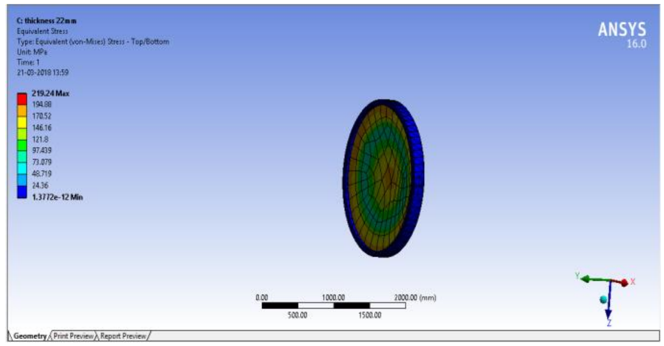

Figure 16 maximum stress = 219.24 N/mm2@ t=22 mm

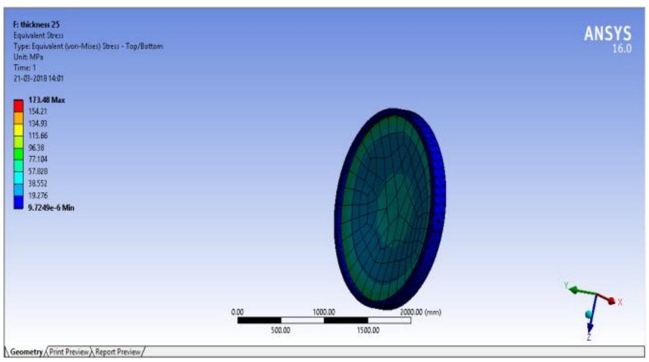

Figure 17 maximum stress =180.14 N/mm2 @ t=25 mm

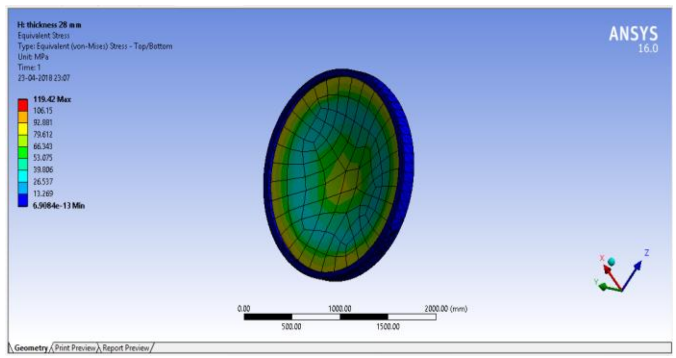

Figure 18 maximum stress =119.42 N/mm2 @ t=28 mm

7.RESULT SUMMARY

RESULTS OF DISC PLATE WITH 20 mm THICKNESS

The results obtained for the existing design of disc plate with a thickness of 20 mm are presented below both theoretically and numerically. This results includes maximum static stress acting on the disc plate and its deflection due to applied uniform pressure load of 2.5 bar.

Table 4 results of disc plate with 20mm thickness

Type of approach	Stress In N/Mm2	Deflection In mm
Analytical Results	249	16.5
Ansys Results	256.01	17.7

The above results are similar in the both the approaches, which validates the design criteria. But the stress acting on the disc plate is of 250 MPa which is more than the yield stress (200 MPa). Hence the major stress concentration for a uniform pressure load of 2.5 bar is discerned as the problem. The redesign of disc plate carried on the different standard plate thicknesses with same uniform pressure load 2.5 bar to decrease stress on the disc plate.

RESULTS OF DISC PLATE WITH VARIOUS STANDRAD PLATE THICKNESSES

The results of redesign of disc plate with various thicknesses of standard plate like 18,22, 25 and 28 are presented below in the table 5.

Table 5 Numerical results of disc plate with varying thickness

S.No	Thickness	Analytical stress, N/mm2	ANSYS Stress, N/mm2
1	18	307	315.17
2	22	206	219.24
3	25	159	180.14
4	28	127	119.42

Analytical calculations based on classic mechanics and ASME standards have been done. The present analysis shows that for the disc plate thickness at 20 mm the stress intensity is more and it tends to deform the plate. At various thicknesses which are in the allowable limit, the stress intensity and deformation is found out both analytically and numerically. At the thickness 25 mm it is seen that the stress and deformation is less and within limited weight also. If thickness 28 mm giving less but it takes more weight on the disc which also effects the operating limits of the hydraulic equipment to lift the disc. Hence at the thickness 25 mm for the disc plate, when there is pressure locking effect in the valve body, the plate can withstand the deformation.

8. CONCLUSION

The components used in gate valves DN1800 x 150 are modeled, detailed and analyzed for the given pressure, using software package ANSYS Workbench. This models are theoretically calculated and analyzed whether the design is safe or not, using relevant standards like ASME SEC VIII, ASME SEC II Part D, and relevant IS standards. Along with the summary analysis the von mises stress and displacement was found to be suitable for working Conditions for the disc plate with 20 mm thickness, but the disc plate tends to fail due to pressure locking. So the redesign is done for the disc plate with varying thickness and it is found that at thickness 25mm it is safe and it can withstand the pressure locking condition.

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