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Finite Element Analysis of Gate Valve

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***Abstract* – Gate valves are used when a straight-line flow of fluid and minimum restriction is desired. Gate valves are so named because the part that either stops or allows flow of fluid through the valve acts somewhat like the opening or closing of a gate and is called, appropriately, the gate. The objective of this paper to perform a stress analysis of the critical component of Gate Valve. The critical components in the Gate Valve are Body, Gate Stem, and slab gate. This paper comprises Finite element analysis of Gate Valve. A model of each element of Gate Valve is developed in CATIA V5R17, and analyzed in ANSYS 11. Gate valve stress analysis is done by FEM using ANSYS 11 and validation is supported by stress analysis using classical theory of mechanics. Finally, the result obtained from FEM software and classical analytical theory are compared.**

***Keywords* : Finite Element Analysis, Gate Valve**

I. Introduction

A Gate Valve, or Sluice Valve, as it is sometimes known, is a valve that opens by lifting a round or rectangular gate/ wedge out of the path of the fluid. The distinct feature of a gate valve is the sealing surfaces between the gate and seats are planar. The gate faces can form a wedge shape or they can be parallel. Gate valves are sometimes used for regulating flow, but many are not suited for that purpose, having been designed to be fully opened or closed. When fully open, the typical gate valve has no obstruction in the flow path, resulting in very low friction loss and when the gate valve is closed there are many obstructions in the flow path which in turn produces high frictional losses [1].

To avoid or minimize the frictional losses study of stress distribution in the parts of the gate valve is done before manufacturing of gate valve. We have selected a 4 $^{1/16}$" Gate Valve for the analysis of stress distribution. The main reason to choose the gate valve is carry out the basic analysis process of all the components [5].

It is tedious & great work for designer to make the accurate stress distribution of any mechanical component. So some deficiencies in the design of part are left. To overcome these deficiencies computer software's are used. Analysis & optimization done by using analysis software gives greater accuracy and also minimizes the time of designer.

II. Slab Gate Valve

Due to the various environments, system fluids, and system conditions in which flow must be controlled, a large number of valve designs have been developed.

A basic understanding of the differences between the various types of valves, and how these differences affect valve function, will help ensure the proper application of each valve type during design and the proper use of each valve type during operation.

A. Gate valve function and its basic parts

A valve is a mechanical device that controls the flow of fluid and pressure within a system or process. A valve controls system or process fluid flow and pressure by performing any of the following functions:[5]

- Stopping and starting fluid flow
- Varying (throttling) the amount of fluid flow
- Controlling the direction of fluid flow
- Regulating downstream system or process pressure
- Relieving component or piping over pressure

1. Valve Bonnet: The cover for the opening in the valve body is the bonnet. In some designs, the body itself is split into two sections that bolt together. Like valve bodies, bonnets vary in design. Some bonnets function simply as valve covers, while others support valve internals and accessories such as the stem, disk, and actuator.

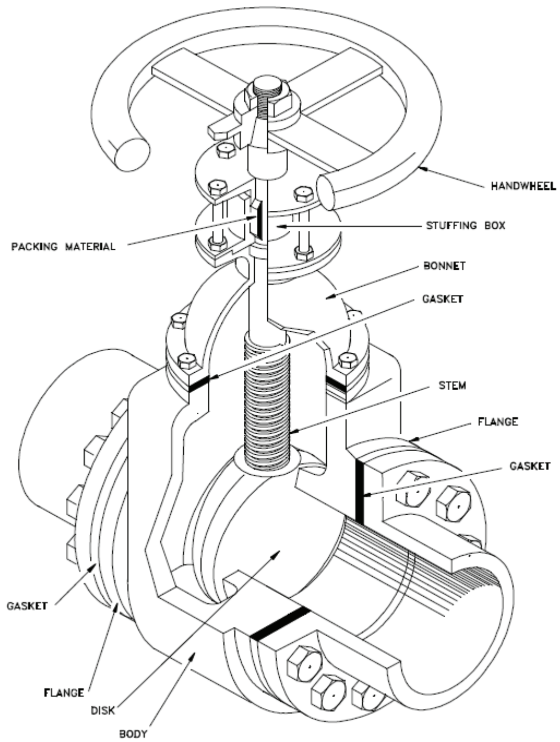

Fig.2.1 Gate Valve General Arrangement

2. Valve Trim: The internal elements of a valve are collectively referred to as a valve's trim. The trim typically includes a disk, seat, stem, and sleeves needed to guide the stem. A valve's performance is determined by the disk and seat interface and the relation of the disk position to the seat.

3. Disk and Seat: For a valve having a bonnet, the disk is the third primary principal pressure boundary. The seat or seal rings provide the seating surface for the disk. In some designs, the body is machined to serve as the seating surface and seal rings are not used.

4. Stem: The stem, which connects the actuator and disk, is responsible for positioning the disk. Stems are typically forged and connected to the disk by threaded or welded joints.

5. Valve Actuator: The *actuator* operates the stem and disk assembly. An actuator may be a manually operated hand wheel, manual lever, motor operator, solenoid operator, pneumatic operator, or hydraulic ram

6. Valve Packing: Most valves use some form of packing to prevent leakage from the space between the stem and the bonnet. *Packing* is commonly a fibrous material (such as flax) or another compound (such as Teflon) that forms a seal between the internal parts of a valve and the outside where the stem extends through the body.

B. Classification of Gate Valve

Gate valves perform an on/off function accomplished by means of a flow-controlling gate centered in the valve body between the inlet and outlet sides of the valve.

The various types of Gate Valves are as follows [4]

- Ball Valves
- Plug Valves
- Butterfly Valves
- Needle Valves
- Parallel Disk Valve

C. Application of Gate valve

A gate valve can be used for a wide variety of fluids and provides a tight seal when closed.

Gate Valves are designed to suit a wide range of applications in Refineries, Petro-chemical Complexes, Fertilizer Plants, Power Generation Plants (Hydro - electric, Thermal and Nuclear) Steel Plants and Allied Industries. They are made from high quality Carbon Steel Castings and embody design features that contribute to strength and durability. Flanges are Raised Face and drilled. Valves are manufactured from materials, which conform to International Specifications and against specific enquiry can be supplied with special trims as Austenitic Stainless Steel, Satellites etc[4]

III. Problem Identification & Solution Methodology

A. Problem definition

The project deals with "Finite Element Analysis of Gate Valve".

The various components of the gate valve are as follows: -

- Body
- Gate
- Bonnet
- Stem
- Hand wheel
- Seat

In the above components the fluid pressure acts on body, gate and stem. So we are treating them as a critical component.

B. Modules of project

Modeling	- 3D models of critical components of Gate Valves are prepared using (CATIAV5 R17). The detailed dimensions are taken from its 2D drawings.
Importing 3d Model	- 3D model prepared using CATIA is imported into FEA software (ANSYS).
Preferences	- Structural analysis method is selected.
Pre-processing	- Define element type
	- Apply material properties
	- Meshing
	- Application of loads and boundary conditions
Solution	- Solving given load step
Post-processing	- Review results

C. Analytical Approach

The force analysis is performed by analytically to find out the loads acting on the Gate Valve components. The loads are due to the internal liquid pressure.

The Gate Valve components are analyzed further by analytical approach, so as to identify stress values at various locations. The FEA results are compared with analytical results for verification.

IV. Theory of Gate Valve

A. Introduction

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. Figure illustrates a gate valve.

The disk of a gate valve is completely removed from the flow stream when the valve is fully open. This characteristic offers virtually no resistance to flow when the valve is open. Hence, there is little pressure drop across an open gate valve.

B. Design of Gate Valve of Body

1. Design considerations of Body.

As per classification of pressure vessels we considered body is thick shell subjected to internal pressure.

Given data:

1. Internal pressure (p_i) = 94.05e6 n/m^2
2. Permissible tensile strength (f_t) = 654.55e6 n/m^2
3. Bore diameter (d_i) = 0.10338 m

2. Design calculations of wall thickness of Body.

Considering Lames Equation

Wall thickness

$= (d_i/2)*[\sqrt{(ft+pi)/(ft-pi)} - 1]$

$= (0.10338/2)*[\sqrt{(654.55e6+94.05e6)/(654.55e6-94.05e6)} - 1]$

= 0.008m

By considering the reliability of load taken into account the factor of safety is 3.5

0.008*3.5 = 0.028

As per standard size available in market is 0.030m.[5]

3. Design of Gate Valve of Stem

Gate valves are classified as either rising stem or non rising stem valves. For the non rising stem gate valve, the stem is threaded on the lower end into the gate. As the hand wheel on the stem is rotated, the gate travels up or down the stem on the threads while the stem remains vertically stationary. Rising stem gate valves are designed so that the stem is raised out of the flow path when the valve is open. Rising stem gate valves come in two basic designs. Some have a stem that rises through the hand wheel while others have a stem that is threaded to the bonnet.

Given data:

1. Hand wheel radius=0.2m
2. Force required to rotate the hand wheel=350N
3. S_{yt} for the stem material(m.s.)=220*e6 N/m^2

Torque Required to Rotate the Hand wheel = F*R = 350*0.2 = 70 N-m

For Stem Material= $S_{SY} = 0.5*S_{YT} = 0.5*220 = 110$ N/m^2

Considering FOS = 2.5

Tensional Shear Stress = (S_{SY}/FOS) = (110/2.5) = 44 N/m^2

Considering Failure of Stem in Torsion

T= ($(\pi/16(\pi/16$)*f_S*d^3)

70 = ($(\pi/16(\pi/16$)*44e6*d^3)

Diameter of Stem d = 0.020 m = 22 mm (approx)

Considering the above diameter analysis of stem is done[7].

4. Design of Slab Gate

Gate valves are available with a variety of disks. Classification of gate valves is usually made by the type disk used: solid wedge, flexible wedge, split wedge, or parallel disk.

Solid wedges, flexible wedges, and split wedges are used in valves having inclined seats. Parallel disks are used in valves having parallel seats. Regardless of the style of wedge or disk used, the disk is usually replaceable. In services where solids or high velocity may cause rapid erosion of the seat or disk, these components should have a high surface hardness and should have replacement seats as well as disks. If the seats are not replaceable, seat damage requires removal of the valve from the line for refacing of the seat, or refacing of the seat in place. Valves being used in corrosion service should normally be specified with replaceable sets.

V. Computer Aided Design

A. Introduction

Solid modeling finds wide applications that cut across functional boundaries, such as use of solid model with finite element analysis. Furthermore solid models can be used to evaluate the size, shape and weight of products early during the conceptual design phase. The modeling of components of gate valve is carried out using CATIA V5 R17.

B. Modeling of Gate Valve Components

The various components of the gate valve are as follows: -

- Body
- Gate
- Bonnet
- Stem
- Hand wheel
- Seat

VI. Finite Element Analysis

A. Introduction to Finite element analysis

FEA consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement. A company is able to verify a proposed design will be able to perform to the client's specifications prior to manufacturing or construction. Modifying an existing product or structure is utilized to qualify the product or structure for a new service condition. In case of structural failure, FEA may be used to help determine the design modifications to meet the new condition.

B. Stresses

When Gate 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 Gate Valve material. Joints and fillets are critical location of body and slab gate that endure the highest level of stress under service loading.

C. Steps in FEA

1. FEA pre-processor

The user constructs a model of the part to be analyzed in which the geometry is divided into a number of discrete sub regions, or elements," connected at discrete points called nodes." Certain of these nodes will have displacements, and others will have prescribed loads. The preprocessor stage in general FE package involves the following:

Creating the model: the model is drawn in 1D 2D or 3D space in the appropriate units (M, mm, in, etc).The model may be created in the pre –processor, or it can be imported from another CAD packages via a neutral file format(IGES, STP, ACICS, Parasolid, DXF, etc.)

2. Solution

This part is fully automatic .the FE solver can be logically divided into three main part the pre-solver the mathematical engine and the post-solver the pre solver reads the model created by the pre processor and formulates the mathematical representation of the problem all parameters defined in the pre processing stage are used to do this so if something is left out the pre solver will complain and cancel the call to the mathematical engine if the model is correct the solver proceeds to form the element stiffness matrix for the problem and calls the mathematical engine which calculates the result (displacement, temp,and pressures, etc)the result are returned to the solver and the post solver is used to calculate strain, stresses ,heat fluxes velocity etc)for each node within the component or continuum. all these result are sent to a file which may be read by the post processor.

3. Post-Processor

Here the results of the analysis are read and interpreted. They can be presented in the form of table, a contour plot, deformed shape of the component or the mode shape and frequencies if frequency analysis is involved. Most post processors provide and animation service, which produces an animation and brings your model to life.

4. FE Model of the Gate Valve

Finite element method is an excellent tool to analyses structures by computer simulation and therefore can help to reduce time and cost required for prototyping and avoids numerous test series. Static finite element analysis of gate valve is used for basic determination of stress behavior due to maximum flow of fluid.

5. Mesh generation

In this module of analysis, the geometric model created in CAD is meshed. Meshing is nothing but converting a whole geometry into number of elements and these elements are connected by nodes. [6]

VII. Results and Discusions

Figure.7.1gives the stress diagram of gate body. It is observed that the stress at outer side of hole is maximum and it is 693N/mm^2.The stress is minimum 1.98N/mm^2.

Fig.7.2 gives Maximum and minimum deformation of gate valve. Maximum deformation is 0.188mm and minimum deformation is 0mm.

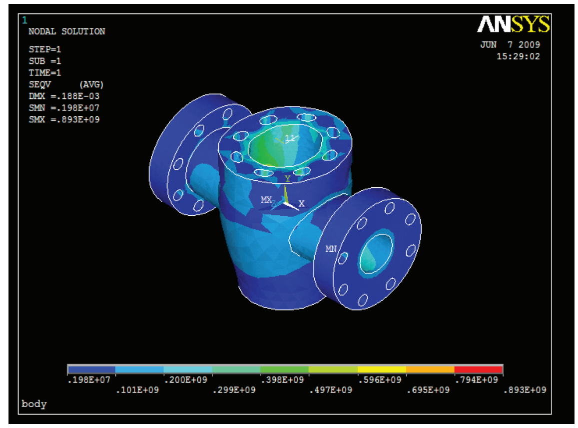

Figure.7.1 Stress Diagram of Gate Body

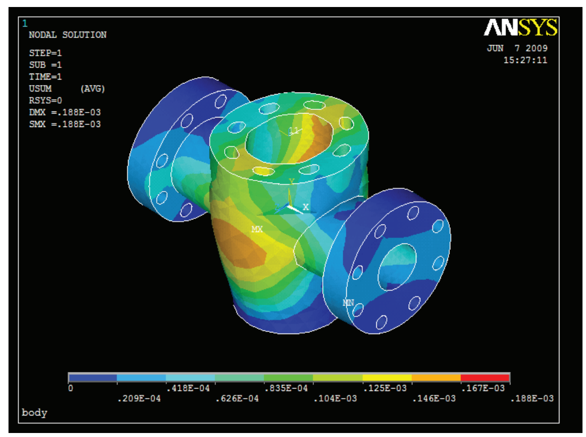

Fig.7.2 maximum displacement diagram

Fig.7.3gives the stress diagram of Stem. It is observed that the maximum stress is 248N/mm^2.The minimum stress is 0.006401x10^{-6} N/mm^2.

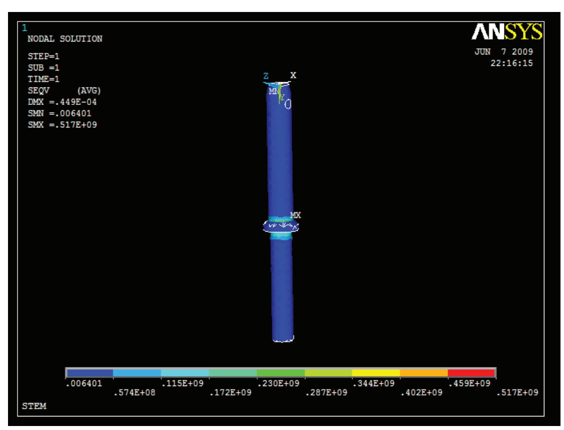

Fig.7.3. Stress Diagram of Stem.

Fig.7.4 gives Maximum and minimum deformation of stem. Maximum deformation is 0.044mm and minimum deformation is 0mm.

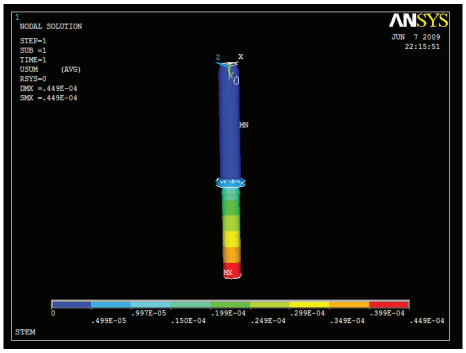

Fig.7.4 Maximum displacement Diagram

Fig.7.5gives the stress diagram of Slab Gate It is observed that the maximum stress is 694N/mm^2.The minimum stress is 110 N/mm^2.

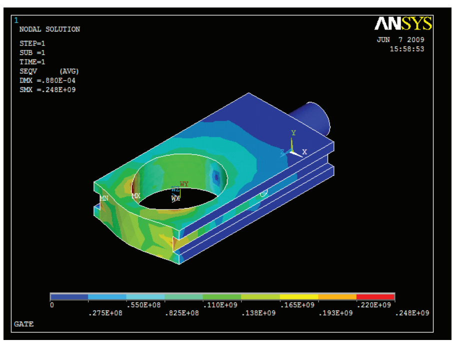

Fig.7.5 Stress Diagram of Slab Gate

Fig.7.6 gives Maximum and minimum deformation of Slab Gate Maximum deformation is 0.088mm and minimum deformation is 0mm.

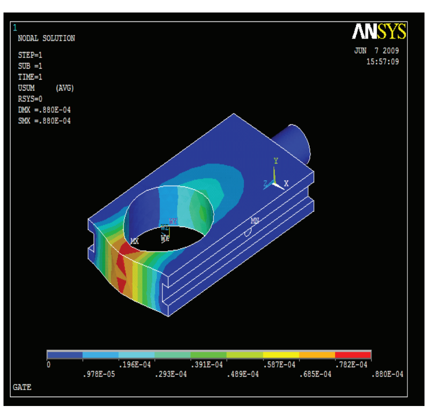

Fig.7.6 dislacement Diagram of Slab Gate

After analysis following are the results obtained by ANSYS.

Component	Actual Stress Value	Obtained Stress Value
Body	516.75 e6 N/m^2	517.00 e6 N/m^2
Gate	694.23 e6 N/m^2	693 e6 N/m^2
Stem	249.23 e6 N/m^2	248 e6 N/m^2

VIII. Conclusion

From the obtained results it is clear that the stress values obtained by classical theory of mechanics & stress values obtained by Finite element method (FEM) are approximately same, so we conclude that the above results are correct and we can use these results in further development of Gate Valve.

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