Design-Analysis and Optimization of Cryogenic Gate Valve

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Design-Analysis and Optimization of Cryogenic Gate Valve

Major Project

Submitted in partial fulfillment of the requirements

For the degree of

Master of Technology in Mechanical Engineering

(CAD/CAM)

By

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Guided by

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MAY 2012

Declaration

This is to certify that,

The thesis comprises my original work towards the degree of Master of Technology in Mechanical Engineering (CAD/CAM) at Nirma University and has not been submitted elsewhere for a degree.

Due acknowledgement has been made in the text to all other material used.

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Undertaking for Originality of the Work

I, **Payal P. Patel**, Roll. No.**10MMCC10** , give undertaking that the Major Project entitled "**Design - Analysis and Optimization of Cryogenic Gate Valve**" submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in (CAD/CAM) of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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Date:_________________

Place: NU, Ahmedabad

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(Signature of Guide)

Certificate

This is to certify that the Major Project entitled **"Design-Analysis and Optimization of Cryogenic Gate Valve"** submitted by **Ms. Payal P. Patel(Roll No: 10MMCC10)**, towards the partial fulfillment of the requirement for the degree of Master of Technology in Mechanical Engineering (CAD/CAM) of Institute of Technology, Nirma University, Ahmedabad is the record of work carried out by her under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The result embodied in this major project, to the best of my knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

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Abstract

The project include Design-Analysis and Optimization of the cryogenic gate valve. Cryogenic gate valve is the component used in low temperature application like transfer of Nitrogen, Hydrogen and Oxygen. The detail design of the cryogenic gate valve is studied thoroughly with the help of manuals of the valves of the company. In this project detail design of cryogenic gate valve components namely stem, wedge and body is carried out which meets the design requirements stipulated by various relevant standards. Assembly model of the gate valve and detail drawing of the components has been created using PRO/E software. Analysis (Thermal/Structural) is carried out for stem, body and wedge in ANSYS workbench and the stress values are compared with acceptance criteria. Design Optimization of the stem has been carried out to reduce the stresses generated in the stem.

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Nomenclature

WP	Maximum working pressure (bar)
f	Allowable stress (MPa)
C	Minimum positive tolerance (mm)
D	Maximum internal diameter of body (mm)
S	Stress factor
E	Joint efficiency
α	Wedge taper angle
ϕ	Friction angle
P_t	Pitch or lead of the screw (mm)
μ	Co efficient of friction
F	Total axial force (N)
M	Gasket factor
A_1	Area confined within gasket (mm^2)
A_2	Area of gasket (mm^2)

Chapter 1

Introduction

1.1 Definition of Cryogenic Service

The branches of physics and engineering that involves the study of very low temperature [-150^{o}C], how to produce them and how materials behave at those temperature is known as cryogenic. Valve used to control the flow and pressure at cryogenic temperature is known as cryogenic valve. The valve is of the extended type with sufficient length and a vapour space between body and stuffing box in order to maintain the gland packing sufficiently near ambient temperature to prevent icing of the top works and keep the packing soft and pliable for optimum sealing characteristics.

1.2 Design of Cryogenic valve

The design of the valve is carried out as an extended bonnets. The length of the extension shall be sufficient to maintain the stem packing at a temperature high enough to permit operation within the normal temperature range of the packing material. The valve shall be designed to relieve pressures above normal working pressure that may build up in trapped cavities due to thermal expansion or evaporation of liquid. The design of the valve are unidirectional in operation, the flow direction shall be clearly indicated either on and integral with the body of the valve.

The clearance between the valve stem and gland extension bore shall be designed to minimize convention heat losses. The valve thickness of the extension shall be minimized, compatible with the rating of the valve and mechanical strength requirements in order to reduce conduction heat losses. The valve stem shall be of one piece construction except for gate valve, in which case the valve design shall be such that the valve stem cannot be blown out of the body in the event of the gland being removed while the valve is under pressure.

1.3 Preliminary remarks

The first important consideration when specifying valves is to select the right valve. The gate valve is the type of valve most often used in industrial piping. Cryogenic gate valves are working at very low temperature like -196^{o}C. The feature of the cryogenic gate valve is less obstruction to flow, with less turbulence within the valve and very little pressure drop. When the valve is wide open the wedge is lifted entirely out of the waterway, providing a straightway flow area through the valve. The gate valve should be specified when pressure drop is to be avoided. Also, gate valves should never be used for throttling purposes, only in the fully open or closed positions.

1.4 Pressure class

An alphanumeric designation that is used for reference purposes relating to valve pressure/temperature capability, taking into account valve material mechanical properties and valve dimensional characteristics. It comprises "Class" followed by a dimensionless whole number. The number following "Class" does not represent a measurable value and is not used for calculation purposes except where specified in ASME, API, ASTM, and BS6364 standards. The allowable pressure for a valve having a class number depends on the valve material and its application temperature.

1.5 Nominal diameter

An alpha numeric designation of size that is common for components used in a piping system, used for reference purposes, comprising the letters "DN" followed by a dimensionless number indirectly related to the physical size of the bore or outside diameter of the end connection as appropriate. The dimensionless number following "DN" does not represent a measurable value and is not used for calculation purposes except where specified.

1.6 Pressure/Temperature Ratings

Pressure/temperature ratings shall be in accordance with those specified in the standards of ASME B16.34 for standard class for the applicable material specification and the applicable class.

The temperature for a corresponding pressure rating is the maximum temperature of the pressure-containing shell of the valve. In general, this temperature is the same as that of the contained fluid. The use of a pressure rating corresponding to a temperature other than that of the contained fluid is the responsibility of the user.

For temperatures below the lowest temperature listed in the pressure/temperature tables given in the API 600, the service pressure shall be no greater than the pressure for the lowest listed temperature. The use of valves at lower temperatures is the responsibility of the user. Consideration should be given to the loss of ductility and impact strength of many materials at low temperature.

Double seated valves, in some design configurations, may be capable of trapping liquid in the center cavity of the valve when in the closed position. If subjected to an increase in temperature, an excessive build-up of pressure can occur, which may result in a pressure boundary failure. Where such a condition is possible, it is the responsibility of the user to provide or require to be provided, means in design, installation, or operating procedure, to assure that the pressure in the valve does not exceed that allowed by this International standard for the resultant temperature.

1.7 Material requirements

Following are the requirements of the material for cryogenic application:
1. Design and service condition (Material as to sustain cryogenic temperature in service).
2. Mechanical properties like strength.
3. Thermal properties like thermal conductivity and thermal expansion.
4. High temperature or corrosion-resistant characteristics.

To meet the above requirements the selection of CF8 material is made for body and wedge. CF8 material is stainless steel alloy and is as per the standard ASTM A 351.Chemical composition and Mechanical properties are as shown in Table 1.1 and Table 1.2 respectively.
For stem SS 304 material is selected.Chemical composition and Mechanical properties are as shown in Table 1.3 and Table 1.4 respectively.

Heat treatment of these alloys is usually necessary to enhance corrosion resistance and in some cases to meet mechanical properties.

Table 1.1: Chemical composition of CF8 material

Element, %	**Chemical composition**
Carbon	0.08
Manganese	1.50
Silicon	2.00
Sulfur	0.04
Phosphorus	0.04
Chromium	18.0 to 21.0
Nickel	8.0 to 11.0
Molybdenum	0.50

Table 1.2: Mechanical properties of CF8 material

Poissons Ratio	0.30
Density	8000 kg/mm^3
Thermal expansion	17.5/^{o}C
Thermal conductivity	16.8 W/mm.^{o}C
Specific heat	500 J/kg^{o}C
Modulus of elasticity	200 GPa

Table 1.3: Mechanical properties of SS 304 material

Poissons Ratio	0.29
Density	8000 kg/mm^3
Thermal expansion	17.2/^{o}C
Thermal conductivity	16.2 W/mm.^{o}C
Specific heat	500 J/kg^{o}C
Modulus of elasticity	200 GPa

Table 1.4: Chemical composition of SS 304 material

Element, %	**Chemical composition**
Carbon	0.06
Manganese	1.50
Silicon	2.00
Sulfur	0.04
Phosphorus	0.04
Chromium	18.0 to 21.0
Nickel	8.0 to 11.0
Molybdenum	0.50

1.8 Aim and scope of the work

To design cryogenic gate valve meeting the requirements stipulated by API 600, ASTM A 351, B16.34 and BS 6364.

Thermal and Structural Analysis of valve components namely stem, body and wedge.

Design optimization of the stem of gate valve using ANSYS.

Chapter 2

Literature Review

2.1 BS 6364 - Specification for valves for cryogenic service

Nominal size and nominal pressure of the cryogenic gate valve selected with the help of BS 6364. Where valves, by design, are unidirectional in operation, the flow direction shall be clearly indicated either on and integral with the body of the valve or on a plate securely attached to the body of the valve.

Valve shall be supplied with extended bonnets. The length of the extension shall be sufficient to maintain the stem packing at a temperature high enough to permit operation within the normal temperature range of the packing material.

Valve shall be designed to relieve pressures above normal working pressure that may build up in trapped cavities due to thermal expansion or evaporation of liquid.

All components in a piping system other than components designated by outside diameters or by thread size. It is a convenient round number for reference purposes and is only loosely related to manufacturing dimensions. Working pressure depends upon materials, design and working temperature and has to be selected from the pressure/temperature rating tables in corresponding standards.

The maximum force required to operate the valves manually under service conditions, when applied at the rim of the handwheel or lever, shall not exceed 350N, except for valve seating and unseating only, when it shall be permissible for this value to be increased to 500N. Where reduction gearing is provided, it shall be suitable for operation at ambient temperature.

2.2 API 600 - Bolted bonnet steel gate valves for petroleum and natural gas industries

This International standard specifies the requirements for a heavy-duty series of bolted bonnet steel gate valves for petroleum refinery and related applications where corrosion, erosion and other service conditions would indicate a need for full port openings, heavy wall sections and large stem diameters.

This International standard sets forth the requirements for the following gate valve features:

bolted bonnet, outside screw and yoke, rising stems, non-rising handwheels, single or double gate, wedge or parallel seating, metallic seating surfaces.

2.2.1 Stem and stem nut

The minimum stem diameter applies to the stem along the surface area that comes into contact with the packing and to the major diameter of the trapezoidal stem thread.

However, the major diameter of the stem thread may be reduced, at the manufacturers option, by no more then 0.06 in. (1.6 mm). The stem surface area in contact with the packing shall have a surface finish or smoother.

Stems shall have a gate attachment means at one end and an external trapezoidal style thread form at the other. Stem nuts shall be used for handwheel attachment and to drive the operating stem thread.

The stem-to-stem nut threads shall be of trapezoidal form as specified in ASME B1.5 or ASME B1.8, with nominal dimensional variations allowed. Stem threads shall be left-handed so that a direct operated handwheel rotated in a clockwise direction closes the valve.The stem shall be one-piece wrought material. A stem that is a welded fabrication or threaded assembly shall not be provided.

The stem design shall be such that the strength of the stem to gate connection and the part of the stem within the valve pressure boundary shall, under axial load, exceed the strength of the stem at the root of the operating thread.

2.3 Technical specification of the Cryogenic valve.

Pressure rating class = Class 150

Standard = Gate valve - API 600 / BS 6364

Material of the component as mention below.

Shell = CF8

Trim = SS 304

Packing = Graphite

Gasket = SPW 304+Graphite

Feature

1. Gate valve wedge shall be flexible design.
2. Wedge is Gr.12 stellited and seatring are Gr.6 stellited.
3. Live loading arrangement shall be provided on gland.
4. SS castings shall be acid pickled.

2.4 Optimization Methods

Optimization is the process of finding the functions which gives the minimum or maximum value of the function. In this case to design of the stem, body and wedge of the cryogenic gate valve. In this case optimized stem component of the cryogenic gate valve. Reduced weight of the stem.There are mainly two type of optimization shape, size.

2.4.1 Shape optimization

To change the shape of the stem in bottom portion to connect of the wedge. To cut two slot and remove material and create model in PRO/E software. Changes of the shape of the structural boundary must be translated into changes of the interior of the mesh.

2.4.2 Size Optimization

it involves modification of cross section or thickness of solid model of the stem in PRO/E version.The optimization is carried out by mathematical algorithms with different objective functions e.g. minimum stress and minimum weight.

Chapter 3

Mathematical Formulation for design calculation

Design analysis of 12" x 150 class cryogenic gate valve is taken as a project. The steps involved in the process of analysis are as mentioned below.

1. Design calculation using analytical methods.
2. Design analysis using ANSYS Workbench software.

Design calculation using analytical method is done for the following parameters.

a. Calculation of stem Diameter.

b. Calculation of shell thickness.

c. Calculation of torque value.

d. Calculation of body to bonnet side flange thickness.

These calculations are done on basis of various formulations used in valve industries and national and international standards like ASME, API, BS 6364 etc. Design analysis using analysis software is being done for stem and various parameters to check its integrity during operation.

3.1 Calculation of stem diameter

Total axial force acting on the stem can be calculated by using an equation given in standard API 600 and is as given below.

$$F = F_{\mathbf{1}} + F_{\mathbf{2}} + F_{\mathbf{3}} \tag{3.1}$$

Where,

F_1 = Compressive force due to pressure acting on the wedge

F_2 = Compressive force due to pressure acting on the stem

F_3 = Force due to packing friction

$$F_{\mathbf{1}} = \frac{\pi}{\mathbf{4}} D^{\mathbf{2}} \; P \; tan\,(\alpha + \emptyset) \tag{3.2}$$

$$= \frac{\pi}{\mathbf{4}} \times \mathbf{3}04^{\mathbf{2}} \times \mathbf{2} \times tan\left(\mathbf{3.5} + \mathbf{t}an^{-\mathbf{1}}\mu\right)$$

$$= \frac{\pi}{\mathbf{4}} \times \mathbf{3}04^{\mathbf{2}} \times \mathbf{2} \times tan\left(\mathbf{3.5} + \mathbf{t}an^{-\mathbf{1}}\mathbf{0.1}\right)$$

$$=\mathbf{2}3539.\mathbf{42}N$$

Where,

Seat opening diameter is selected using table no.5 of API 600 for the combination of material and size of the valve. Design pressure is selected using table no.3 of BS 6364 for the combination size and pressure class of the valve.

D = Seat opening diameter in mm

P = Design pressure in N/mm^2

α = Wedge taper angle in degree(Fixed values)

ϕ= Friction angle(Packing friction material as per ASTM A351 Sec. VIII of Div.1)

$$F_{\mathbf{2}}= \frac{\pi}{\mathbf{4}}\, d^{\mathbf{2}}\ P= \frac{\pi}{\mathbf{4}}\times\ \mathbf{37}^{\mathbf{2}}\times\mathbf{2}=\mathbf{2}150.\mathbf{4}2\ \mathbf{N} \tag{3.3}$$

Where

d = Assumed stem diameter in mm(Pressure vessel and boiler Division VII of table.8)

P = Design pressure in N/mm^2

Design pressure is selected using table no.3 of BS 6364 for the combination size and pressure class of the valve.

$$F_{\mathbf{3}}\ = \pi\mu\ d\ \mathbf{L}\ P= \pi\ \times\mathbf{0.2}\times\mathbf{37}\times\mathbf{5}2\times\mathbf{2}=\mathbf{2}417.\mathbf{8}\ \mathbf{N} \tag{3.4}$$

Where,

P = Design pressure in N/mm^2

d = Assumed stem diameter in mm

L = Length of stuffing box in mm(Selected from the corresponding non cryogenic gate valve)
μ = Packing friction co-efficient(Packing friction material as per ASTM A351 Sec. VIII of Div.1)

Since the packing friction in cryogenic valve will be high due to ring formation in stuffing box. The packing friction force may be considered higher. It is taken 50% higher than normal.
Hence,

$$F_{\mathbf{3}} = \pi\mu d\ \mathbf{L}\ P \times \mathbf{1.5} = \mathbf{2}417.\mathbf{8} \times \mathbf{1.5} = \mathbf{3}626.\mathbf{6}\ \mathbf{N} \tag{3.5}$$

$$F = F_{\mathbf{1}} + F_{\mathbf{2}} + F_{\mathbf{3}} = \mathbf{2}9316.\mathbf{2}7\ \mathbf{N} \tag{3.6}$$

$$\mathbf{M}in\ \mathbf{r}oot\ \mathbf{a}rea = \frac{\mathbf{F}}{\mathbf{f_c}} = \frac{\mathbf{2}9316.\mathbf{27}}{\mathbf{1}37.\mathbf{8}8} = \mathbf{2}12.\mathbf{6}2\ \mathbf{m}m^{\mathbf{2}} \tag{3.7}$$

Where,
fc = Allowable stress in compression = 137 MPa(As per standard ASTM A 351)

$$\text{Minimum root diameter dc} = \sqrt{\text{min root area} \times \frac{4}{\pi}} = 16.4535\ mm$$

3.2 Calculation of shell thickness

3.2.1 Calculation of shell thickness as per IBR code

$$t = \frac{WP \times D}{2f + WP} + C = \frac{19 \times 38.3}{(2 \times 984) + 19} + 0.5 = 9.04\ mm \tag{3.8}$$

Where,

Minimum positive tolerance is selected using of IBR code for the combination of material and pressure class of the valve.

WP = Maximum working pressure in N/mm^2

D = External diameter of chest in mm(Selected Selected from the corresponding non cryogenic gate valve)

F = Allowable stress in kg/mm^2 (As per standard ASTM A351)

C = Minimum positive tolerance in mm (As per standard IBR code)

3.2.2 Calculation of shell thickness using ASME B16.34 formula

$$t = 1.5 \times \frac{P_c D}{2S - 1.2P_c} = 1.5 \times \frac{150 \times 12}{(2 \times 7000) - (1.2 \times 150)} = 4.96\ mm \tag{3.9}$$

Where,

Pc = Pressure rating class designation in Psi

D = Inside diameter or port opening in $Inch$

S = Stress factor(As per standard ASME B16.34 in table 3)

3.2.3 Calculation of shell thickness by using formula as per valve design hand book

$$t = \frac{PD}{2f} + C = \frac{1.98 \times 304}{2 \times 96.5} + 6.5 = 9.5\ mm \tag{3.10}$$

Where,

P = Working pressure in MPa

D = Inside diameter or port opening in mm(Selected from the corresponding non cryogenic gate valve)

f = Allowable stress in MPa (As per material selection)

C = Constant in mm(As per standard ASME SEC. VIII Div.2)

3.2.4 Calculation of shell thickness using formula as per ASME SEC VIII DIV - 1

$$t = \frac{PR}{SE - 0.6P} = \frac{20.12 \ \times 174}{(984 \times 1) \ - \ (0.6 \ \times 20.12)} = 3.7 \ mm \tag{3.11}$$

Where,

P = Working pressure in kg/cm^2

S = Allowable stress in kg/cm^2

R = Inside radius of shell in cm(Selected from the corresponding non cryogenic gate valve)

E = Joint efficiency = 1(As per standard pressure vessel book SEC.V)

As summarized in the Table 3.1 the maximum thickness is 16mm as obtained by

Table 3.1: Shell thickness using different formulas

Using different formulas	Shell Thickness mm
IBR	9.04
ASME B16.34	4.96
Design hand book	9.5
ASMEE SEC VIII DIV-I	3.7
API 600	16

API 600 code. Hence the thickness of shell is taken as 16mm.

3.3 Calculation of body to bonnet side flange thickness

Body to bonnet side flange thickness can be calculated by using the formula :

$$t = \sqrt{\frac{6LX}{Cf}} \tag{3.12}$$

$$= 0.0158 \times \frac{6 \times \text{ P } (\text{A}_1 + \text{A}_2\text{M}) \times 25.5}{1050 \times 96.5}$$

$$= 0.0158 \times \frac{6 \times 1.98\,(55352 + 12418 \times 5.5) \times 25.5}{1050 \times 96.5}$$

$$= 16.639\ mm$$

Where,

Values of C, X, A_1 and A_2 taken from the corresponding non cryogenic gate valve.

C = Perimeter of neck joint in mm

X = Distance of bolt center line to neck joint in mm

f = Maximum allowable working stress value in MPa

L = Torque bolting load = P (A_1 + A_2M) = 183359.88 N

A_1 = Area confined within gasket = $\pi/4$ (gasket id)2 = 55352 mm^2

A_2 = Area of gasket = $\pi/4$ {(gasket od)2 - (gasket id)2} = 12418 mm^2

P = Internal pressure in MPa

M = Gasket factor (Material selected for gasket is SPW 304+grafoil As per standard gasket material code 3)

Provided thickness = 25mm

Based on the final dimensions obtained through design calculations final drawing of individual components and assembly drawing of the gate valve is attached in APPENDIX I.

Chapter 4

Analysis of stem

Here analysis of stem is carried out using ANSYS software for the specification used in manual design calculation.

MATERIAL PROPERTIES AND OPERATING CONDITIONS
Stainless steel(CF8)

Design pressure = 20 N/mm^2
Pressure class = 150 class
EXPECTED TEMP = Ambient temperature

For the stem material selected is Stainless steel (SS 304), the properties of which are as given below.
Packing friction co-efficient = 0.2
Poison's ratio= 0.30
Factor of safety = 3
Limiting stress (compression) = 137 MPa(As per standard ASTM A 351)
Limiting Stress (tension) = 96 MPa(As per standard ASTM A 351)
Thermal analysis of stem permissible heat flux = 5 W/mm^2
Thermal analysis of body and wedge permissible heat flux = 8 W/mm^2

MODELING IN PRO/E

Based on the dimension obtained through design calculation PRO/E model of stem is created. PRO/E model is transferred to ANSYS in IGES format. Structural, thermal and buckling analysis is carried out in ANSYS workbench.

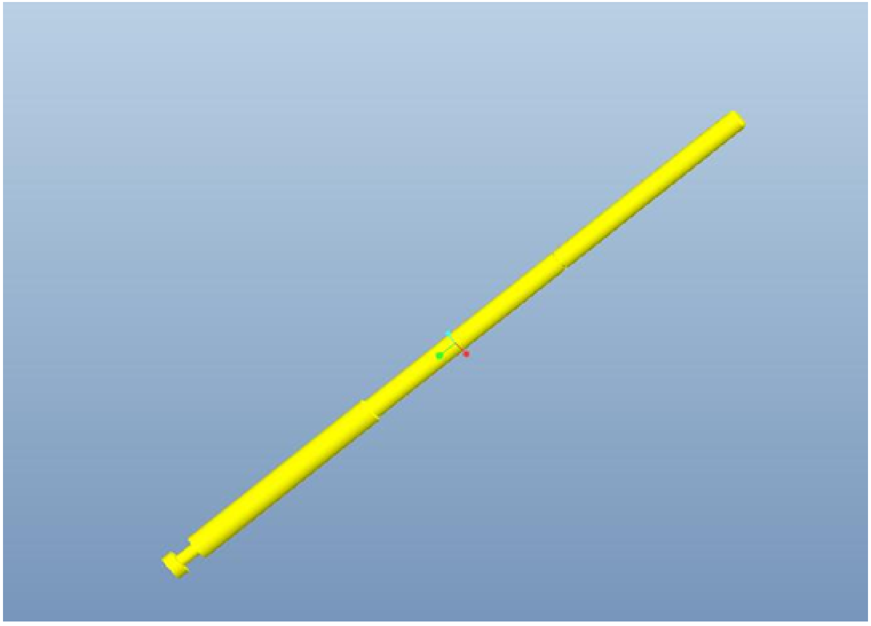

Figure 4.1: Solid model of stem

ANALYSIS IN ANSYS WORKBENCH

PRO/E model of the stem is shown in figure 4.1. Stem is analyzed under the following two conditions.

Case 1 : The static structural analysis in which the wedge is fixed and force (F) 29316 N is applied at the end of the stem in tension.

Case 2 : The static structural analysis in which the wedge is fixed and force (F) 29316 N is applied at the end of the stem in compression.

For the analysis solide 186 elements is choosen. When meshed model consist of 16547 nodes, 8460 elements.

4.0.1 Results

Case 1 : Wedge is fixed and Force (F) 29316 N is applied at end of the stem in tension.

Figure 4.2 shows the force applied on the model.

Figure 4.3 shows the deformation plot of the stem.The maximum deformation of the stem in tension load is $0.16334mm$. Induced deformation ($0.16334mm$) is less than the permissible deformation ($0.3mm$) and hence the design is safe.

Figure 4.4 shows the equivalent stress plot of the stem.The maximum equivalent stress of the stem in tension load is 81.92 N/mm^2. Induced equivalent stress (81.92 N/mm^2.) is less than the permissible stress (96 N/mm^2) and hence the design is safe.

Induced deformation $0.16mm$ does not cause major problem and leakage in the valve.

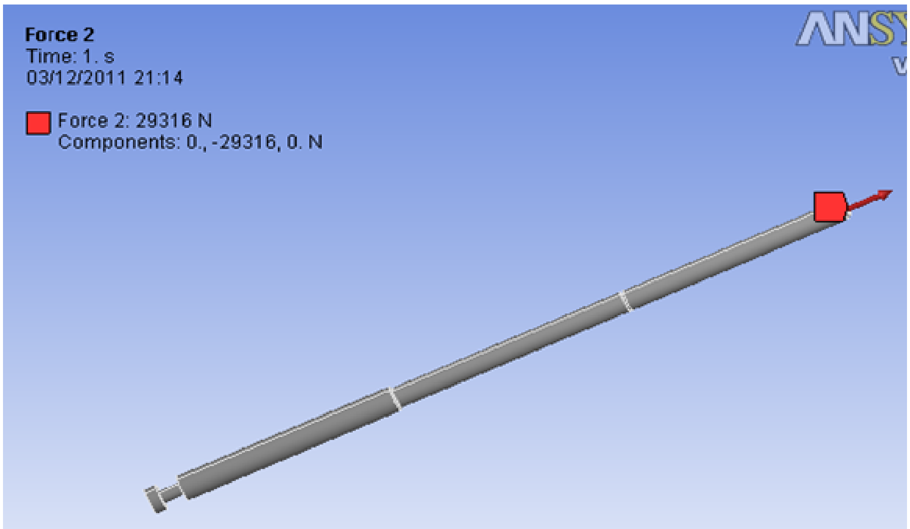

Figure 4.2: Wedge is fixed and force is applied at the end of stem in tension

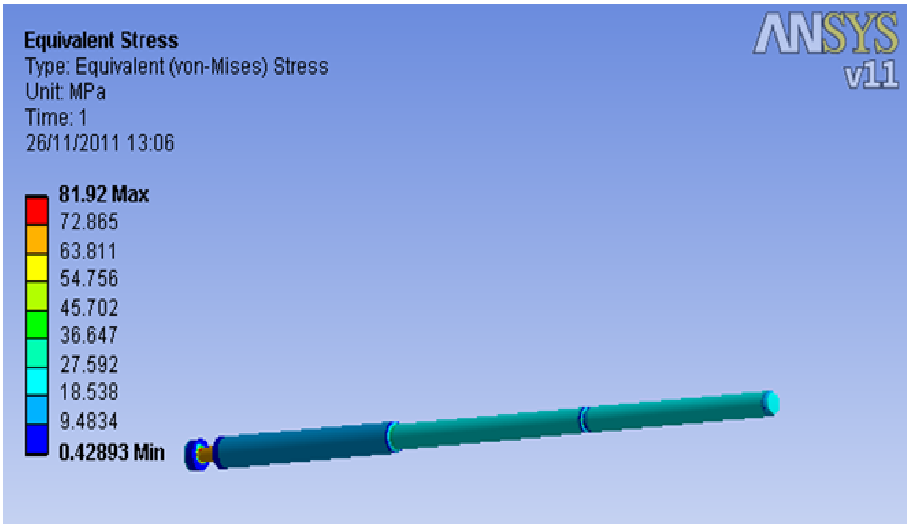

Figure 4.3: Equivalent stress of stem

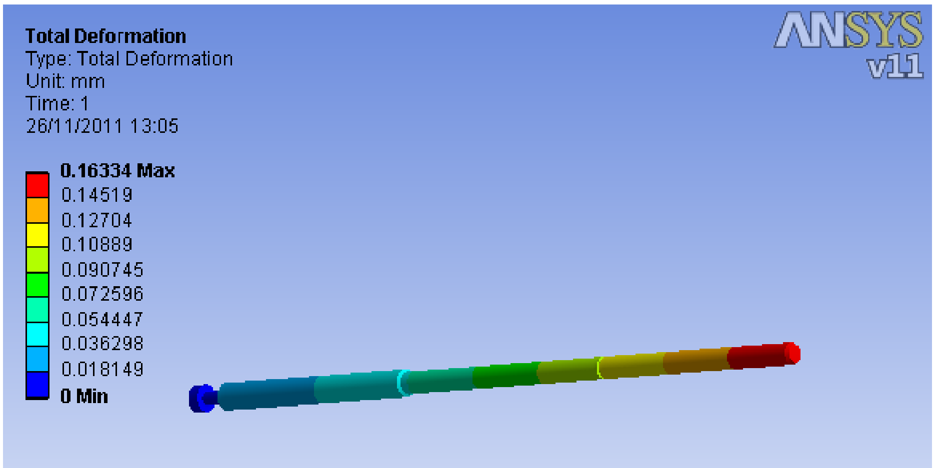

Figure 4.4: Total deformation of stem

Case 2 : Wedge is fixed and Force (F) 29316 N is applied at end of the stem in compression.

Figure 4.5 shows the force applied on the model.

Figure 4.6 shows the deformation plot of the stem. The maximum deformation of the stem in compression load is $0.16284mm$. Induced deformation ($0.16284mm$) is less than the permissible deformation ($0.3mm$) and hence the design is safe.

Figure 4.7 shows the equivalent stress plot of the stem. The maximum equivalent stress of the stem in tension load is 72.65 N/mm^2. Induced equivalent stress (72.65 N/mm^2.) is less than the permissible stress (137 N/mm^2) and hence the design is safe.

Induced deformation $0.16mm$ does not cause major problem and leakage in the valve.

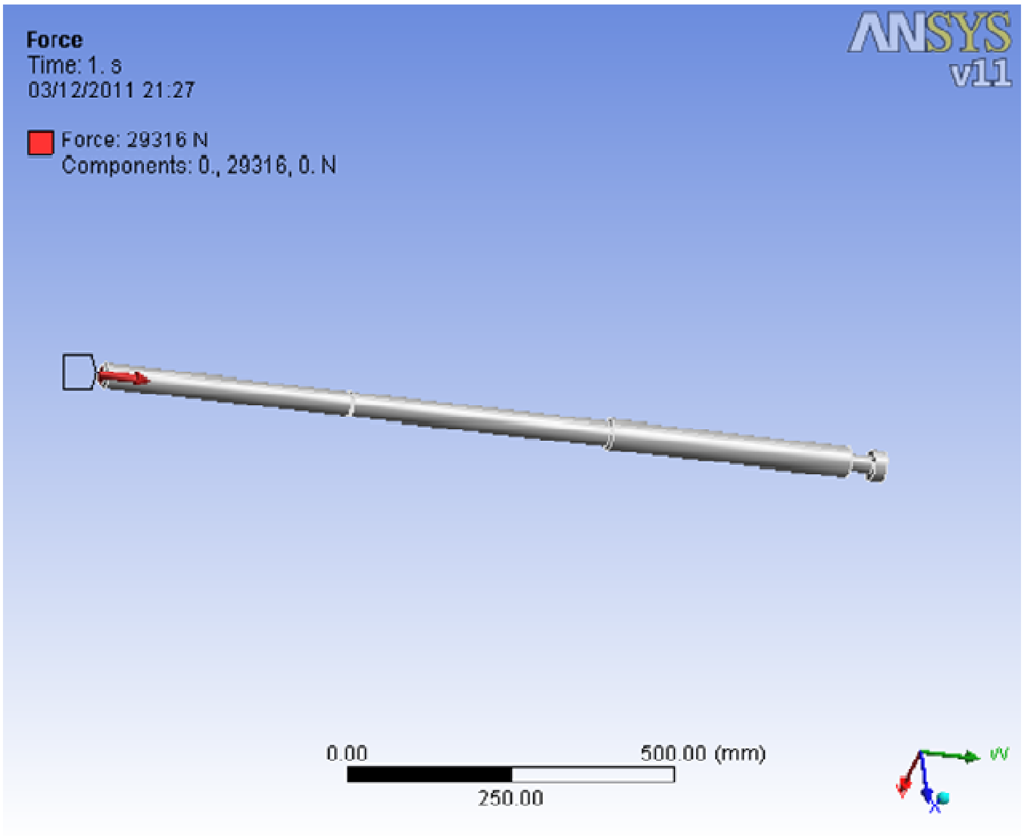

Figure 4.5: Wedge is fixed and force is applied at the end of the stem in compression.

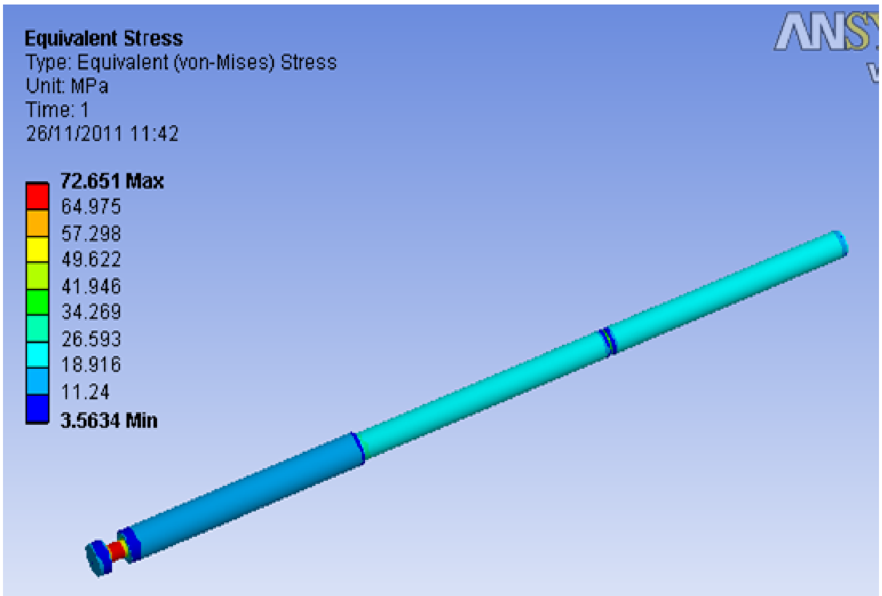

Figure 4.6: Equivalent stress of stem in compression force

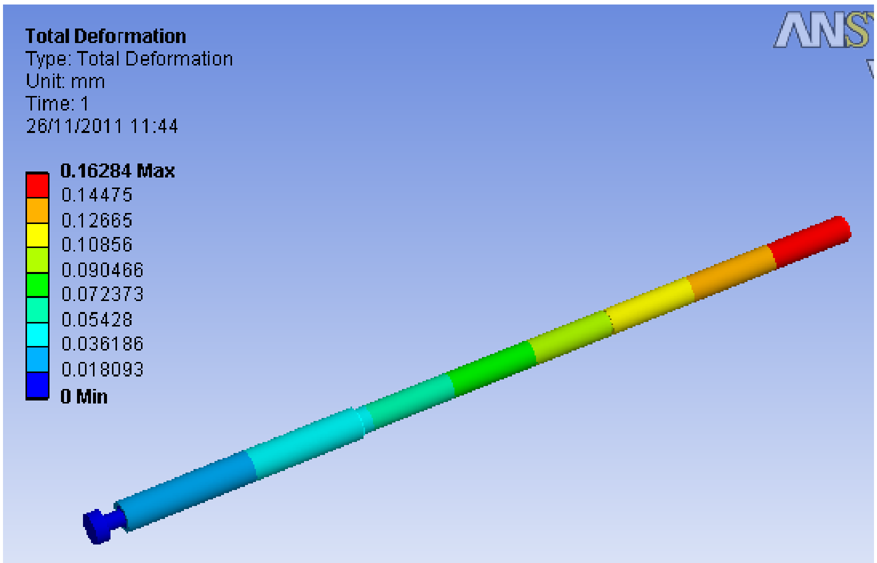

Figure 4.7: Total deformation of stem in compression force

4.0.2 Buckling Analysis of stem

Packing clearance increases after certain wear and tear and hence its advisible to cross check the stem for buckling. In this case buckling of a strut with one end fixed and the other end free is used in buckling load equitation as mention below.

Buckling load $= \pi^2 EI/4L^2 = 38930.5N$

Where,

E = Youngs modulus = $1.93 \times 10^5 N/mm^2$

I = Moment of inertia = $\pi \times D^4$ / 64

D = Stem diameter = 38.3 mm

L = Length of the stem = 1270 mm

Buckling analysis of the stem is carried out. From the buckling analysis the load multiplier obtained is 1.3433. The buckling load ($39380N$) can be calculated as original load ($29316N$) times the load multiplier (1.3433). Buckling load obtained through ANSYS is less than the theoretical buckling load and hence design is safe.

Figure 4.8 shows the buckling deformation plot of the stem. The maximum buckling deformation of the stem in compression load is $0.20mm$. Induced buckling deformation ($0.20mm$) is less than the permissible buckling deformation ($0.3mm$) and hence the design is safe.

Figure 4.9 shows the equivalent stress plot of the stem.The maximum equivalent stress of the stem in compression load is 73.68 N/mm^2. Induced equivalent stress (73.68 N/mm^2.) is less than the permissible stress (137 N/mm^2) and hence the design is safe.

Figure 4.10 shows the deformation plot of the stem. The maximum deformation of the stem in compression load is $0.15mm$. Induced deformation ($0.15mm$) is less than the permissible buckling deformation (0.3mm) and hence the design is safe. Deformation of 0.15 mm does not cause major problem and leakage in the valve.

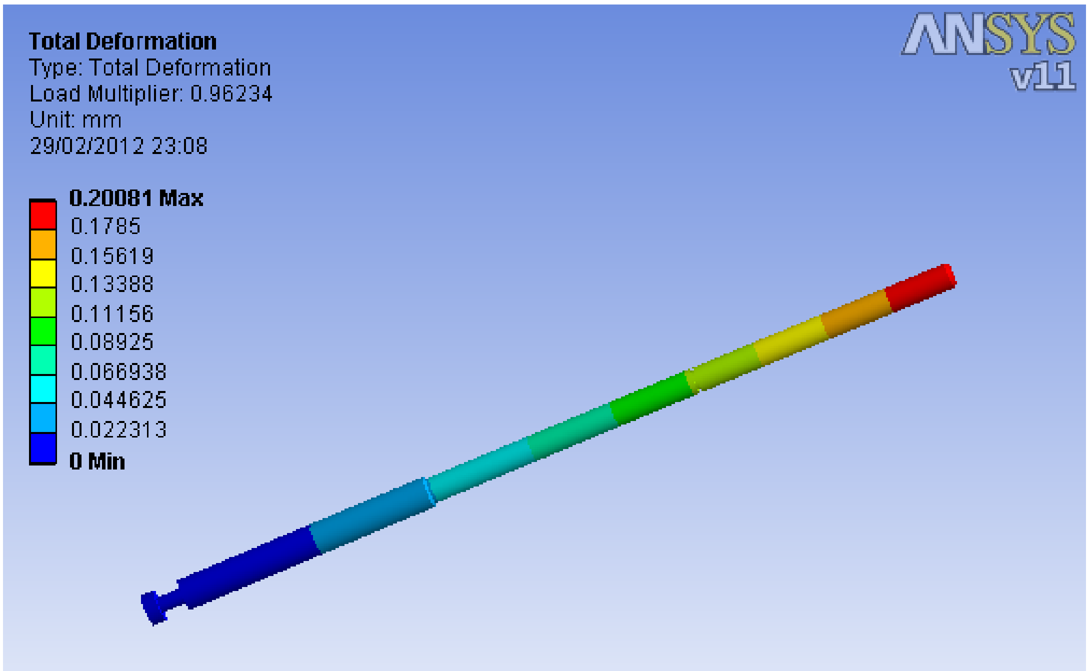

Figure 4.8: Buckling deformation in compression force

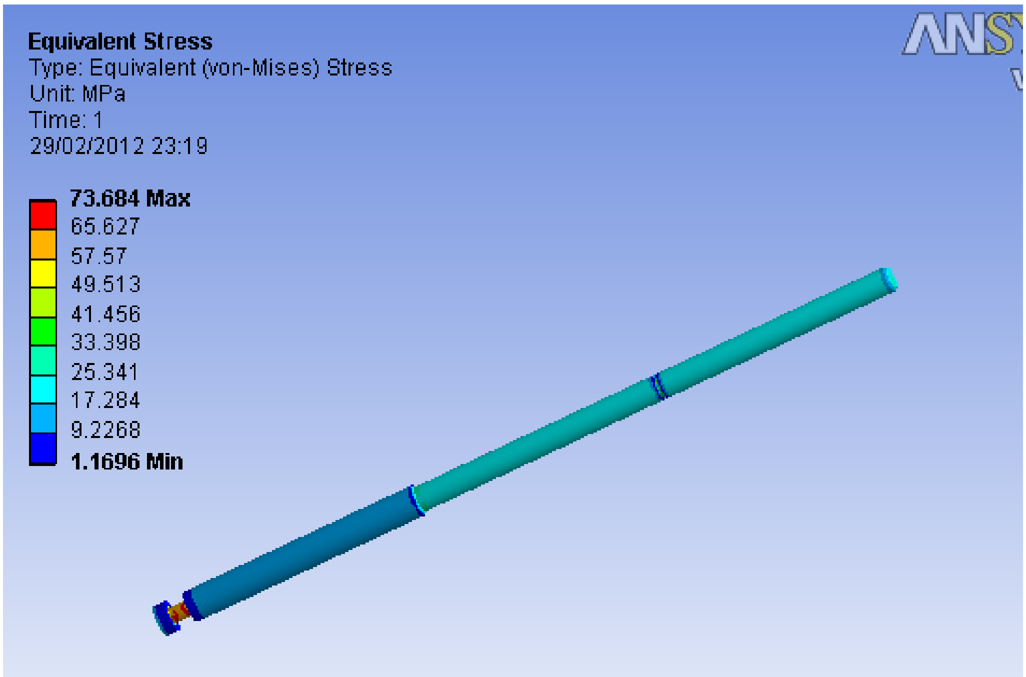

Figure 4.9: Equivalent stress in compression force

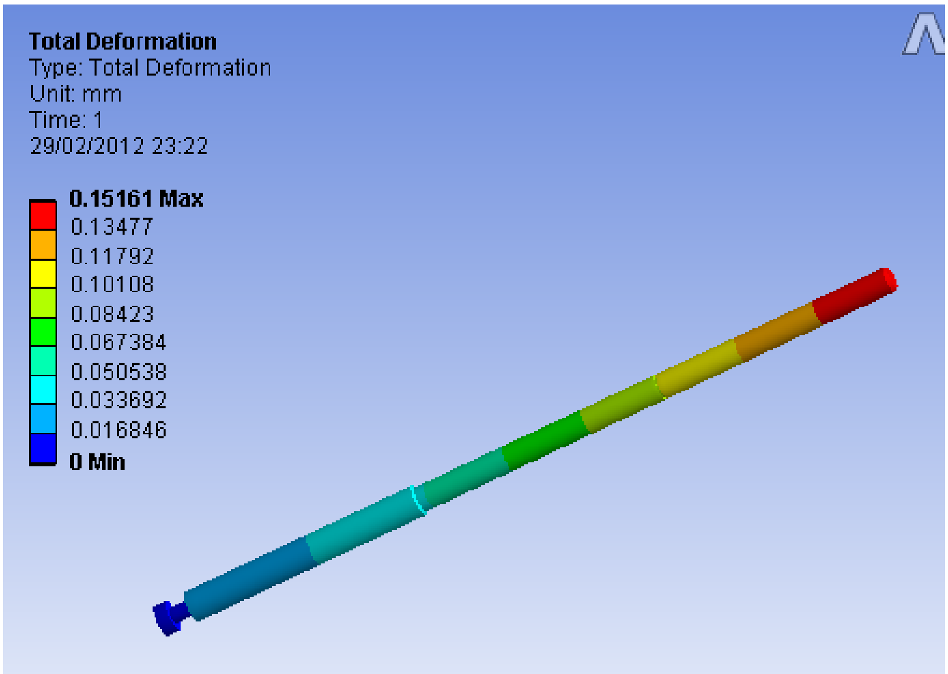

Figure 4.10: Total deformation in compression force

4.0.3 Thermal Analysis of stem

Thermal analysis is done at -196^{o}C. In this case top of the stem part temperature is 22^{o}C and bottom of the stem part temperature is -196^{o}C. Thermal analysis is carried out to obtain the total heat flux and temperature rate.

Figure 4.11 Shows the heat flux plot of the stem. The maximum heat flux of the stem in -196^{o}C temperature is 2.12 W/mm^2. Induced heat flux (2.12W/mm^2) is less than the permissible heat flux (5W/mm^2) and hence the design is safe.

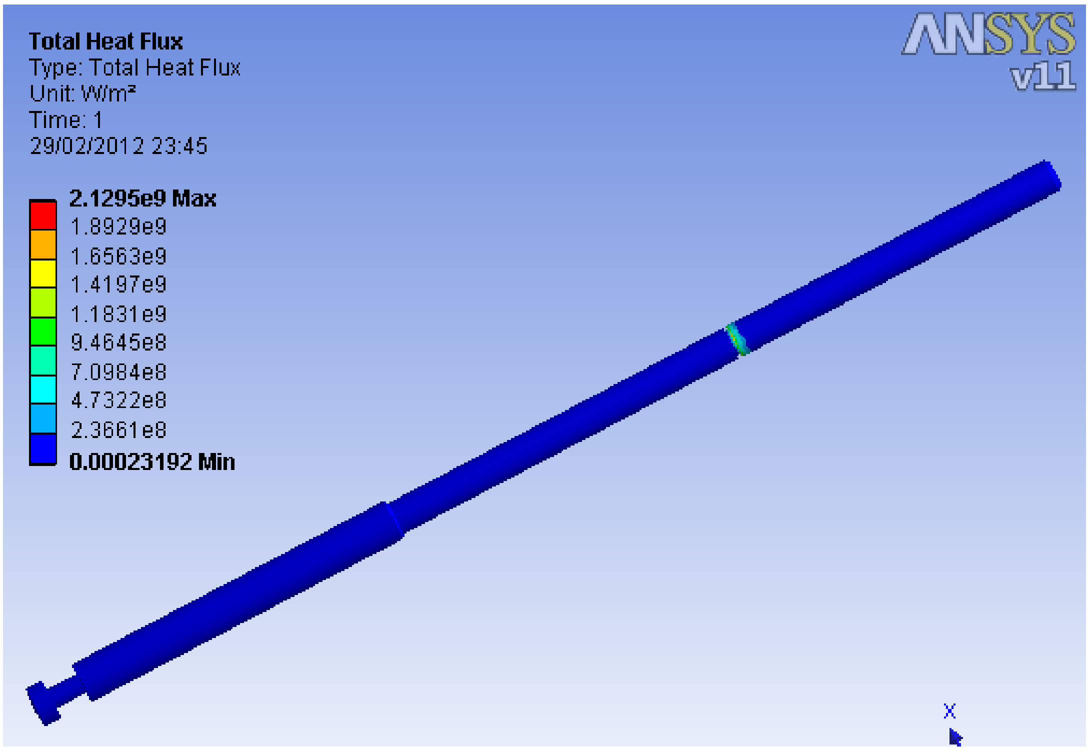

Figure 4.11: Heat flux of stem

Temperature rate of the stem as given in Figure 4.12.

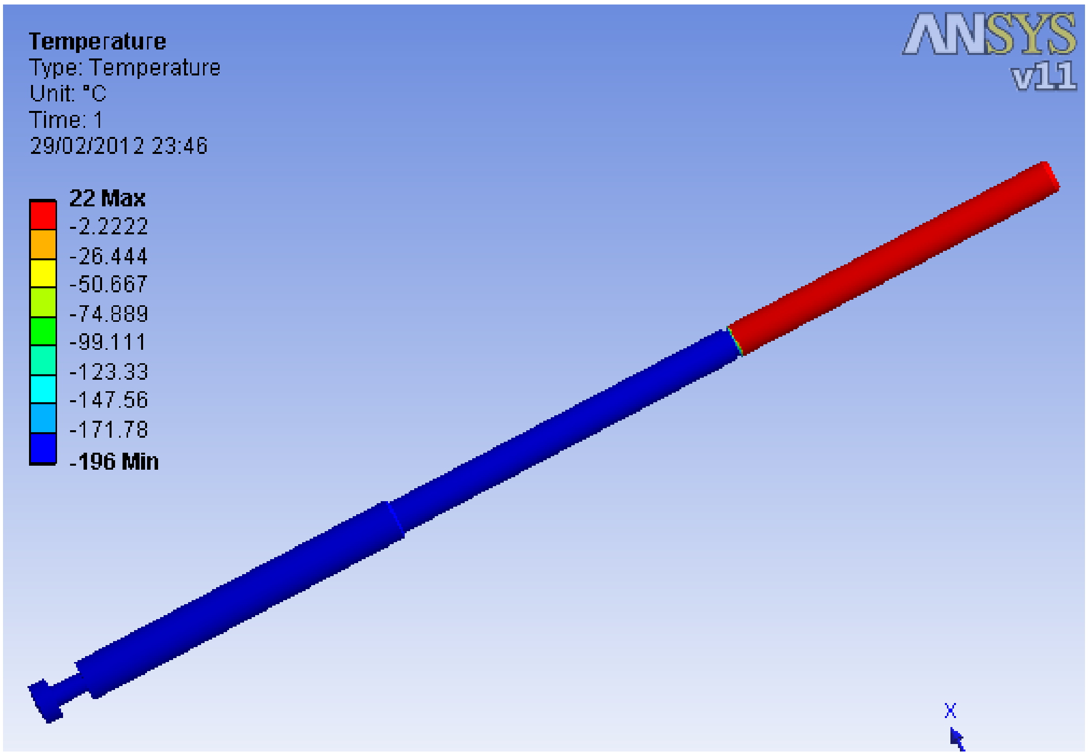

Figure 4.12: Temperature rate of stem

Chapter 5

Optimization of Stem

OPERATING CONDITIONS

Running Pressure class = 150 class (20 bar)
EXPECTED TEMP = -196^{o}C

MODELLING IN PRO/E
Design of the stem is changed by providing a slot in the stem where it is connected to the wedge. PRO/E model of the modified stem is shown in Figure 5.1. The model is transferred to ANSYS in IGES format.

Model is meshed using ANSYS workbench. Model is meshed using solide 186 element which consist of 82453 nodes and 46727 elements.

Analysis is carried out for the valve in open condition. Total force acting in this condition $29316N$.

Figure 5.2 shows the deformation plot of the stem. The maximum deformation of the stem in compression load is $0.14mm$. Induced deformation ($0.14mm$) is less than the permissible deformation ($0.3mm$) and hence the design is safe.

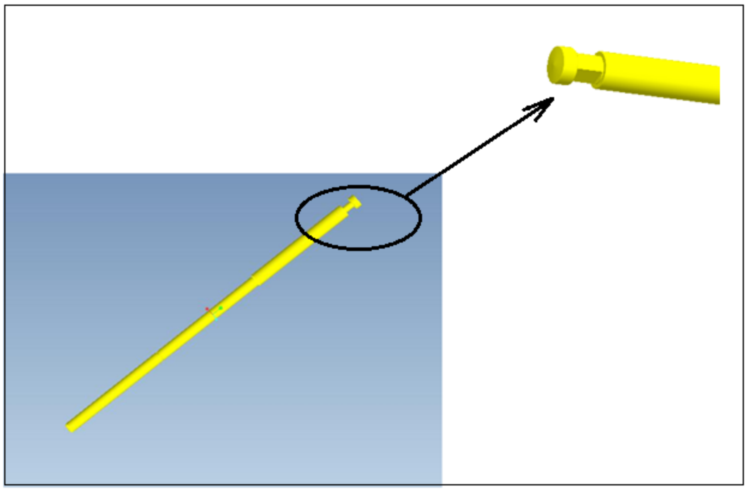

Figure 5.1: Solid model of optimization of stem

Figure 5.3 shows the equivalent stress plot of the stem. The maximum stress of the stem in compression load is 59.87 N/mm^2. Induced equivalent stress (59.87N/mm^2) is less than the permissible stress (137N/mm^2) and hence the design is safe.

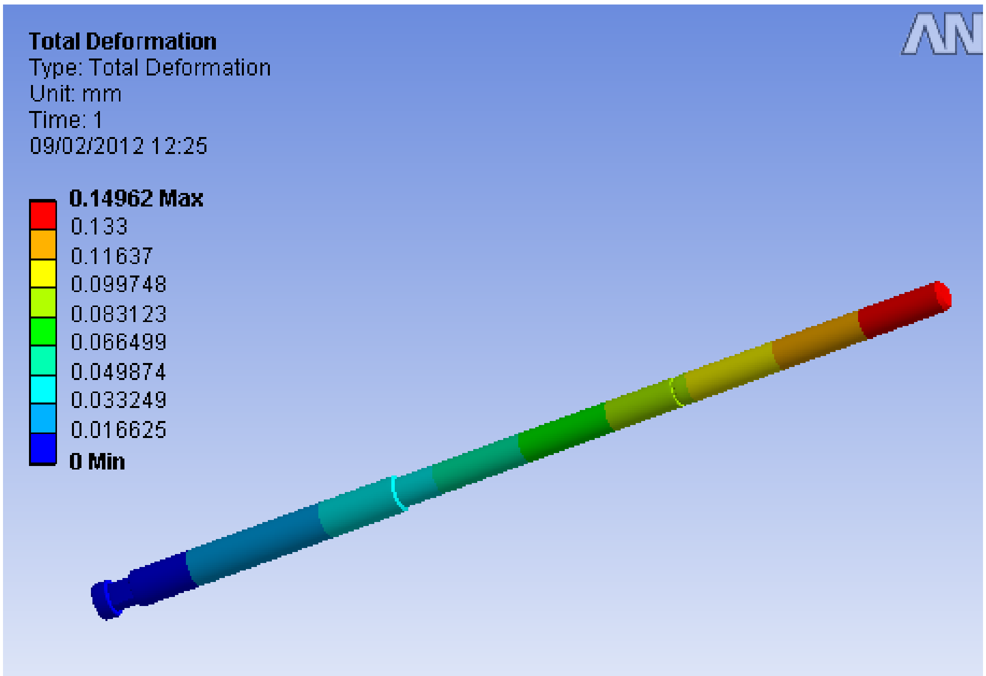

Figure 5.2: Total deformation of optimization of stem

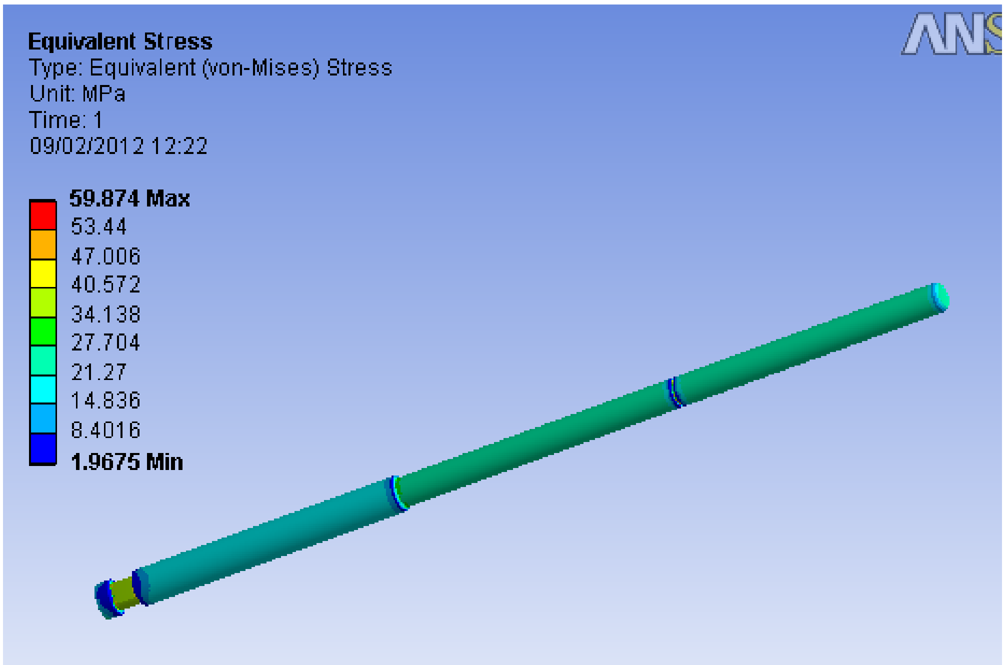

Figure 5.3: Equivalent stress of optimization of stem

5.1 Buckling Analysis of optimized stem

Buckling analysis of the stem is carried out. From the buckling analysis the load multiplier obtained is 0.39643. The buckling load ($11620N$) can be calculated as original load ($29316N$) times the load multiplier (0.39643). Buckling load obtained through ANSYS is less than the theoretical buckling load and hence design is safe.

Figure 5.4 shows the buckling deformation plot of the optimized stem. The maximum buckling deformation of the stem in compression load is $0.16mm$. Induced buckling deformation ($0.16mm$) is less than the permissible buckling deformation ($0.3mm$) and hence the design is safe.

Figure 5.5 shows the equivalent stress plot of the optimization stem. The maximum equivalent stress of the stem in compression load is 80.41 N/mm^2. Induced equivalent stress (80.41N/mm^2) is less than the permissible stress (137 N/mm^2) and hence the design is safe.

Figure 5.6 shows the deformation plot of the optimized stem. The maximum deformation of the stem in compression load is $0.20mm$. Induced deformation ($0.20mm$) is less than the permissible buckling deformation ($0.3mm$) and hence the design is safe. Deformation of 0.16 mm does not cause major problem and leakage in the valve.

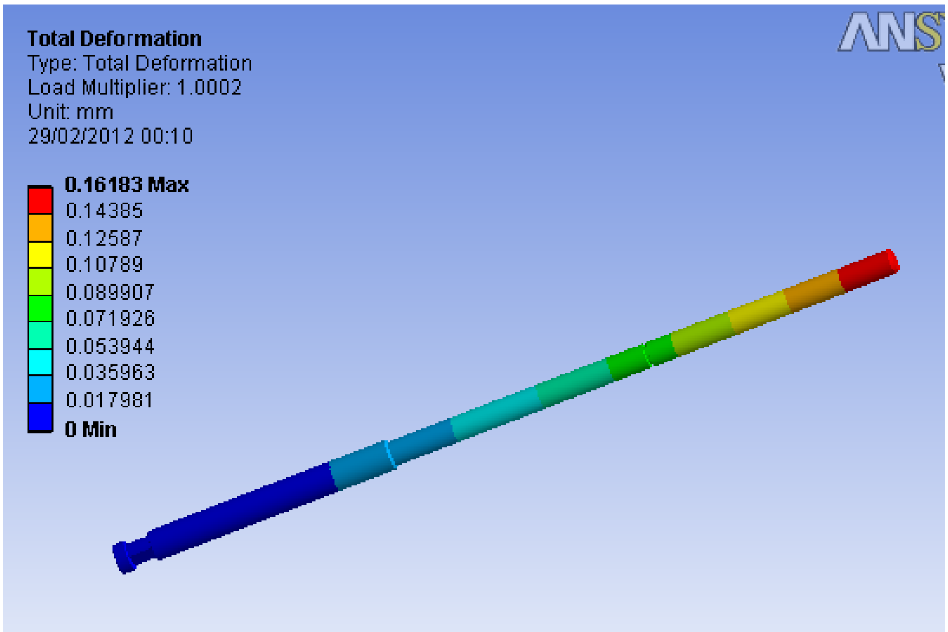

Figure 5.4: Buckling deformation of optimization stem

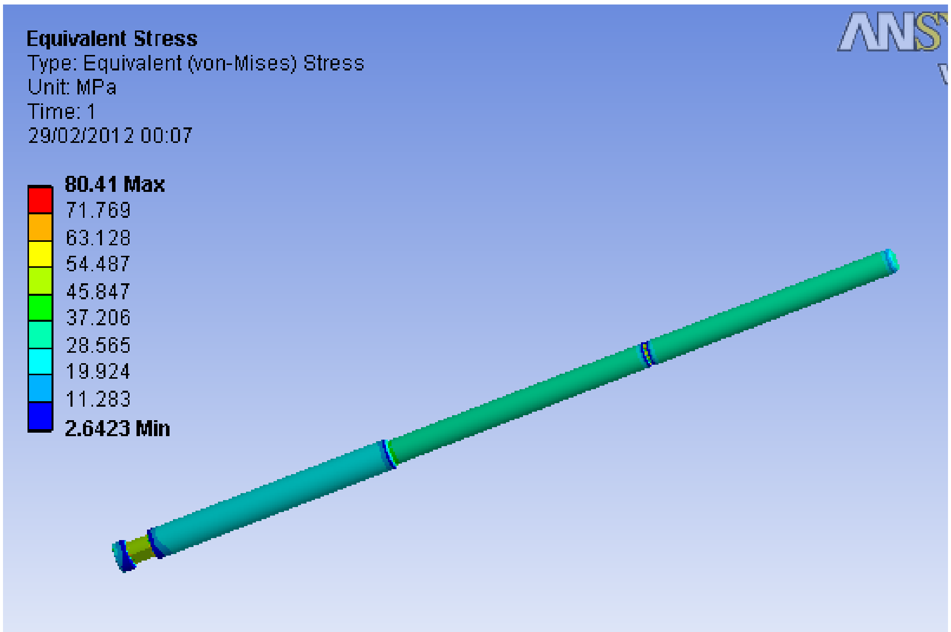

Figure 5.5: Equivalent stress of optimization stem

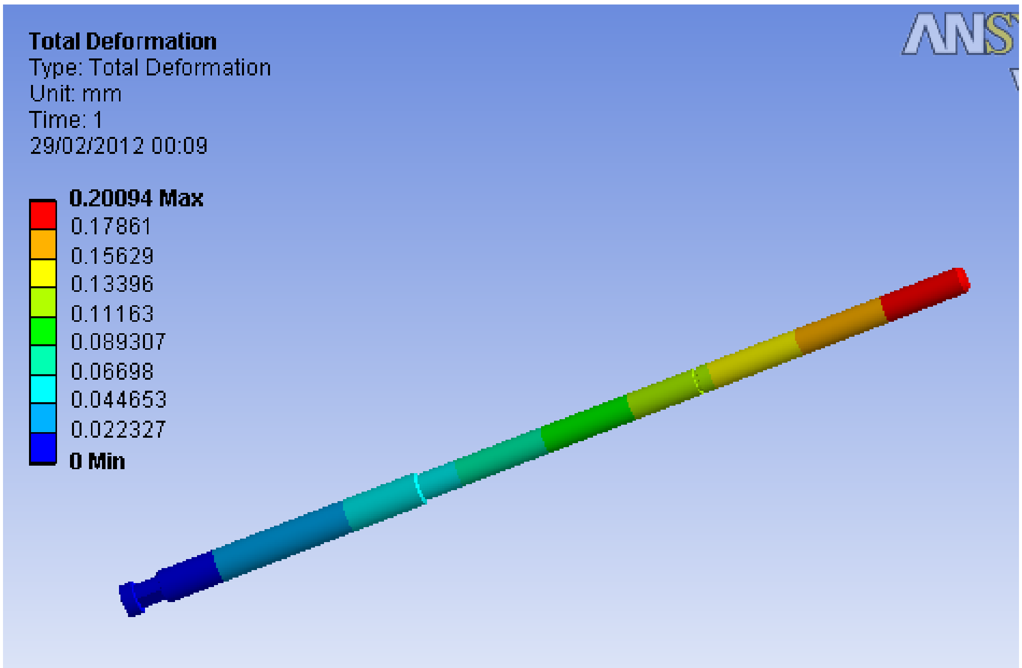

Figure 5.6: Total deformation of optimization stem

5.2 Thermal Analysis of optimized stem

Thermal analysis is carried out at -196^{o}C. In this case top of the stem part temperature is 22^{o}C and bottom of the stem part temperature is -196^{o}C. Thermal analysis is carried out to obtain the total heat flux and temperature rate.

Figure 5.7 Shows the heat flux plot of the stem. The maximum heat flux of the stem at -196^{o}C temperature is 3.23 W/mm^2. Induced heat flux (3.23W/mm^2) is less than the permissible heat flux (5W/mm^2) and hence the design is safe.

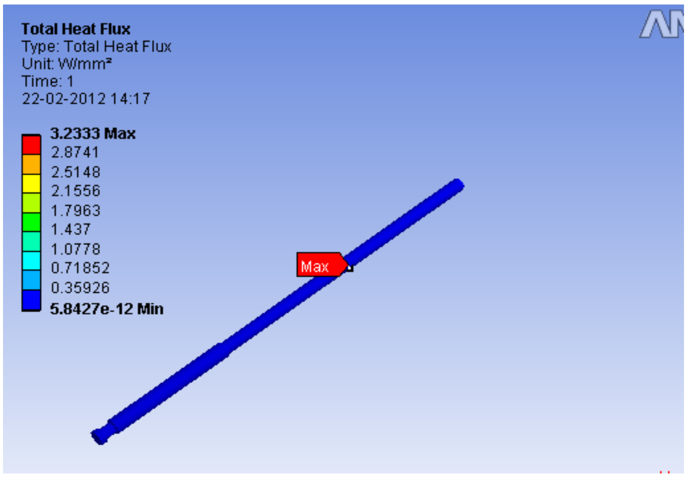

Figure 5.7: Heat flux of optimized stem

Temperature rate of optimized stem as shown in Figure 5.8

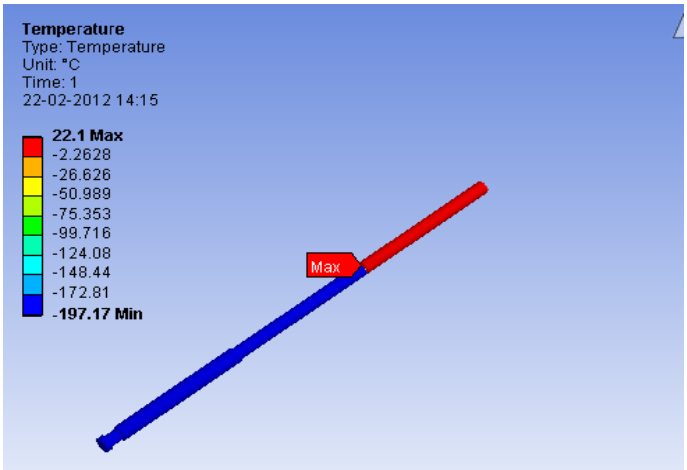

Figure 5.8: Temperature rate of optimized stem

5.3 Analysis of wedge

MATERIAL PROPERTIES AND OPERATING CONDITIONS.

Stainless steel (ASTM A351 Gr.CF8)

Design pressure = 2 N/mm^2

Packing friction co-efficient (μ) = 0.2

Thermal expansion = 17.5 e-6/K

Thermal conductivity = 16.8 W/m.K

Poison's ratio= 0.30

Limiting stress (compression) = 137 MPa (As per standard ASTM A 351)

Model of the wedge is created in PRO/E and than exported to ANSYS in IGES format. For volume meshing solid 186 element is used. Meshed model consists of 199450 nodes and 121825 elements. Structural analysis of the wedge is carried out to find out equivalent stress and total deformation.

Here wedge is considered fixed and force of the fluid (F) 2N/mm^2 is applied at one side of the wedge.

Figure 5.9 shows the force applied on the model.

Figure 5.10 shows the deformation plot of the wedge. The maximum deformation of the wedge is 0.01mm. Induced deformation (0.01mm) is less than the permissible deformation (0.1mm) and hence the design is safe.

Induced deformation 0.01mm does not cause major problem and leakage in the valve.

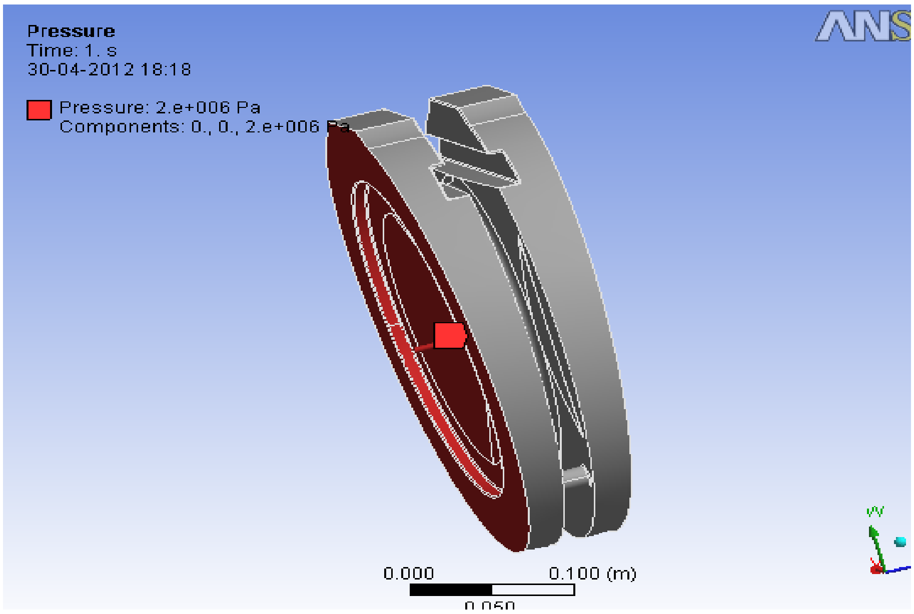

Figure 5.9: Pressure applied on the wedge

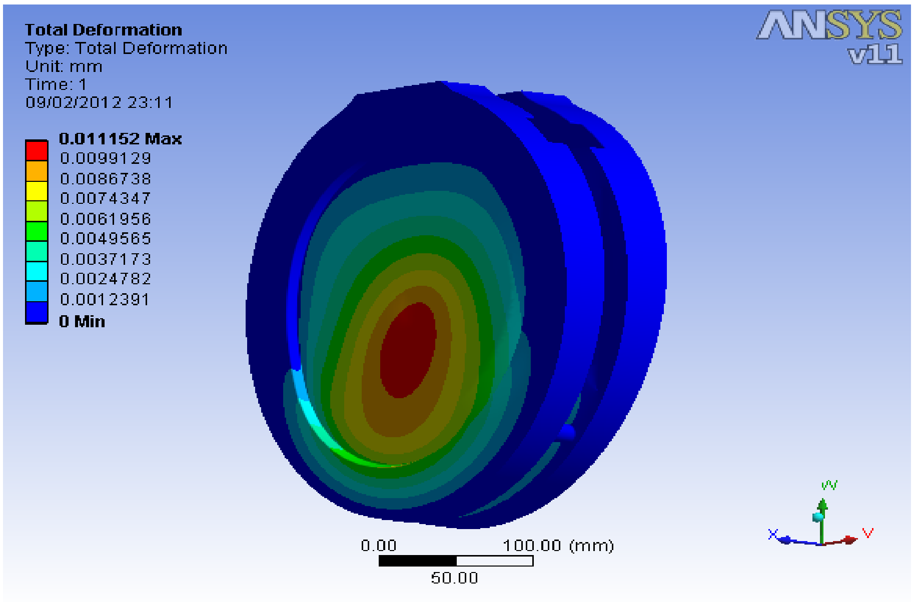

Figure 5.10: Total deformation of the wedge

Figure 5.11 shows the equivalent stress plot of the wedge. The maximum equivalent stress of the wedge is 53.52 N/mm^2. Induced equivalent stress (53.52 N/mm^2) is less than the permissible stress (96 N/mm^2) and hence the design is safe.

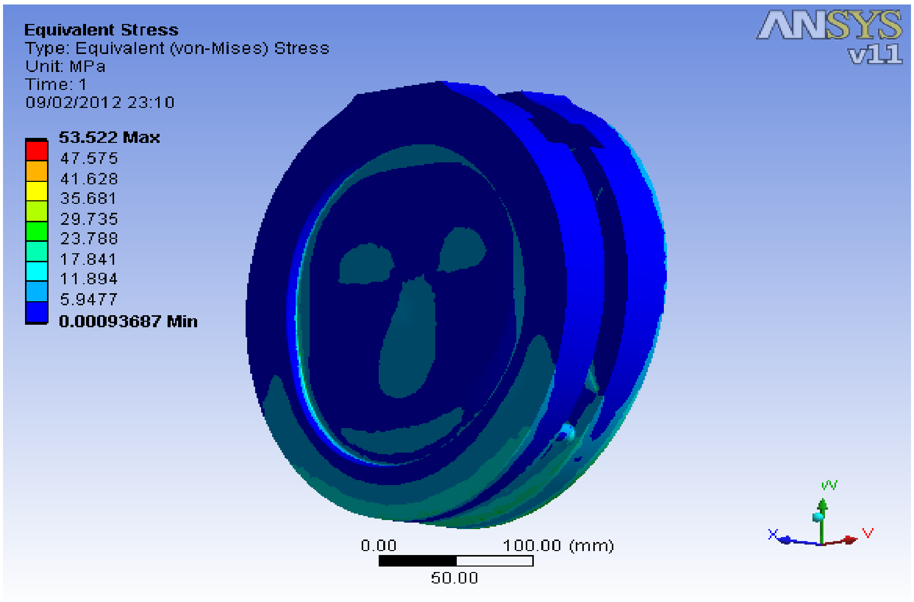

Figure 5.11: Equivalent stress of the wedge

5.3.1 Thermal Analysis of wedge

Thermal analysis of the wedge is carried out at temperature -196^{o}C to find out total heat flux. This heat flux is compared to allowable heat flux.

Figure 5.12 shows the heat flux plot of the wedge. The maximum heat flux of the wedge at -196^{o}C temperature is 7.89 W/mm^2. Induced heat flux (7.89W/mm^2) is less than the permissible heat flux (8W/mm^2) and hence the design is safe.

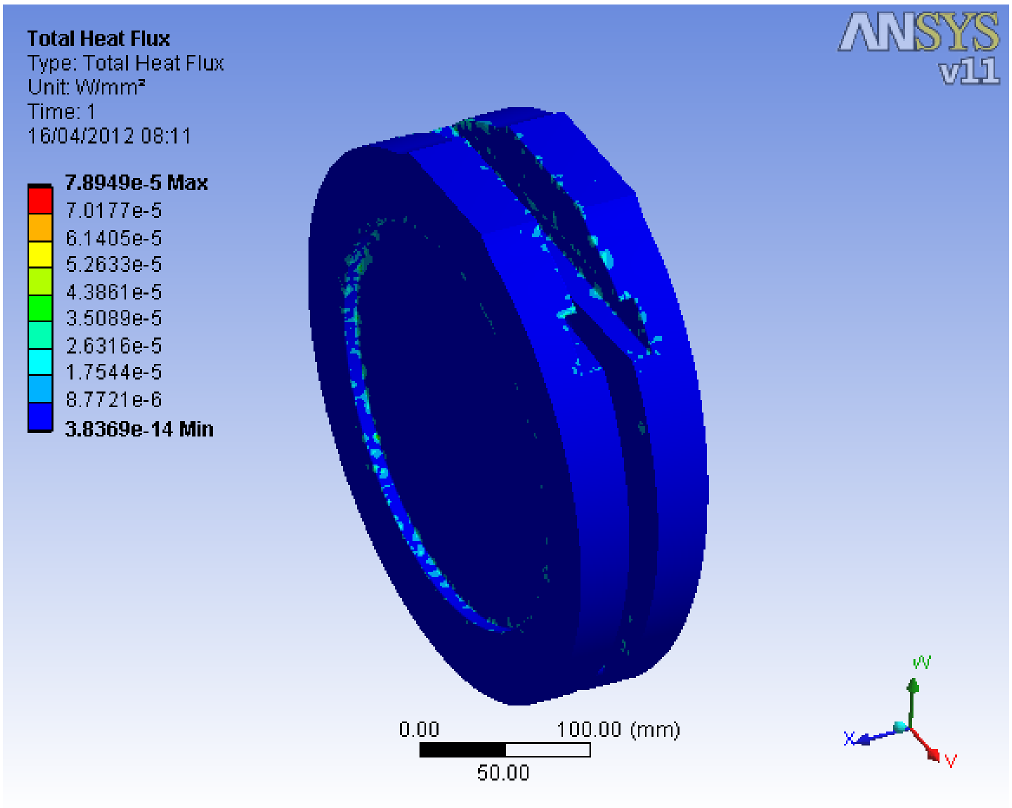

Figure 5.12: Heat flux of the wedge

5.4 Analysis of body

Model of the valve body is prepared in PRO/E and exported to ANSYS workbench in IGES format. Meshing of the model is done using solid 186 element. Meshed model consists of 39033 nodes and 19956 elements. Structural analysis of the valve body is carried out to find equivalent stress and total deformation.
Body is considered fixed in bolting side and force of the fluid (F) 2N/mm^2 is applied at one side of the body.

Figure 5.13 shows the equivalent stress plot of the body. The maximum equivalent stress of the body is 35.11 N/mm^2. Induced equivalent stress (35.11 N/mm^2) is less than the permissible stress (96 N/mm^2) and hence the design is safe.

Figure 5.14 shows the deformation plot of the body. The maximum deformation of the body is 0.007mm. Induced deformation (0.007mm) is less than the permissible deformation (0.1mm) and hence the design is safe.

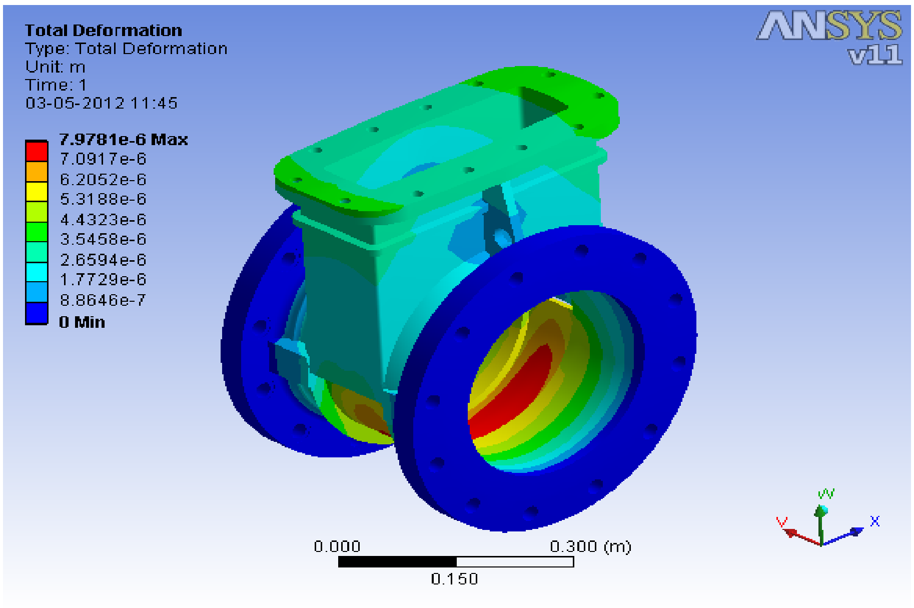

Figure 5.13: Equivalent stress of body

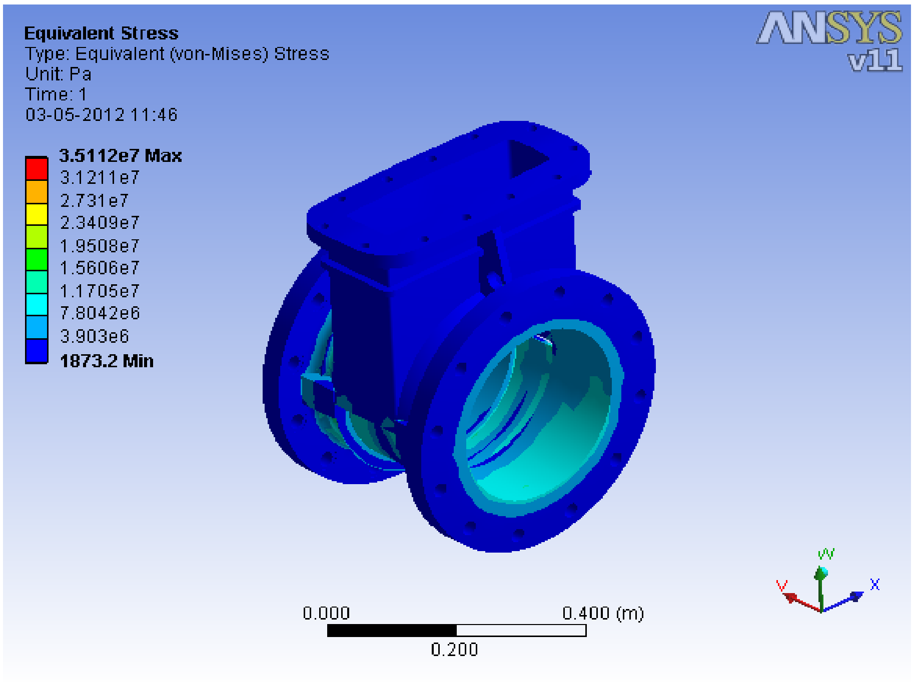

Figure 5.14: Total deformation of the body

5.4.1 Thermal Analysis of Body

Thermal analysis of the body is carried out at temperature -196^{o}C to find out total heat flux. This heat flux compared to allowable heat flux.

Figure 5.15 Shows the heat flux plot of the body. The maximum heat flux of the body at -196^{o}C temperature is 6.22 W/mm^2. Induced heat flux (6.22W/mm^2) is less than the permissible heat flux (8W/mm^2) and hence the design is safe.

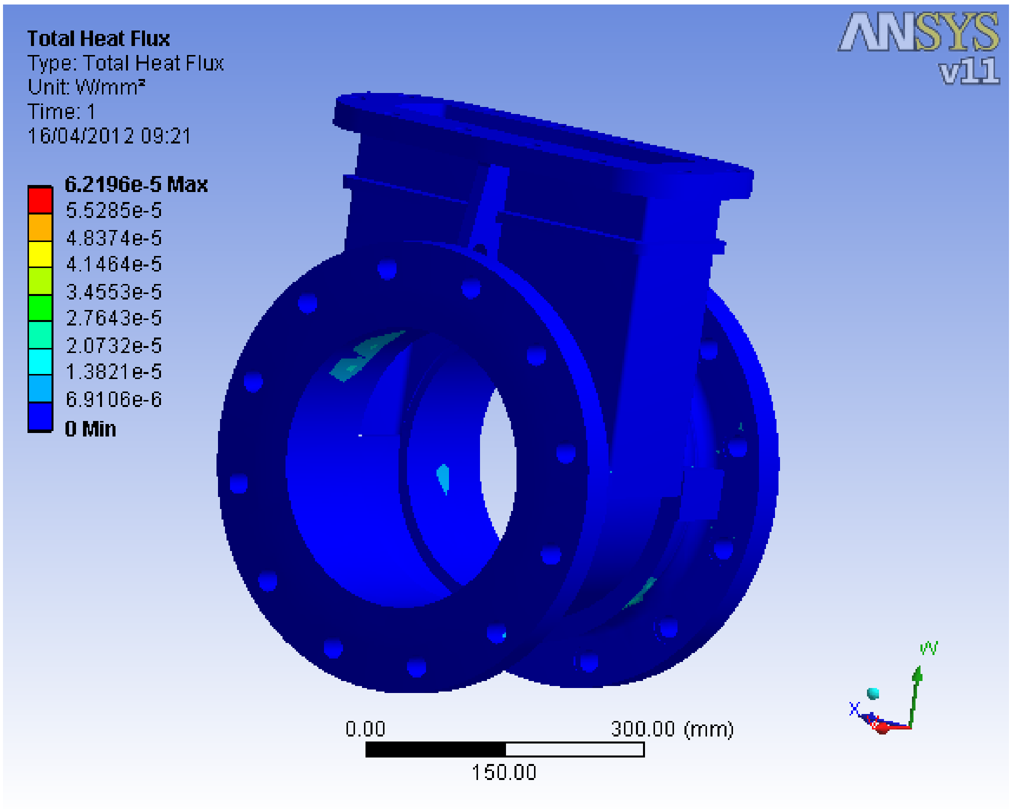

Figure 5.15: Heat flux of the body

Chapter 6

Conclusion and Future Scope

Diameter of the stem is calculated by using the relevant standards and final value for the cryogenic valve dessign under consideration is 16.4535 mm.

Shell thickness is calculated using the different relevant standards and is summarized in Table 6.1. Maximum thickness is as per API 600 and hence it is selected for this cryogenic application.

Table 6.1: Shell thickness using different formulas

Using different formulas	Shell Thickness mm
IBR	9.04
ASME B16.34	4.96
Design hand book	9.5
ASMEE SEC VIII DIV-I	3.7
API 600	16

Table 6.2 shows the summery of analysis of the stem using ANSYS. Induced deformation and stresses generated in existing and optimized model are well within the permissible limits.

Table 6.2: Summary of analysis of the stem component

For Stem	Existing	Existing	Optimized	Permissible
	Tensile	Compression		
StressN/mm^2	81.96	72.65	59.87	137
Deformation(mm)	0.16334	0.16284	0.14	0.30
Buckling deformation (mm)	-	0.20	0.16	0.30
Heat flux (W/mm^2)	-	2.12	-	5

Table 6.3 shows the summery of analysis of the body using ANSYS. Induced deformation and stresses generated in existing and are well within the permissible limits.

Table 6.3: Summary of analysis of the body Component

For Body	Existing	Permissible
StressN/mm^2	35.11	96
Deformation(mm)	0.01	0.1
Heat flux (W/mm^2)	6..21	8

Table 6.4shows the summery of analysis of the wedge using ANSYS. Induced deformation and stresses generated in existing and are well within the permissible limits.

Table 6.4: Summary of analysis of the wedge Component

For Body	Existing	Permissible
StressN/mm^2	53.52	96
Deformation(mm)	0.01	0.1
Heat flux (W/mm^2)	7.8	8

References

[1] API 600 , Bolted bonnet steel gate valves for petroleum and natural gas industries.

[2] ASME B16.34 , Pressure and temperature chart to specified material of CF8.

[3] BS 6364 , Specification for valves for cryogenic service.

[4] ASTM A 351 , Specified chemical and mechanical properties.

[5] WM. Powel company, Valve selection and information, first edition, 1985.

[6] Boiler and pressure vessel ASME VIII Section. Second edition 2000.

[7] ASME boiler and pressure vessel code part D, edition 2004, July 1.

[8] Xue Guan Song, Lin Wang, Seok Heum Baek " Multidisciplinary optimization of butterfly valve ." Elsevier Science-Finite Elements in Analysis and Design (48 (2009) 370 - 377).

[9] Cheng Lin, Raman Mathur, Kostantin Aizikov, single on the cryogenic valve for mass spectrometer resonance.

Appendix A

Detail Drawing of Gate Valve

- Stem
- Body
- Wedge
- Assembly Drawing