DETERMINATION OF FRICTIONAL FORCE FROM RUBBER SEALING AROUND THE NEEDLE

Group P2

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ABSTRACT

Waterjet cutting is used for cutting variety of materials using high pressure water exiting through a nozzle. On/off valves are used to turn on and off the waterjet in cutting operations. Different parameters are to be studied to enhance the number of on/off cycles the valve can be used before service. This paper deals with the frictional forces from the rubber sealing around the needle during the transient opening of the needle for operating pressure in a Normally closed valve. The model is based on the design provided by the KMT waterjet solutions and simulated in ANSYS workbench using Explicit Dynamics module. Stress distribution on the inner surface of the seal is observed and the influence of outer diameter of the sealing on the frictional forces is suggested.

CONTENTS

INTRODUCTION

Waterjet cutting is used for fabrication purposes for materials that are sensitive to high temperatures generated by other methods. It is used to cut variety of materials like metals, alloys, rubbers, glass, wood, food and some composite materials. They can cut hardest materials like carbon fiber and soft materials like cake as well. Waterjet cutting is used in many applications such as cutting, shaping, reaming in industries like mining, aerospace etc.

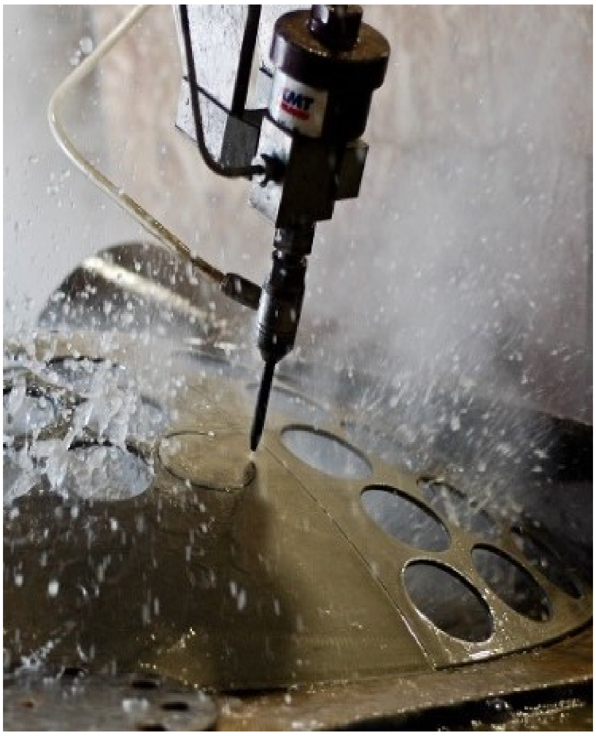


Figure 1: Waterjet cutting head

The principle of waterjet cutting process is cutting materials using waterjet of very high pressure coming out of nozzle. There are two types of waterjet cutting machines.

1. Pure water waterjet cutting machine
2. Abrasive waterjet cutting machine

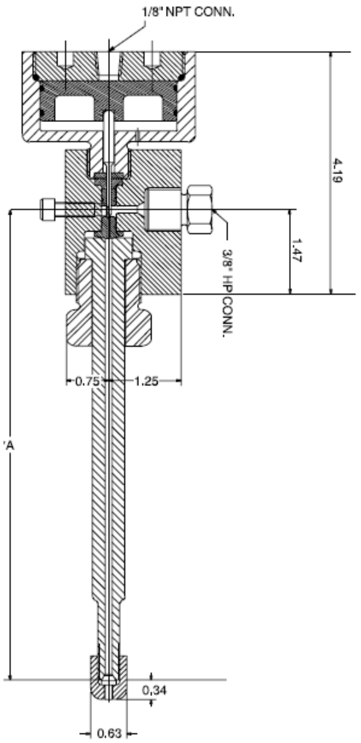
Pure water waterjet machines uses only water to cut materials. They cut soft materials like non-metallic materials, foam, rubbers and some plastics.

Abrasive waterjet cutting machines adds abrasives in the waterjet to cut materials. They cut hard materials like metals, alloys and some other composite materials.

The flow of waterjet in cutting process is controlled by pneumatic valves. Pneumatic valves are used to turn on and off the waterjet. The on/off motion of the actuator is sealed internally, reducing dust/grime and extending the valve life. There are different types of valves used for many applications but, the main two types of valves are Normally open valve and Normally closed valve. Air pressure is used to open and close the valves during operation of waterjet machine.

A Normally open valve requires air pressure to close it. Loss of air pressure automatically opens a Normally open valve and releases any stored water pressure. A Normally open valve is designed for high frequency operation (with the maximum cycle performance).

A Normally closed valve requires air pressure to open it. A Normally closed design provides fail-safe operation, shutting off the waterjet if electricity or air pressure fail. Loss of air pressure closes the valve and no water pressure is lost.



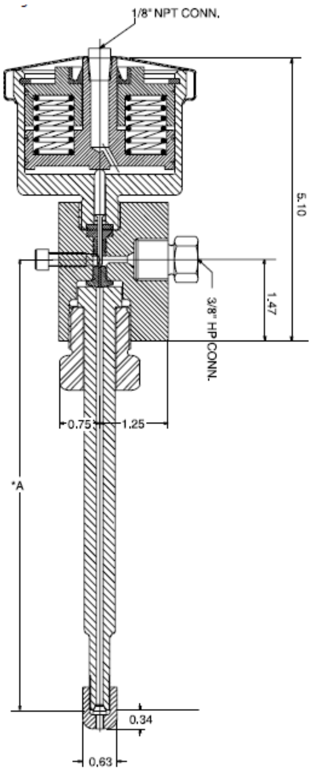


Figure 2(a): Normally open valve *Figure 2(b): Normally closed valve*

The valves in waterjet cutting machines are subjected to many on/off cycles in various applications. The number of on/off cycles is different for different waterjet cutting applications. Therefore there is a need to understand and study the parameters that could enhance the number of cycles of the valve before service.

The waterjet cutting machine is designed such that the needle is placed below the piston in the machine. A portion of the lower part of the needle is surrounded by a rubber sealing. During the operation of the valve, the waterjet is projected on the tip of the needle which forces the needle upwards thus projecting the waterjet. During this operation, frictional forces are created between the inner surface of the Rubber sealing and the lower part of the needle.

PROBLEM STATEMENT

The task is to determine the frictional force from the rubber sealing around the needle during the transient opening of the needle in a Normally closed valve for an operating pressure of 4000 bar. The further task is to suggest on how the outer diameter of the sealing influences the behavior.

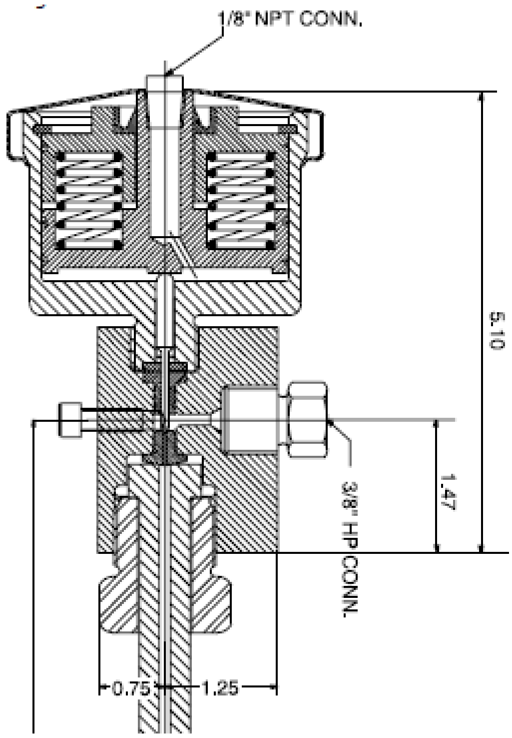


Figure 3: Functioning region of needle in the valve

METHOD

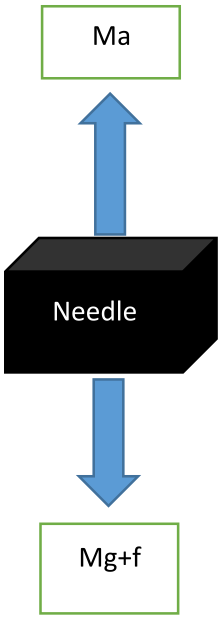
For the initial approach to solve the problem, modelling the whole spring assembly and piston of the normally closed valve, the needle, the sealing and the nozzle were considered. To narrow down the design space and to save the simulation time, only the needle and the rubber sealing are modelled. Thus only the design of the needle and the sealing are sufficient.

After the design of the needle and the sealing are completed, they are saved in a cad file format which is supported by all the simulation software's.

The modelling is done in Autodesk inventor and the simulation is carried out in ANSYS Workbench in the explicit dynamics module.

Trial 1

The given problem was solved analytically considering the free body diagram of the system in consideration.



- For the needle to move in the upward direction it sum of the upward force must be greater than the sum of downward forces. As the dynamic condition is considered.
- M = 0.004kg

$$Ma > Mg + f$$

- From the Equations of motion
- In this case the Needle moves in the upward direction hence,

$$S = ut - \frac{1}{2} \times gt^2$$

The needle moves 3.6mm in the span of 48Ms (Acquired from KMT Waterjet Catalogue)

⇨ $3.6 = 0 \times t - (9810 - a) \times (48 \times 10^{-3})^2$

⇨ $a = 12.935 \frac{m}{s^2}$

- From the equation

$$Ma > Mg + f$$

- Frictional Force,

$$f < Ma - Mg$$

⇨ $f < 1.25 \times 10^{-3}\ N$

Trail 1 was not considered as there would be many other factors influencing the frictional force which make the frictional force not reliable therefore Trail 2 was implemented.

Trial 2

First to know how the sealing works we have chosen static structural module and considered only the rubber sealing. Fixing the outer surface of the rubber sealing an arbitrary pressure is applied on the base of the sealing. After solving the model, the total deformation of the sealing is observed. From the results obtained we can see that because of the pressure applied on the base, the sealing has a push affect inside and this acts as the seal which prevents the water flow.

Comsol Multiphysics is used to solve the problem initially. As no perfect results were obtained, the Explicit dynamics module in Ansys workbench is used and the results obtained from this are considered.

From the results obtained in Ansys workbench the frictional force is carried out as follows:

The output from the simulation is the distribution of shear stress on the inner surface of the rubber sealing. As the rubber sealing is fixed and the needle is moving upwards, the force due to the movement of the needle produces a frictional shear stress on the inner surface of the sealing. From the frictional shear stress, the frictional force is calculated.
Frictional force = Frictional shear stress * Inner surface area of the rubber sealing.

To check the influence of the outer diameter of the sealing on the frictional force, different models were created with different outer diameters of the sealing. The thickness which is the difference of the outer diameter and the inner diameter of the sealing is varied and the frictional force is calculated in each case.

The frictional force obtained originally (between the sealing and needle for the given dimensions) is noted down. Then the frictional force is calculated using different thickness values and compared to the basic value. From the results obtained, a general conclusion is made on how the outer diameter value effects the frictional force.

SOLUTION

Modelling:

The needle and the rubber sealing are modelled in Autodesk Inventor separately and are assembled together.

For the modelling of needle the known dimensions which were presented in the parts video are used and the unknown dimensions were scaled from the dimensions chart of the normally closed valve. The seal is also modelled by scaling its dimensions from the dimensions chart.

The figures of the needle and the seal that are created are shown in the below figures

Figure 4: Design of the needle

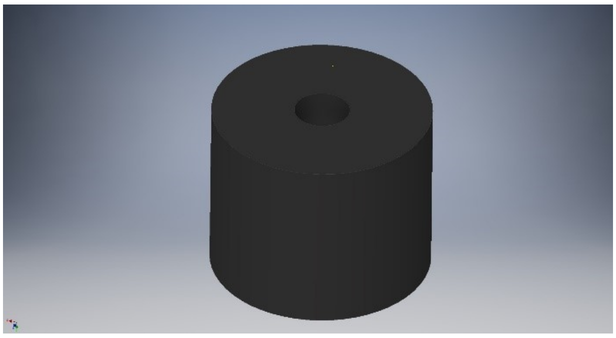


Figure 5: Design of the rubber Sealing

These two are assembled and the figure is shown below:

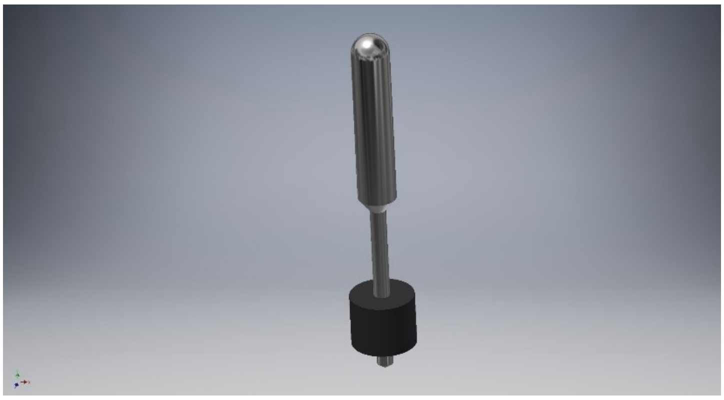


Figure 6: Assembly of the needle and the Sealing

Simulation

First to know how the sealing works we have chosen static structural module and considered only the rubber sealing. Fixing the outer surface of the rubber sealing an arbitrary pressure is applied on the base of the sealing. After solving the model, the total deformation of the sealing is observed. From the results obtained we can see that because of the pressure applied on the base, the sealing has a push affect inside and this acts as the seal which prevents the water flow. The results can be seen in the figure below:

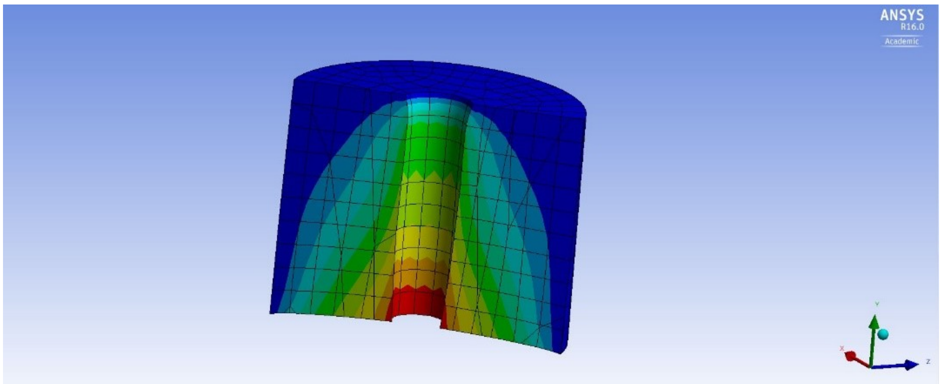


Figure 7: Deformation of the sealing when pressure is acting

Using the pressure and the boundary conditions such as the displacement of the needle in Y direction, the time for the analysis and the fixed supports the problem is solved in the Explicit dynamics module of Ansys Workbench. Because of the properties of the rubber we have considered and due to the high pressure acting on the lower sealing surface, the rubber wasn't able to handle this pressure and it exploded. The results obtained from this method are not reliable and hence they weren't considered. The obtained results are shown in the below figure:

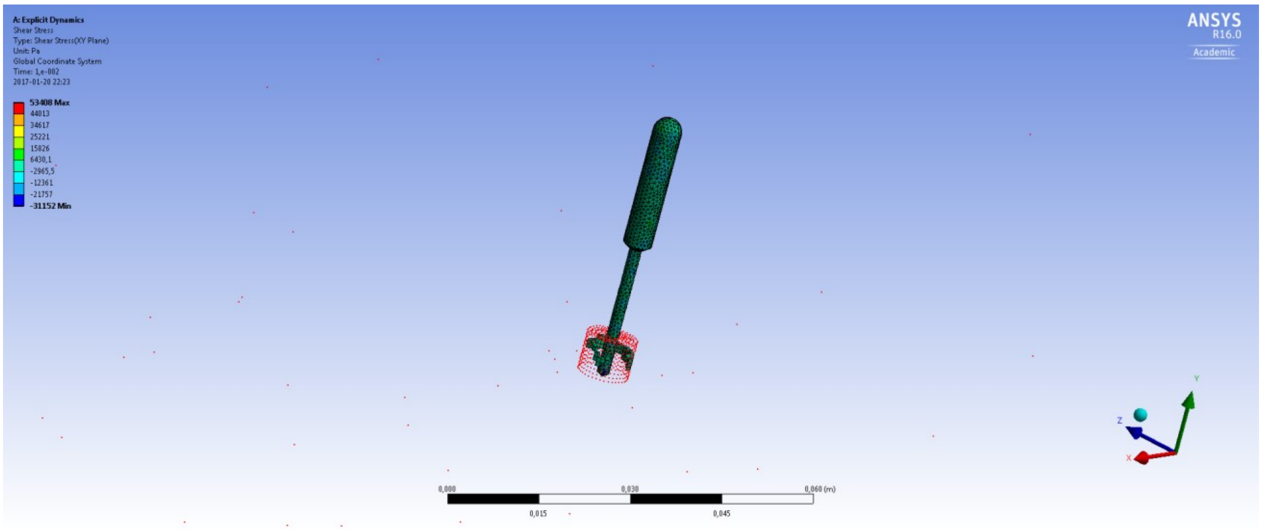


Figure 8: simulation of the system with pressure

So Comsol Multiphysics was used to solve the problem.

Initially, the flow in the pipe is observed by carrying out computational fluid dynamic analysis in COMSOL Multiphysics.

A pressure of 4000 bar is given at the inlet of the pipe and using the equation of continuity, the velocity at the exit of the pipe is calculated which is applied to the flow at the exit.

The output from the simulation is pressure at the exit of the pipe. Using this pressure, the force on the tip of the needle that is in contact with the water is calculated. Applying equations of motion, the frictional force is calculated. It was observed that the force at the tip of the needle is equal to the frictional force from rubber sealing around the needle which implies the needle doesn't move upwards. Hence, this approach is considered to be wrong.

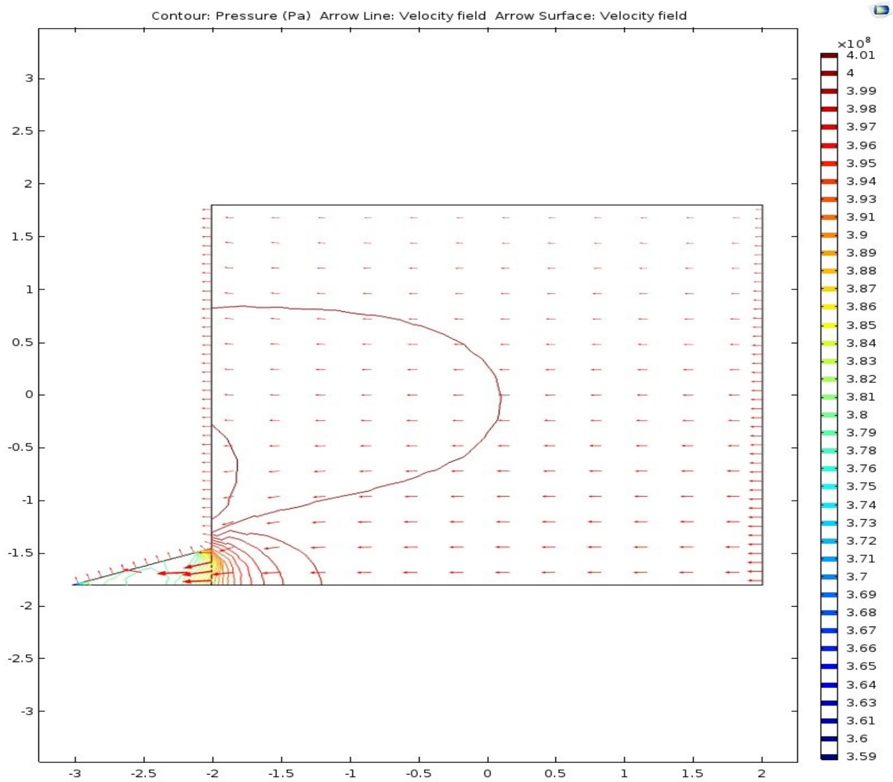


Figure 9: Results obtained from Comsol

Hence to solve the problem in a different software, the model is imported into ANSYS Workbench and from the analysis systems, the explicit dynamics module is chosen.

In Ansys Workbench, in the explicit dynamics module first the materials are chosen. Stainless steel is chosen for the needle as it prevents corrosion and rubber was chosen as the sealing material. The properties of rubber such as the material constants and the incompressibility parameters were considered from the Experimental data from Treloar and from the stress strain data of vulcanized rubber under various types of loading conditions.

The geometry file is then imported into Ansys and the Mechanical Set-up tab is opened. First the contact type between the target body which is the sealing and the contact body which is the needle are defined. The co-efficient of friction and the dynamic co-efficient are also defined. The co-efficient of friction is obtained from a reference and is given as 0.6 and the dynamic co-efficient is given as 0.3. These co-efficient's are between steel and rubber.

After defining the contact surfaces, the boundary conditions such as the fixed support, the displacement of the needle and the analysis time are given.

The outer surface of the bearing and the upper surface are fixed. The displacement for the needle is given as 3.6mm in the positive Y direction. The analysis time is chosen as 48 milliseconds as it was given in the KMT waterjet catalogue. For the mesh, advanced meshing feature with proximity and curvature sizing is used.

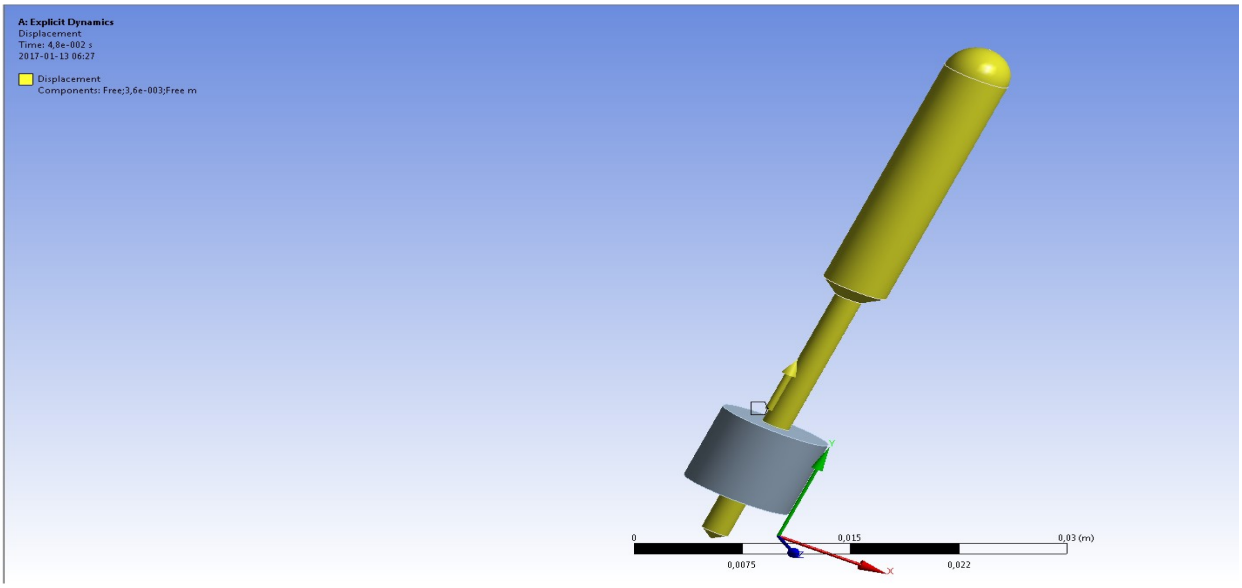


Figure 10: Displacement of the needle

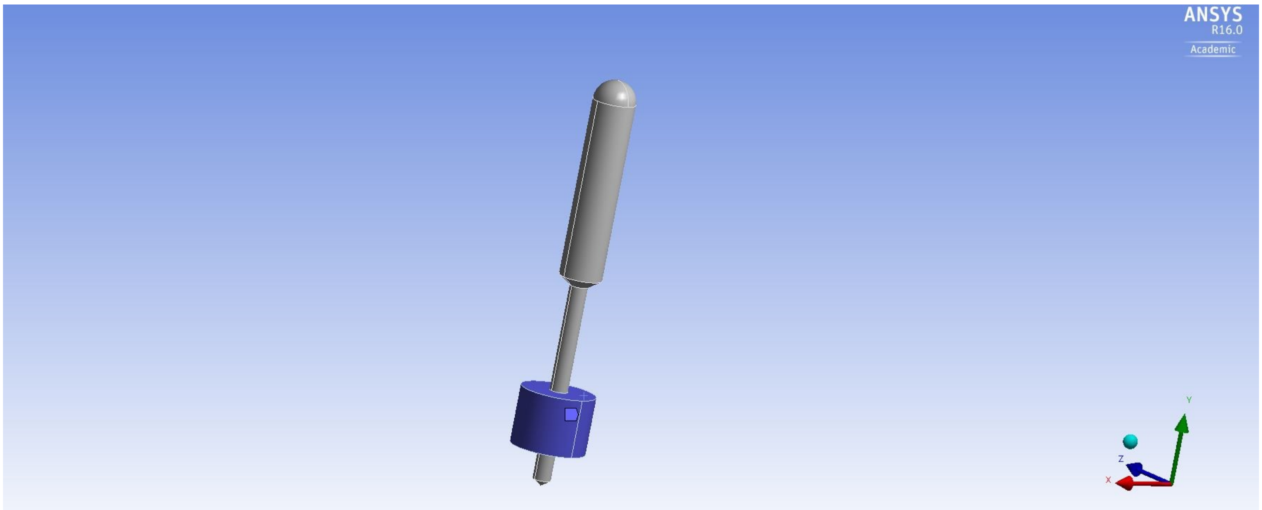


Figure 11: Fixed constrains

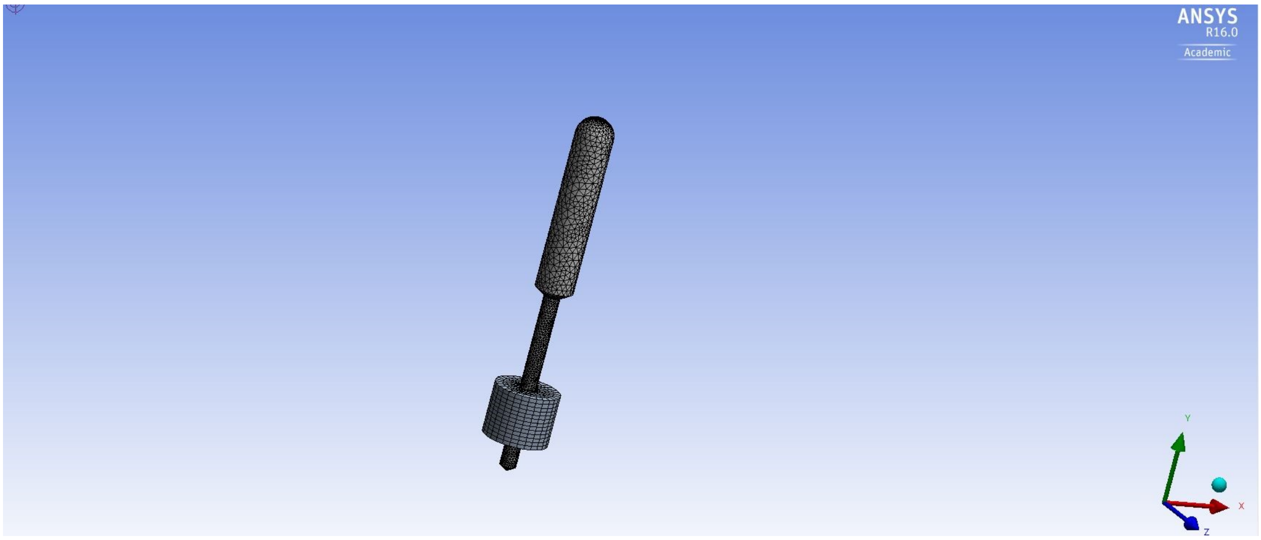


Figure 12: Parts after Meshing

After meshing the problem was solved and the shear stresses were determined and from these shear stresses the frictional force was calculated.

RESULTS

The shear stresses obtained from the solution at the inner surface of the seal is 4737.2Pa.

Multiplying it with the internal surface area of the seal gives the frictional force around the needle which was obtained as 0.1954 N

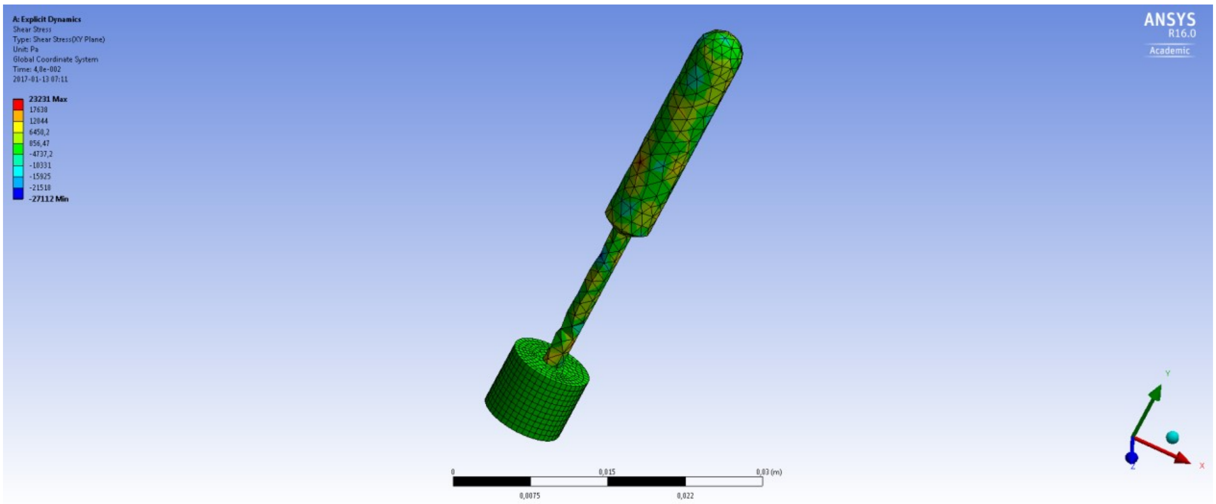


Figure 13: Simulated result for 3mm rubber thickness

S.No.	Inner diameter (mm)	Outer diameter (mm)	Thickness (mm)
1	2.02	8.22	3.1
2	2.02	8.42	3.2
3	2.02	8.62	3.3
4	2.02	8.82	3.4

The Influence of outer diameter rubber sealing on the behavior of frictional forces was analyzed by simulating the problem for various outer diameters for the rubber seal.

Design 1

The shear stress obtained at the interface of rubber sealing and the needle for the rubber thickness of 3.1mm is obtained as 3470 Pa and the frictional force is 0.1431 N.

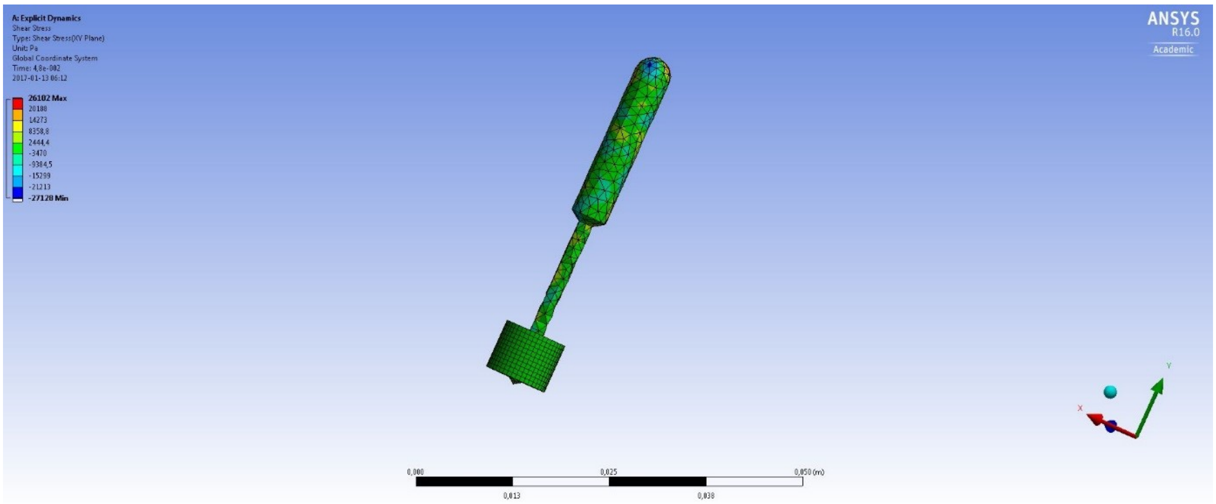


Figure 14: Simulated result for 3.1mm rubber thickness

Design 2

The shear stress obtained at the interface of rubber sealing and the needle for the rubber thickness of 3.2mm is obtained as 1482 Pa and the frictional force is 0.0631 N.

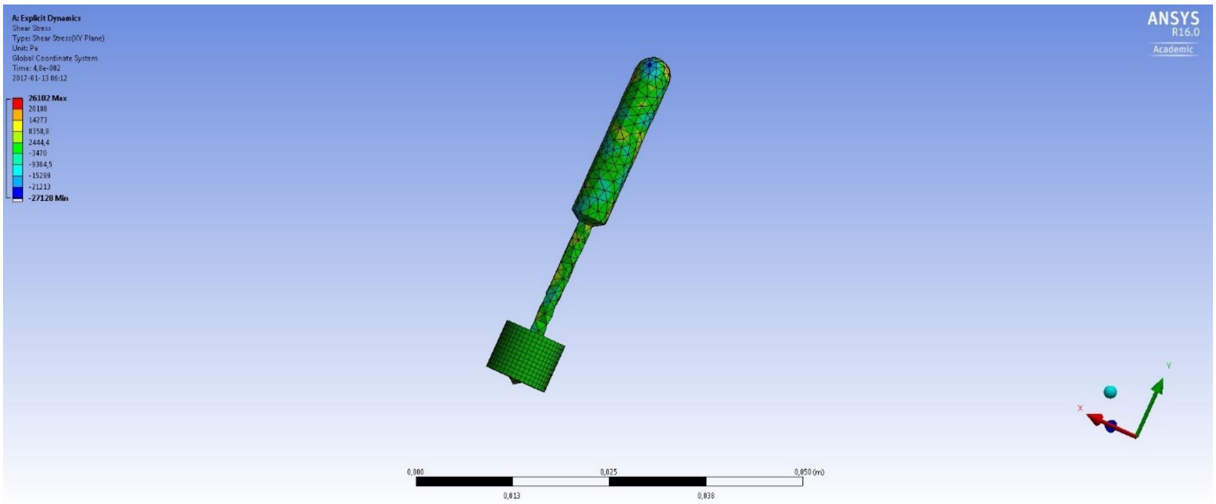


Figure 15: Simulated result for 3.2mm rubber thickness

Design 3

The shear stress obtained at the interface of rubber sealing and the needle for the rubber thickness of 3.3mm is obtained as 1051 Pa and the frictional force is 0.0434 N.

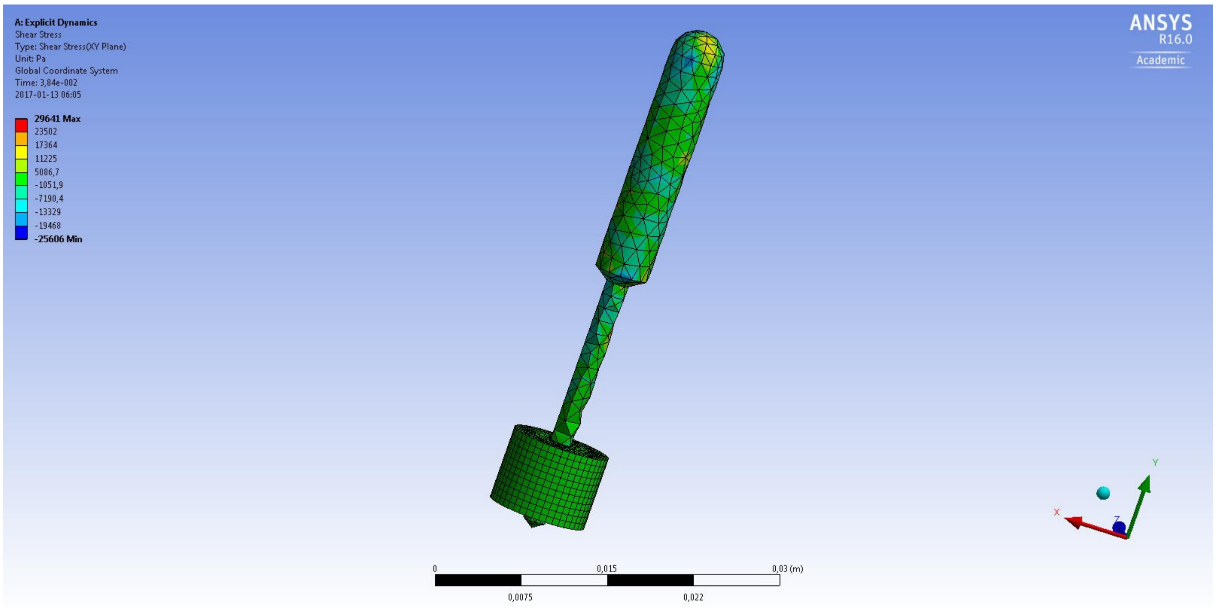


Figure 16: Simulated result for 3.3mm rubber thickness

Design 4

The shear stress obtained at the interface of rubber sealing and the needle for the rubber thickness of 3.4mm is obtained as 1484.6 Pa and the frictional force is 0.0612 N.

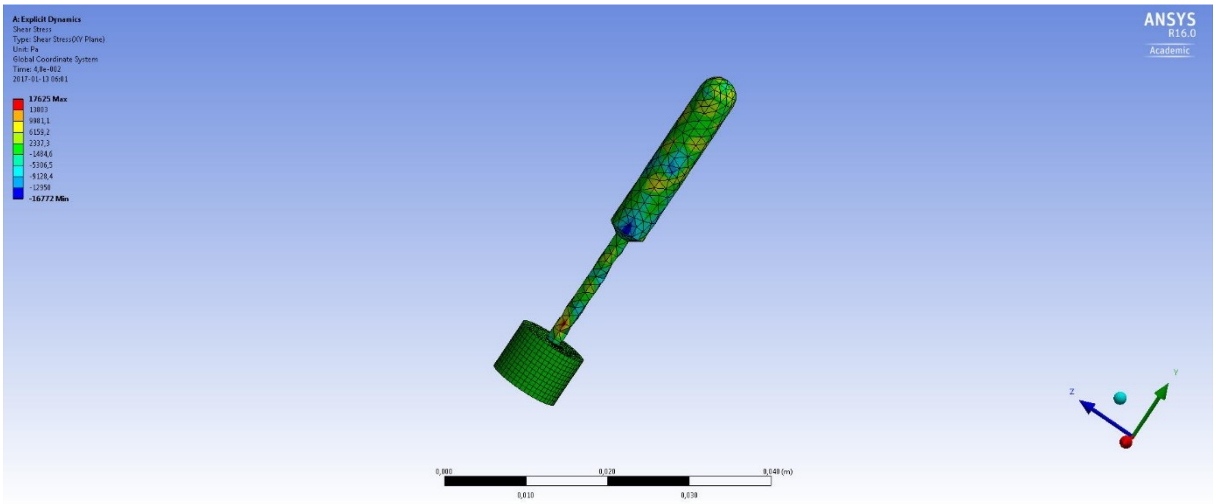


Figure 17: Simulated result for 3.4mm rubber thickness

The value of the frictional force for different outer diameters is plotted in a graph and is presented in the below figure.

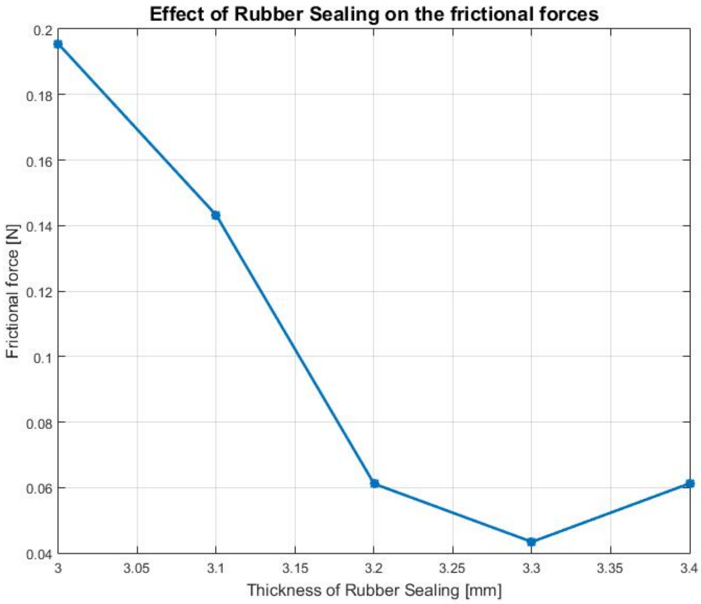


Figure 18: Effect of outer diameter of rubber sealing

DISCUSSIONS & CONCLUSIONS

From the work carried out, it was observed that the frictional force was less for the given system which can be neglected. But the frictional force is comparatively less when the thickness of the sealing is increased from 3 mm to 3.3 mm.

Hence, the sealing with 3.3 mm thickness is suggested as the better one because there is no much increase in material.
Increase in volume of the sealing = 49.401e-9 m^3.

The appropriate results can be obtained by considering the actual conditions of the flow at the tip of the needle, the displacement and the opening time of the needle.

FUTURE WORKS

- Tip angle of the needle could be considered.
- Materials of Needle and the rubber sealing could be considered for precise results.
- Influence of Ogden parameters, incompressibility of the rubber material could be taken into considerations.
- Dimensions of the rubber sealing especially length could be considered more precisely.
- The Inlet Flow could be taken as mixed flow.
- Influence of the length of needle Head could also be taken into consideration.

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SELF-EVALUATION

Name of group members	**Much More**	**More**	**Equal**	**Less**	**Much Less**	**Absent**
Akhil Mora		**X**				
Chetan Bhandare					**X**	
Raghavendra Machipeddi			**X**			
Venkata Sai Vijay Krishna Burra		**X**				
Yashpal Surendhar Goud Pulicherla			**X**			

APPENDIX

```
clc;
clear all;
close all;
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rout1=4.01e-3;
rout2=4.11e-3;
rout3=4.21e-3;
rout4=4.31e-3;
rout5=4.41e-3;
l=6.5e-3;
s1=4737.2;
s2=3470;
s3=1482;
s4=1051.9;
s5=1484.6;
a=2*pi*rin*l;
f1=s1*a
f2=s2*a
f3=s3*a
f4=s4*a
f5=s5*a
f=[f1 f2 f3 f4 f5]
thick=[3 3.1 3.2 3.3 3.4]
plot(thick,f,'-*','LineWidth',2)
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ylabel('Frictional force [N]','fontsize',12);
```

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```