AE242 : METROLOGY AND COMPUTER AIDED INSPECTION

DESIGNING AND MANUFACTURING OF A VISCOMETER

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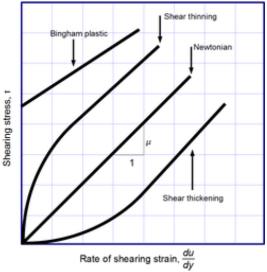
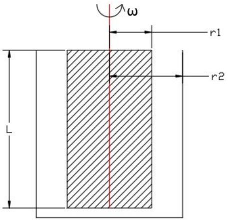
The viscosity of a fluid is a measure of its resistance to deformation at a given rate. A measure of viscosity called the coefficient of viscosity (denoted by μ) is defined as the slope of the curve between shear stress and rate of shear strain (between fluid layers)



It is an important property of any fluid and has major implications in a variety of situations for instance the boundary layer concept which occurs in flow of air over a wing, internal flows of liquids and gases in heat exchangers and variety of other applications.

Methodology

The methodology used by us to measure viscosity is based on the relation obatined below-
Consider two cylinders one hollow and the other one solid, as shown in the below figure.



The radius of the inner and outer cylinder are r_1 and r_2 respectively. The height of the liquid being L.

When a liquid is introduced between these cylinders and the inner solid cylinder is rotated at a particular angualr speed (ω). The liquid as a virtue of its viscosity would resist the rotation of the cyliner and hence a torque msut be applied by the motor.

$$shear \;\; stress = \mu \frac{du}{dy} \tag{1}$$

$$shear \;\; stress = \mu \frac{\omega r_1}{r_2 - r_1} \tag{2}$$

$$dF = \mu \frac{\omega r_1}{r_2 - r_1} r_1 L d\theta \tag{3}$$

Hence we get

$$\tau = \int_{r_1}^{r_2} r dF = \mu \frac{\omega r_1^2}{r_2 - r_1} 2\pi r_1 L \tag{4}$$

Thus we get the expression

$$\tau = \frac{\mu \omega r_1^3 2\pi L}{r_2 - r_1} \tag{5}$$

Hence the expression for μ is obatined as

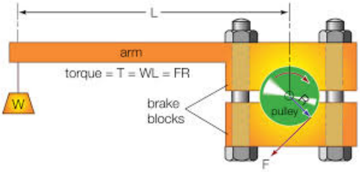
$$\mu = \tau \frac{r_2 - r_1}{\omega r_1^3 2\pi L} \tag{6}$$

Components of the Viscometer

- NEMA 17 STEPPER MOTOR and corresponding STEPPER MOTOR DRIVER
- LOAD CELL and HX711 AMPLIFIER
- COUPLING
- INNER and OUTER CYLINDER
- PRONY BRAKE
- ARDUINO UNO
- THRUST BEARING

PRONY BRAKE SYSTEM

- Prony Brake is a system that comprises of two blocks with semi circluar slots that together hold a shaft.
- It applies dry friction on the shafts and due to the reaction force the prony brake spins.
- By measuring the force at the free end of the prony brake using a load cell and knowing the length of the prony brake, it is possible to find the torque applied by the shaft.



NEMA 17 stepper motor would be used to rotate the inner cylinder at a constant angular speed.
Specifications:

- Step Angle: 1.8°
- Current: 1.2 A/Phase
- Holding Torque: 5.6 kg-cm
- Lead Wires: 4
- Shaft diameter: 5 mm

A TB6560 Stepper Motor Driver would be used to interface the stepper motor alog with the current source.
Specifications:

- Rated output: $\pm$ 3A ,peak 3.5A.
- Excitation Mode: synchronizing, half step, 1/8 step, 1/16 step, a maximum of 16 segments.
- Working voltage: DC 10V-35V

A coupling must be used to couple to shafts of the stepper motor and the rotating cylinder. Also a thrust bearing must be used between the coupling and the shaft of the rotating cylinder so as to decrease the load on the stepper motor.

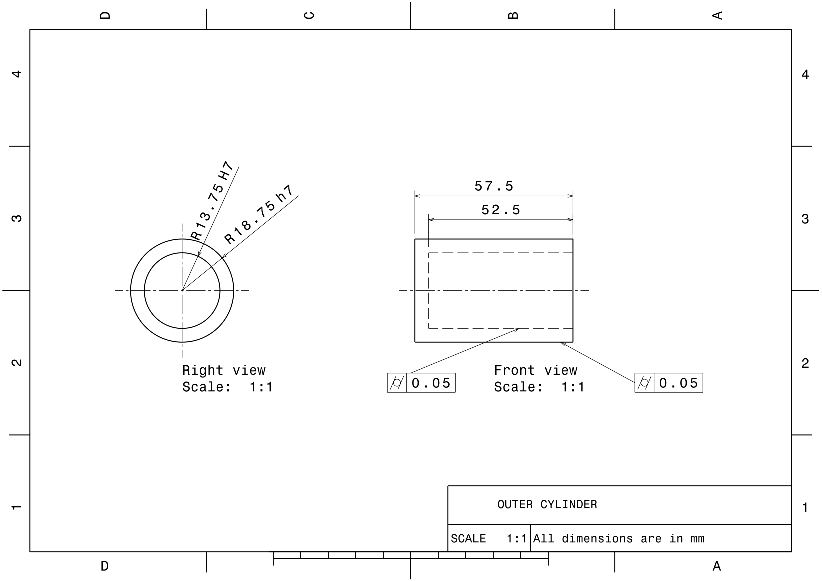
Figure: 5mm-8mm Coupling

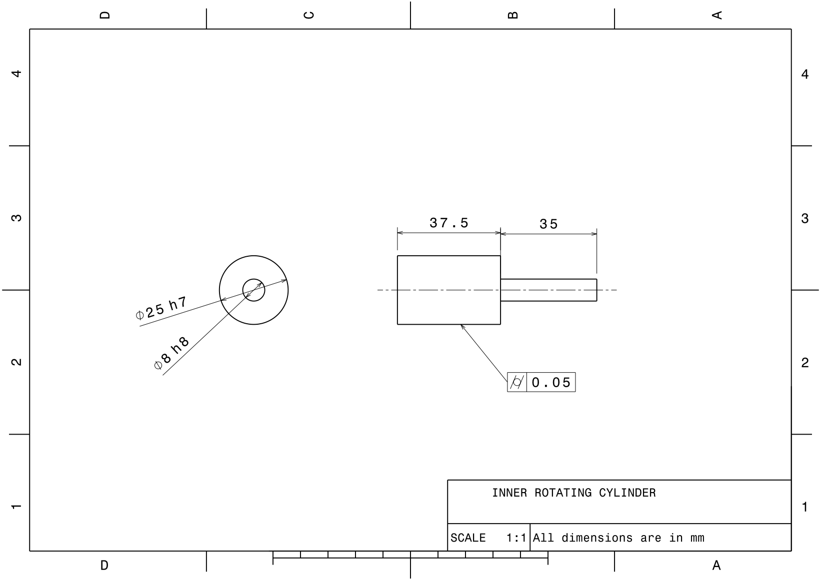
Figure: Thrust Bearing

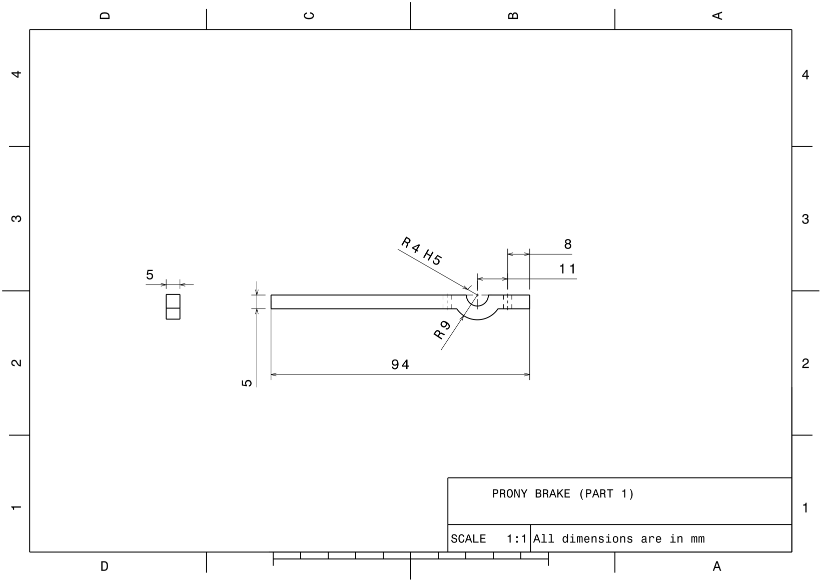
A Load cell would be used to measure the force and hence torque through the prony brake. Specifications:

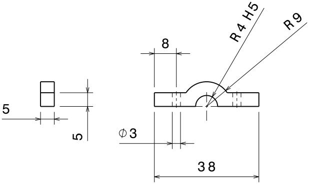
- Total Size: 8 x 1.3 x 1.3cm / 3.1" x 0.5" x 0.5"(L*W*T)
- Rated Load: 0-5Kg

Also HX711 is a 24 bit ADC which load cell and is connected in between the load cell and the arduino.
The drawings of the inner cylinder, outer cylinder, the two parts of the prony brake, outer cover and the top cover are shown in the following slides respectively.


R13.75 H7
R18.75 h7
Right view
Scale: 1:1
57.5
52.5
Front view
Scale: 1:1
0.05
0.05
OUTER CYLINDER
SCALE 1:1
All dimensions are in mm
D C B A
4 3 2 1

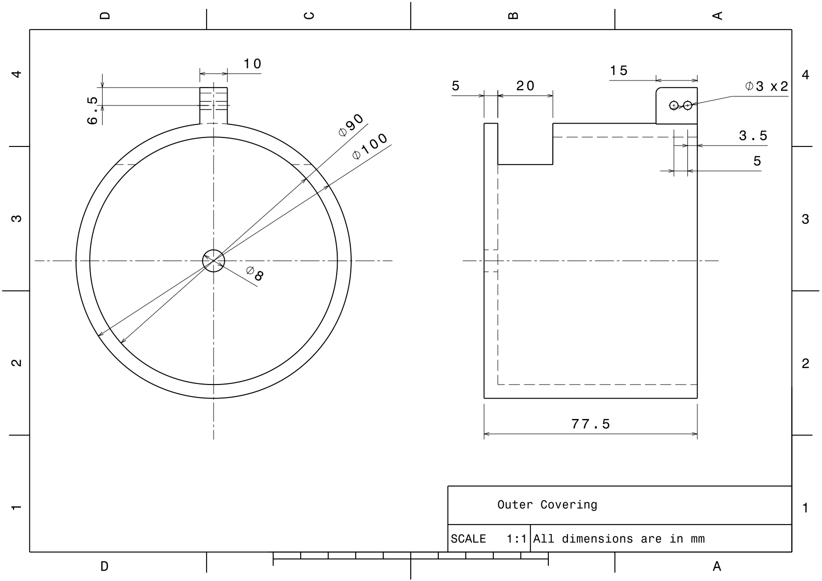

D
C
B
A
4
3
2
1
37.5
35
ϕ25 h7
ϕ8 h8
0.05
INNER ROTATING CYLINDER
SCALE 1:1
All dimensions are in mm

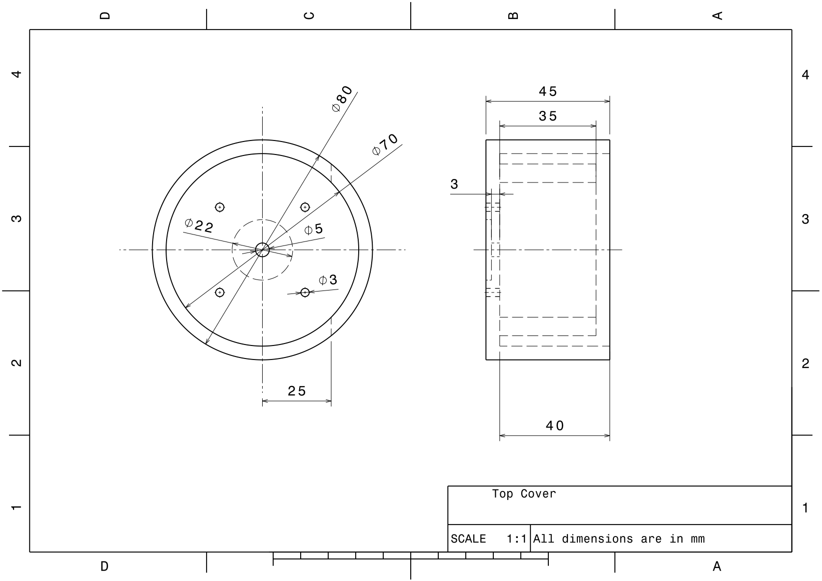

D
C
B
A
4
3
2
1
5
R4 H5
8
11
R9
94
5
PRONY BRAKE (PART 1)
SCALE 1:1
All dimensions are in mm



PRONY BRAKE (PART 2)

SCALE 1:1 All dimensions are in mm


10
6.5
⌀90
⌀100
⌀8
5
20
15
⌀3 x2
3.5
5
77.5
Outer Covering
SCALE 1:1
All dimensions are in mm



D
C
B
A
4
3
2
1
⌀80
⌀70
⌀22
⌀5
⌀3
25
45
35
3
40
Top Cover
SCALE 1:1
All dimensions are in mm

MANUFACTURING

- The inner and outer cylinder of the viscometer can be made of aluminum. By the use of lathe and the drilling operation the geometries required can be manufactured from aluminum shafts of suitable diameters.
- The prony brake parts can be 3D printed.
- The top and the outer cover can be made from pipes of preferably Mild Steel of suitable diameters by cutting them to the specified dimensions.

ASSEMBLY

- The stepper motor shaft is connected to the shaft of the inner cylinder with the help of a coupling, through a thrust bearing fixed on the outer covering.
- The Prony Brake is connected to the shaft and is free to rotate. At the other end of the prony brake the load cell is placed whose other end is attached to the outer cover.
- The stepper motor is fixed onto the top cover.
- L shape connectors are welded to the top cover, outer cover and the outer cylinder on two opposite sides of the geometry.
- With the help of the welded L-shape connectors the top cover is joined with the outer cover. Both the outer cylinder and the outer cover are connected to a wooden base board through the welded connectors.

The schematic of the assembly is as shown.

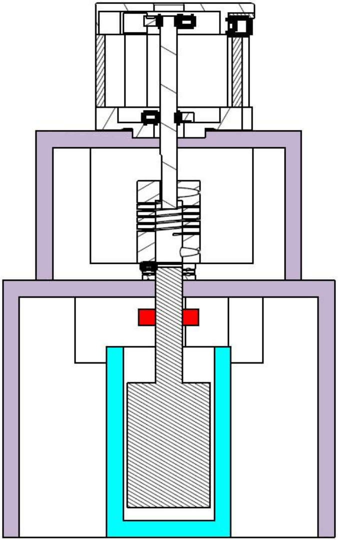


Figure: Sectional View of the setup

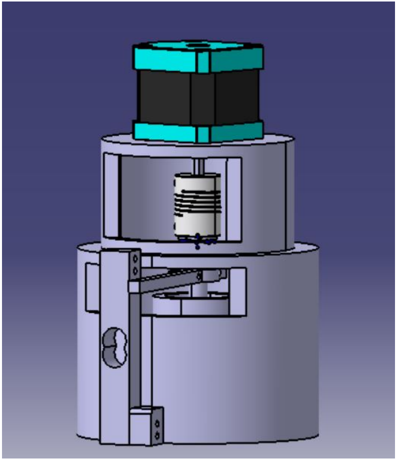


Figure: 3D view of the setup

Figure: L-shaped Connector

WORKING

- The test sample (liquid) must introduced in between the cylinders.
- The Stepper motor must be switched on and is made to rotate at a constant angular velocity.
- The shaft of the inner cylinder which is connected to the motor shaft through a coupling rotates.
- The fluid has some viscosity and hence it resists the rotation due to which to continue to rotate at the same angular speed the motor applies a torque.
- The prony brake helps us measure this torque through the load cell.
- With all the variables of the expression 6 we find the coefficient of viscosity.

CALIBRATION

The load cell is calibrated in the following way:

- The circuit is made according to the diagram shown in the next slide.
- The load cell is fixed on one end and at the other end a known weight in the form of standard weights is applied.
- The reading from the load cell is taken which would be in mV.
- The calibration factor is found using the formula
  $calibration \;\; factor = \frac{applied \;\; weight}{load \;\; cell \;\; reading} \; kg/mV$
- This must be repeated with several weights and the average value of the calibration factor must be considered.
- Thus the load on the load cell would be :
  $Load = calibration \;\; factor \; x \; load \;\; cell \;\; reading$ kg.

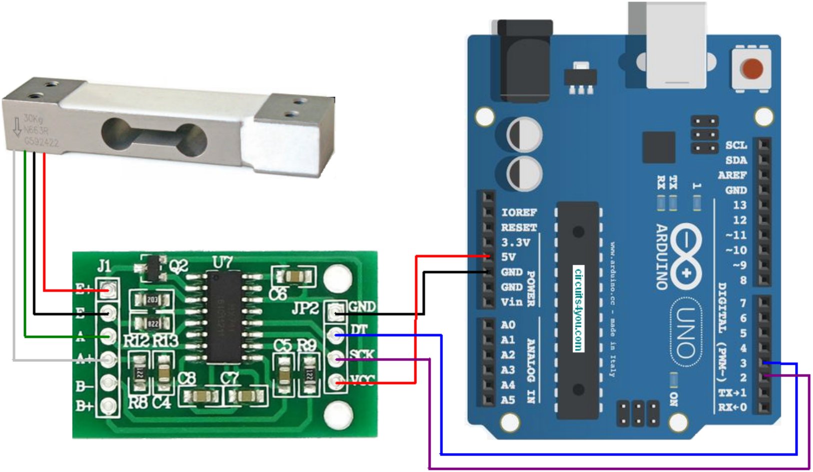


Figure: Circuit diagram for the calibration process of the Load Cell

The Calibration factor of the Viscometer 'C' is found in the following method:

- We must perform experiments using liquids of known viscosities and find the value of μ using the expression 6.
- C for this experiment is $C = \frac{\mu_{actual}}{\mu_{experimental}}$
- In the following way further experiments must be conducted using the same liquid as well as using other liquids of known viscosities.
- After the experimentation we will have a large number of values for the Calibration Factor 'C'.
- We then find the mean and the standard deviation of $C_i's$.
- Then based on the results we set the control limits(cl) for the Calibartion factor. Usually it is taken to be the standard deviation but it can also vary.
- After this we can report the Calibration factor for the machine as C $= C_{mean} \pm cl$ where C_{mean} is the mean of $C_i's$.

The different values of variables and the least counts of our measuring instruments are as follows:

- $r_1 = 12.5\text{mm}$
- $r_2 = 13.75\text{mm}$
- $L = 37.50\text{mm}$
- max torque supported by the stepper motor (holding torque) $= 5.6\text{kg-cm} = 0.55$ Nm.
- $\omega =$ In the range of 100-500 rpm
- Least count of the Load cell $= \frac{1}{2^{24}} x 5kg = 3x10^{-7} kg$.

Considering all this using expression 6 we can expect to find μ upto 179 Pa.s And considering the least count of the load cell the least value of $9.56x10^{-5}$ Pa.s can be measured by the viscometer.

The prony brake system even though effective has some drawbacks:

- The prony brake is a hanging cantiliver which can bend over time and affect results.
- The system is a mechanical one and it will have losses which can't be accounted easily.
- Due to this we can't ensure repeatability and reproducibility of the experiment and the results.
- Another reason for non repeatability is that the central part of the system is the fact that the friction force acts equally and opposite to the shaft and the prony brake. There can be some slipping in this case and to prevent this precautions have to be taken.

Hence another alternative for the prony brake system is the use of a electronic torquemeter which wouldn't have such issues as mentioned above.

The UTM II a torquemeter has a larger range of measurable torque, 0.05Nm to 10,000Nm and a resolution of 1/10000 which is better than the Prony brake arrangement.

REFERENCES

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