HOMEWORK-5

In [1]:
```
#sympy library used to express matrices in terms of symbols
# matplot lib used to plot the graph

from sympy import *
from IPython.display import Image,display,HTML
import matplotlib.pyplot as plt
from matplotlib import cm
import numpy as np

from mpl_toolkits.mplot3d.axes3d import get_test_data
init_printing()

thetadot,t=symbols('thetadot,t')
theta,d,a,alpha=symbols('theta,d,a,alpha')
d_1,d_3,d_5,d_7,a_3=symbols('d_1,d_3,d_5,d_7,a_3')
theta_1,theta_2,theta_3,theta_4,theta_5,theta_6,theta_7=symbols('theta_1,theta_2,theta_3
Rot_z_theta=Matrix([[cos(theta),-sin(theta),0,0],
                    [sin(theta),cos(theta),0,0],
                    [0,0,1,0],
                    [0,0,0,1]])
Trans_z_d=Matrix([[1,0,0,0],
                  [0,1,0,0],
                  [0,0,1,d],
                  [0,0,0,1]])
Trans_x_a=Matrix([[1,0,0,a],
                  [0,1,0,0],
                  [0,0,1,0],
                  [0,0,0,1]])
Rot_x_alpha=Matrix([[1,0,0,0],
                   [0,cos(alpha),-sin(alpha),0],
                   [0,sin(alpha),cos(alpha),0],
                   [0,0,0,1]])
```

In [2]:
```
# Transfromation matrix for each frame
A=Rot_z_theta*Trans_z_d*Trans_x_a*Rot_x_alpha
```

In [3]:
```
# Substituting values form DH table
A_1=A.subs({theta:theta_1,d:d_1,a:0,alpha:pi/2})
A_2=A.subs({theta:theta_2,d:0,a:0,alpha:-pi/2})
A_3=A.subs({theta:0,d:d_3,a:a_3,alpha:-pi/2})
A_4=A.subs({theta:theta_4,d:0,a:-a_3,alpha:pi/2})
A_5=A.subs({theta:theta_5,d:d_5,a:0,alpha:pi/2})
A_6=A.subs({theta:theta_6,d:0,a:a_3,alpha:-pi/2})
A_7=A.subs({theta:theta_7,d:-d_7,a:0,alpha:0})
```

In [4]:
```
# Transformation matrix for each frame with respect to origin

Transformation=A_1*A_2*A_3*A_4*A_5*A_6*A_7
Transformation
T_1=A_1
T_2=A_1*A_2
T_4=A_1*A_2*A_3*A_4
T_5=A_1*A_2*A_3*A_4*A_5
T_6=A_1*A_2*A_3*A_4*A_5*A_6
T_7=A_1*A_2*A_3*A_4*A_5*A_6*A_7
```

In [5]:
```python
# 1st frame wrt origin
T_1.subs({d_1:33.30,
    d_3:31.60,
    d_5:38.40,
    a_3:8.80,
    d_7:20.7})
```

Out[5]:

$$\begin{bmatrix} \cos(\theta_1) & 0 & \sin(\theta_1) & 0 \\ \sin(\theta_1) & 0 & -\cos(\theta_1) & 0 \\ 0 & 1 & 0 & 33.3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

In [6]:
```python
# 2nd frame wrt origin
T_2.subs({d_1:33.30,
    d_3:31.60,
    d_5:38.40,
    a_3:8.80,
    d_7:20.7})
```

Out[6]:

$$\begin{bmatrix} \cos(\theta_1)\cos(\theta_2) & -\sin(\theta_1) & -\sin(\theta_2)\cos(\theta_1) & 0 \\ \sin(\theta_1)\cos(\theta_2) & \cos(\theta_1) & -\sin(\theta_1)\sin(\theta_2) & 0 \\ \sin(\theta_2) & 0 & \cos(\theta_2) & 33.3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

In [7]:
```python
# 4th framw frame wrt origin
T_4.subs({d_1:33.30,
    d_3:31.60,
    d_5:38.40,
    a_3:8.80,
    d_7:20.7})
```

Out[7]:

$$\begin{bmatrix} \sin(\theta_2)\sin(\theta_4)\cos(\theta_1) + \cos(\theta_1)\cos(\theta_2)\cos(\theta_4) & -\sin(\theta_1) & -\sin(\theta_2)\cos(\theta_1)\cos(\theta_4) + \sin(\theta \\ \sin(\theta_1)\sin(\theta_2)\sin(\theta_4) + \sin(\theta_1)\cos(\theta_2)\cos(\theta_4) & \cos(\theta_1) & -\sin(\theta_1)\sin(\theta_2)\cos(\theta_4) + \sin(\theta \\ \sin(\theta_2)\cos(\theta_4) - \sin(\theta_4)\cos(\theta_2) & 0 & \sin(\theta_2)\sin(\theta_4) + \cos(\theta_2 \\ 0 & 0 & 0 \end{bmatrix}$$

In [8]:
```python
# 5th frame wrt origin
T_5.subs({d_1:33.30,
    d_3:31.60,
    d_5:38.40,
    a_3:8.80,
    d_7:20.7})
```

Out[8]:

$$\begin{bmatrix} (\sin(\theta_2)\sin(\theta_4)\cos(\theta_1) + \cos(\theta_1)\cos(\theta_2)\cos(\theta_4))\cos(\theta_5) - \sin(\theta_1)\sin(\theta_5) & -\sin(\theta_2)\cos(\theta_1) \\ (\sin(\theta_1)\sin(\theta_2)\sin(\theta_4) + \sin(\theta_1)\cos(\theta_2)\cos(\theta_4))\cos(\theta_5) + \sin(\theta_5)\cos(\theta_1) & -\sin(\theta_1)\sin(\theta_2) \\ (\sin(\theta_2)\cos(\theta_4) - \sin(\theta_4)\cos(\theta_2))\cos(\theta_5) & \sin(\theta_2)\mathrm{si} \\ 0 & \end{bmatrix}$$

In [9]:
```python
# 6th frame wrt origin
T_6.subs({d_1:33.30,
    d_3:31.60,
    d_5:38.40,
    a_3:8.80,
    d_7:20.7})
```

Out[9]:

$$\left[\begin{matrix}\left(\left(\sin\left(\theta_2\right)\sin\left(\theta_4\right)\cos\left(\theta_1\right)+\cos\left(\theta_1\right)\cos\left(\theta_2\right)\cos\left(\theta_4\right)\right)\cos\left(\theta_5\right)-\sin\left(\theta_1\right)\sin\left(\theta_5\right)\right)\cos\left(\theta_6\right) \\ +\left(-\sin\left(\theta_2\right)\cos\left(\theta_1\right)\cos\left(\theta_4\right)+\sin\left(\theta_4\right)\cos\left(\theta_1\right)\cos\left(\theta_2\right)\right)\sin\left(\theta_6\right) \\ \\ \left(\left(\sin\left(\theta_1\right)\sin\left(\theta_2\right)\sin\left(\theta_4\right)+\sin\left(\theta_1\right)\cos\left(\theta_2\right)\cos\left(\theta_4\right)\right)\cos\left(\theta_5\right)+\sin\left(\theta_5\right)\cos\left(\theta_1\right)\right)\cos\left(\theta_6\right) \\ +\left(-\sin\left(\theta_1\right)\sin\left(\theta_2\right)\cos\left(\theta_4\right)+\sin\left(\theta_1\right)\sin\left(\theta_4\right)\cos\left(\theta_2\right)\right)\sin\left(\theta_6\right) \\ \\ \left(\sin\left(\theta_2\right)\sin\left(\theta_4\right)+\cos\left(\theta_2\right)\cos\left(\theta_4\right)\right)\sin\left(\theta_6\right)+\left(\sin\left(\theta_2\right)\cos\left(\theta_4\right)-\sin\left(\theta_4\right)\cos\left(\theta_2\right)\right)\cos\left(\theta_5\right)\cos \\ \left(\theta_6\right) \\ \\ 0\end{matrix}\right.$$

In [10]:
```python
# 7th frame wrt origin
T_7.subs({d_1:33.30,
    d_3:31.60,
    d_5:38.40,
    a_3:8.80,
    d_7:20.7})
```

Out[10]:

$$\left[\begin{matrix}\left(\left(\left(\sin\left(\theta_2\right)\sin\left(\theta_4\right)\cos\left(\theta_1\right)+\cos\left(\theta_1\right)\cos\left(\theta_2\right)\cos\left(\theta_4\right)\right)\cos\left(\theta_5\right)-\sin\left(\theta_1\right)\sin\left(\theta_5\right)\right)\cos\left(\theta_6\right) \\ +\left(-\sin\left(\theta_2\right)\cos\left(\theta_1\right)\cos\left(\theta_4\right)+\sin\left(\theta_4\right)\cos\left(\theta_1\right)\cos\left(\theta_2\right)\right)\sin\left(\theta_6\right)\right)\cos\left(\theta_7\right) \\ +\left(-\left(\sin\left(\theta_2\right)\sin\left(\theta_4\right)\cos\left(\theta_1\right)+\cos\left(\theta_1\right)\cos\left(\theta_2\right)\cos\left(\theta_4\right)\right)\sin\left(\theta_5\right)-\sin\left(\theta_1\right)\cos\left(\theta_5\right)\right)\sin\left(\theta_7\right) \\ \\ \left(\left(\left(\sin\left(\theta_1\right)\sin\left(\theta_2\right)\sin\left(\theta_4\right)+\sin\left(\theta_1\right)\cos\left(\theta_2\right)\cos\left(\theta_4\right)\right)\cos\left(\theta_5\right)+\sin\left(\theta_5\right)\cos\left(\theta_1\right)\right)\cos\left(\theta_6\right) \\ +\left(-\sin\left(\theta_1\right)\sin\left(\theta_2\right)\cos\left(\theta_4\right)+\sin\left(\theta_1\right)\sin\left(\theta_4\right)\cos\left(\theta_2\right)\right)\sin\left(\theta_6\right)\right)\cos\left(\theta_7\right) \\ +\left(-\left(\sin\left(\theta_1\right)\sin\left(\theta_2\right)\sin\left(\theta_4\right)+\sin\left(\theta_1\right)\cos\left(\theta_2\right)\cos\left(\theta_4\right)\right)\sin\left(\theta_5\right)+\cos\left(\theta_1\right)\cos\left(\theta_5\right)\right)\sin\left(\theta_7\right) \\ \\ \left(\left(\sin\left(\theta_2\right)\sin\left(\theta_4\right)+\cos\left(\theta_2\right)\cos\left(\theta_4\right)\right)\sin\left(\theta_6\right)+\left(\sin\left(\theta_2\right)\cos\left(\theta_4\right)-\sin\left(\theta_4\right)\cos\left(\theta_2\right)\right)\cos\left(\theta_5\right)\cos \\ \left(\theta_6\right)\right)\cos\left(\theta_7\right)-\left(\sin\left(\theta_2\right)\cos\left(\theta_4\right)-\sin\left(\theta_4\right)\cos\left(\theta_2\right)\right)\sin\left(\theta_5\right)\sin\left(\theta_7\right) \\ \\ 0\end{matrix}\right.$$

In [11]:
```python
# End effector position
Xp=Transformation.col(3)
Xp.row_del(3)
```

In [12]:
```
# substituting values to end effector positions
Xp_copy=Xp.subs({d_1:33.30,
    d_3:31.60,
    d_5:38.40,
    a_3:8.80,
    d_7:20.7})
```

In [13]:
```
# Taking individual x,y,z for the end effector position
x=Xp[0]
y=Xp[1]
z=Xp[2]
```

In [14]:
```
# Setting up the Jacobian Matrix

J=Matrix(([diff(x,theta_1),diff(x,theta_2),diff(x,theta_4),diff(x,theta_5),diff(x,theta_
        [diff(y,theta_1),diff(y,theta_2),diff(y,theta_4),diff(y,theta_5),diff(y,theta_6)
        [diff(z,theta_1),diff(z,theta_2),diff(z,theta_4),diff(z,theta_5),diff(z,theta_6)
        [T_1[0,2],T_2[0,2],T_4[0,2],T_5[0,2],T_6[0,2],T_7[0,2]],
        [T_1[1,2],T_2[1,2],T_4[1,2],T_5[1,2],T_6[1,2],T_7[1,2]],
        [T_1[2,2],T_2[2,2],T_4[2,2],T_5[2,2],T_6[2,2],T_7[2,2]]))
```

In [15]:
```
# Substituting values to Jacobian Matrix
J=J.subs({d_1:33.30,
    d_3:31.60,
    d_5:38.40,
    a_3:8.80,
    d_7:20.7})
```

In [16]:
```
J
```

Out[16]:

$$\left[\begin{matrix}20.7 \left(\left(- \sin{\left(\theta_{1} \right)} \sin{\left(\theta_{2} \right)} \sin{\left(\theta_{4} \right)} - \sin{\left(\theta_{1} \right)} \cos{\left(\theta_{2} \right)} \cos{\left(\theta_{4} \right)}\right) \cos{\left(\theta_{5} \right)} - \sin{\left(\theta_{5} \right)} \cos{\left(\theta_{1} \right)}\right) \sin{\left(\theta_{6} \right)} + 8.8 \left(\left(- \sin{\left(\theta_{1} \right)} \sin{\left(\theta_{2} \right)} \sin{\left(\theta_{4} \right)} - \sin{\left(\theta_{1} \right)} \cos{\left(\theta_{2} \right)} \cos{\left(\theta_{4} \right)}\right) \cos{\left(\theta_{5} \right)} - \sin{\left(\theta_{5} \right)} \cos{\left(\theta_{1} \right)}\right) \cos{\left(\theta_{6} \right)} + 8.8 \left(\sin{\left(\theta_{1} \right)} \sin{\left(\theta_{2} \right)} \cos{\left(\theta_{4} \right)} - \sin{\left(\theta_{1} \right)} \sin{\left(\theta_{4} \right)} \cos{\left(\theta_{2} \right)}\right) \sin{\left(\theta_{6} \right)} - 20.7 \left(\sin{\left(\theta_{1} \right)} \sin{\left(\theta_{2} \right)} \cos{\left(\theta_{4} \right)} - \sin{\left(\theta_{1} \right)} \sin{\left(\theta_{4} \right)} \cos{\left(\theta_{2} \right)}\right) \cos{\left(\theta_{6} \right)} + 8.8 \sin{\left(\theta_{1} \right)} \sin{\left(\theta_{2} \right)} \sin{\left(\theta_{4} \right)} + 38.4 \sin{\left(\theta_{1} \right)} \sin{\left(\theta_{2} \right)} \cos{\left(\theta_{4} \right)} + 31.6 \sin{\left(\theta_{1} \right)} \sin{\left(\theta_{2} \right)} - 38.4 \sin{\left(\theta_{1} \right)} \sin{\left(\theta_{4} \right)} \cos{\left(\theta_{2} \right)} + 8.8 \sin{\left(\theta_{1} \right)} \cos{\left(\theta_{2} \right)} \cos{\left(\theta_{4} \right)} - 8.8 \sin{\left(\theta_{1} \right)} \cos{\left(\theta_{2} \right)}\\20.7 \left(\left(\sin{\left(\theta_{2} \right)} \sin{\left(\theta_{4} \right)} \cos{\left(\theta_{1} \right)} + \cos{\left(\theta_{1} \right)} \cos{\left(\theta_{2} \right)} \cos{\left(\theta_{4} \right)}\right) \cos{\left(\theta_{5} \right)} - \sin{\left(\theta_{1} \right)} \sin{\left(\theta_{5} \right)}\right) \sin{\left(\theta_{6} \right)} + 8.8 \left(\left(\sin{\left(\theta_{2} \right)} \sin{\left(\theta_{4} \right)} \cos{\left(\theta_{1} \right)} + \cos{\left(\theta_{1} \right)} \cos{\left(\theta_{2} \right)} \cos{\left(\theta_{4} \right)}\right) \cos{\left(\theta_{5} \right)} - \sin{\left(\theta_{1} \right)} \sin{\left(\theta_{5} \right)}\right) \cos{\left(\theta_{6} \right)} + 8.8 \left(- \sin{\left(\theta_{2} \right)} \cos{\left(\theta_{1} \right)} \cos{\left(\theta_{4} \right)} + \sin{\left(\theta_{4} \right)} \cos{\left(\theta_{1} \right)} \cos{\left(\theta_{2} \right)}\right) \sin{\left(\theta_{6} \right)} - 20.7 \left(- \sin{\left(\theta_{2} \right)} \cos{\left(\theta_{1} \right)} \cos{\left(\theta_{4} \right)} + \sin{\left(\theta_{4} \right)} \cos{\left(\theta_{1} \right)} \cos{\left(\theta_{2} \right)}\right) \cos{\left(\theta_{6} \right)} - 8.8 \sin{\left(\theta_{2} \right)} \sin{\left(\theta_{4} \right)} \cos{\left(\theta_{1} \right)} - 38.4 \sin{\left(\theta_{2} \right)} \cos{\left(\theta_{1} \right)} \cos{\left(\theta_{4} \right)} - 31.6 \sin{\left(\theta_{2} \right)} \cos{\left(\theta_{1} \right)} + 38.4 \sin{\left(\theta_{4} \right)} \cos{\left(\theta_{1} \right)} \cos{\left(\theta_{2} \right)} - 8.8 \cos{\left(\theta_{1} \right)} \cos{\left(\theta_{2} \right)} \cos{\left(\theta_{4} \right)} + 8.8 \cos{\left(\theta_{1} \right)} \cos{\left(\theta_{2} \right)}\\0\\\sin{\left(\theta_{1} \right)}\\- \cos{\left(\theta_{1} \right)}\\0\end{matrix}\right]$$

In [17]:

```
q_current=Matrix(([0],
          [0],
          [pi/2],
          [0],
          [pi],
          [0]))
J_initial=J.subs({theta_1:q_current[0],
    theta_2:q_current[1],
    theta_4:q_current[2],
    theta_5:q_current[3],
    theta_6:q_current[4],
    theta_7:q_current[5]})
J_initial
```

Out[17]:

$$\left[\begin{matrix}0 & -49.2 & 17.6 & 0 & -8.8 & 0\\67.9 & 0 & 0 & -8.8 & 0 & 0\\0 & 67.9 & -59.1 & 0 & 20.7 & 0\\0 & 0 & 1 & 0 & -1 & -1\\-1 & 0 & 0 & -1 & 0 & 0\\0 & 1 & 0 & 0 & 0 & 0\end{matrix}\right]$$

In [18]:

```
# The velocity matrix for end effector velocity
X_dot=Matrix(([0],
             [-10*sin(pi/2+ thetadot*t)*thetadot],
             [10*cos(pi/2 + thetadot*t)*thetadot],
```

```
                [0],
                [0],
                [0]))
X_dot=X_dot.subs({thetadot:(2*pi)/200})
X_dot
```

Out[18]:

$$\left[\begin{matrix}0\\-\frac{\pi\cos\left(\frac{\pi t}{100}\right)}{10}\\-\frac{\pi\sin\left(\frac{\pi t}{100}\right)}{10}\\0\\0\\0\end{matrix}\right]$$

In [19]:

```
# mass for each link
m1=3.06+4.97
m2=3.228+0.646
m4=3.58
m5=1.225
m6=1.666
m7=0.73+0.735



# center of gravity for each link
cog1=Matrix([[0],[0],[33.30/2],[1]])
cog2=Matrix([[0],[0],[31.6/2],[1]])
cog4=Matrix([[0],[0],[5],[1]])
cog5=Matrix([[0],[38.4/2],[0],[1]])
cog6=Matrix([[0],[0],[0],[1]])
cog7=Matrix([[0],[0],[-10.7/2],[1]])

# gravitational accelaretion
G=9.8

CoG1 = cog1
CoG2 = T_1*cog2
CoG4 = T_4*cog4
CoG5 = T_5*cog5
CoG6 = T_6*cog6
CoG7 = T_7*cog7

# Potential Energy
P = m1*CoG1[2]*G + m2*CoG2[2]*G + m4*CoG4[2]*G + m5*CoG5[2]*G + m6*CoG6[2]*G + m7*CoG7[2

# g(theta) matrix
g = Matrix([[diff(P,theta_1)],[diff(P,theta_2)],[diff(P,theta_4)],[diff(P,theta_5)],[dif

# force matrix
F=Matrix([[-5],[0],[0],[0],[0],[0]])

# substituting values in g
g=g.subs({d_1:33.30,
    d_3:31.60,
    d_5:38.40,
    a_3:8.80,
    d_7:20.7})
g
```

Out[19]:

$$\left[\begin{array}{c}0\\ 373.99985\left(\sin\left(\theta_2\right)\sin\left(\theta_4\right)+\cos\left(\theta_2\right)\cos\left(\theta_4\right)\right)\sin\left(\theta_6\right)\cos\left(\theta_5\right)\\ +270.01744\left(\sin\left(\theta_2\right)\sin\left(\theta_4\right)+\cos\left(\theta_2\right)\cos\left(\theta_4\right)\right)\cos\left(\theta_5\right)\cos\left(\theta_6\right)\\ +270.01744\left(-\sin\left(\theta_2\right)\cos\left(\theta_4\right)+\sin\left(\theta_4\right)\cos\left(\theta_2\right)\right)\sin\left(\theta_6\right)\\ -373.99985\left(-\sin\left(\theta_2\right)\cos\left(\theta_4\right)+\sin\left(\theta_4\right)\cos\left(\theta_2\right)\right)\cos\left(\theta_6\right)-684.40064\sin\left(\theta_2\right)\sin\left(\theta_4\right)\\ -2045.16592\sin\left(\theta_2\right)\cos\left(\theta_4\right)-2457.62048\sin\left(\theta_2\right)+2045.16592\sin\left(\theta_4\right)\cos\left(\theta_2\right)\\ -684.40064\cos\left(\theta_2\right)\cos\left(\theta_4\right)+684.40064\cos\left(\theta_2\right)\\ 373.99985\left(-\sin\left(\theta_2\right)\sin\left(\theta_4\right)-\cos\left(\theta_2\right)\cos\left(\theta_4\right)\right)\sin\left(\theta_6\right)\cos\left(\theta_5\right)\\ +270.01744\left(-\sin\left(\theta_2\right)\sin\left(\theta_4\right)-\cos\left(\theta_2\right)\cos\left(\theta_4\right)\right)\cos\left(\theta_5\right)\cos\left(\theta_6\right)\\ +270.01744\left(\sin\left(\theta_2\right)\cos\left(\theta_4\right)-\sin\left(\theta_4\right)\cos\left(\theta_2\right)\right)\sin\left(\theta_6\right)\\ -373.99985\left(\sin\left(\theta_2\right)\cos\left(\theta_4\right)-\sin\left(\theta_4\right)\cos\left(\theta_2\right)\right)\cos\left(\theta_6\right)+684.40064\sin\left(\theta_2\right)\sin\left(\theta_4\right)\\ +2045.16592\sin\left(\theta_2\right)\cos\left(\theta_4\right)-2045.16592\sin\left(\theta_4\right)\cos\left(\theta_2\right)+684.40064\cos\left(\theta_2\right)\cos\left(\theta_4\right)\\ -373.99985\left(\sin\left(\theta_2\right)\cos\left(\theta_4\right)-\sin\left(\theta_4\right)\cos\left(\theta_2\right)\right)\sin\left(\theta_5\right)\sin\left(\theta_6\right)\\ -270.01744\left(\sin\left(\theta_2\right)\cos\left(\theta_4\right)-\sin\left(\theta_4\right)\cos\left(\theta_2\right)\right)\sin\left(\theta_5\right)\cos\left(\theta_6\right)\\ 373.99985\left(\sin\left(\theta_2\right)\sin\left(\theta_4\right)+\cos\left(\theta_2\right)\cos\left(\theta_4\right)\right)\sin\left(\theta_6\right)\\ +270.01744\left(\sin\left(\theta_2\right)\sin\left(\theta_4\right)+\cos\left(\theta_2\right)\cos\left(\theta_4\right)\right)\cos\left(\theta_6\right)\\ -270.01744\left(\sin\left(\theta_2\right)\cos\left(\theta_4\right)-\sin\left(\theta_4\right)\cos\left(\theta_2\right)\right)\sin\left(\theta_6\right)\cos\left(\theta_5\right)\\ +373.99985\left(\sin\left(\theta_2\right)\cos\left(\theta_4\right)-\sin\left(\theta_4\right)\cos\left(\theta_2\right)\right)\cos\left(\theta_5\right)\cos\left(\theta_6\right)\\ 0\end{array}\right]$$

In [20]:

```
list1=[]
x_plt=[]
y_plt=[]
z_plt=[]
i=0
j=0
x=[]
# The initial q_current values are given to us
q_current=Matrix(([0],
          [0],
          [pi/2],
          [0],
          [pi],
          [0]))
tau1=[]
tau2=[]
tau4=[]
tau5=[]
tau6=[]
tau7=[]

# Using while loop for
while(i<=200):
    Orientation=J
    print(1)
```

```
Orientation=Orientation.subs({theta_1:q_current[0],
theta_2:q_current[1],
theta_4:q_current[2],
theta_5:q_current[3],
theta_6:q_current[4],
theta_7:q_current[5]
})

Orientation_inverse=Orientation.evalf().inv()

q_dot=Orientation_inverse*X_dot
Z=q_dot
Z=Z.subs({t:i}).evalf()
q_current=q_current+Z*1

list1.append(q_current)

x_plt.append(Xp_copy[0].subs({theta_1:q_current[0],
theta_2:q_current[1],
theta_4:q_current[2],
theta_5:q_current[3],
theta_6:q_current[4],
theta_7:q_current[5]}).evalf())

y_plt.append(Xp_copy[1].subs({theta_1:q_current[0],
theta_2:q_current[1],
theta_4:q_current[2],
theta_5:q_current[3],
theta_6:q_current[4],
theta_7:q_current[5]}).evalf())

z_plt.append(Xp_copy[2].subs({theta_1:q_current[0],
theta_2:q_current[1],
theta_4:q_current[2],
theta_5:q_current[3],
theta_6:q_current[4],
theta_7:q_current[5]}).evalf())

i=i+1
plt.axis("equal")
plt.scatter(y_plt[j],z_plt[j])
j+=1
plt.xlabel("y_position in cm ")
plt.ylabel("z_position in cm")
x.append(67.9)

tau=g.subs({theta_1:q_current[0],
theta_2:q_current[1],
theta_4:q_current[2],
theta_5:q_current[3],
theta_6:q_current[4],
theta_7:q_current[5]}).evalf()-Orientation.T*F

tau1.append(tau[0]/100)
tau2.append(tau[1]/100)
tau4.append(tau[2]/100)
tau5.append(tau[3]/100)
tau6.append(tau[4]/100)
tau7.append(tau[5]/100)
```

```
1
1
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1
```
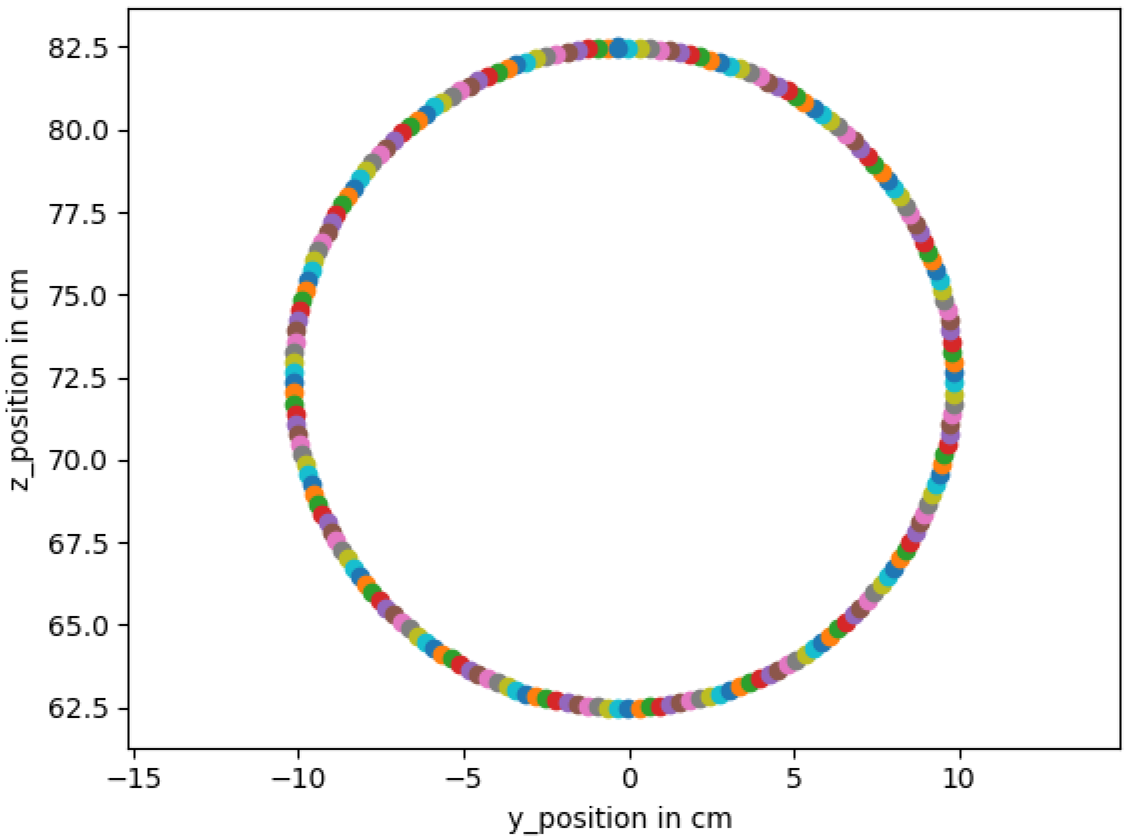
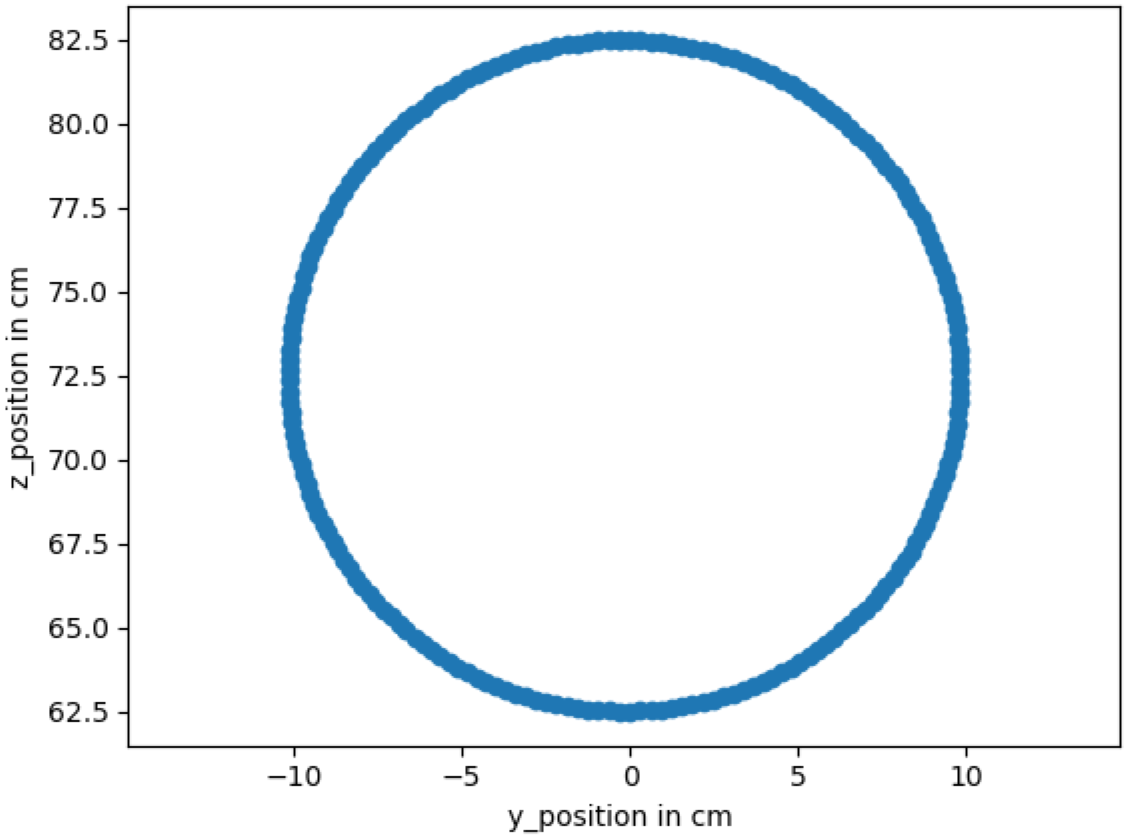



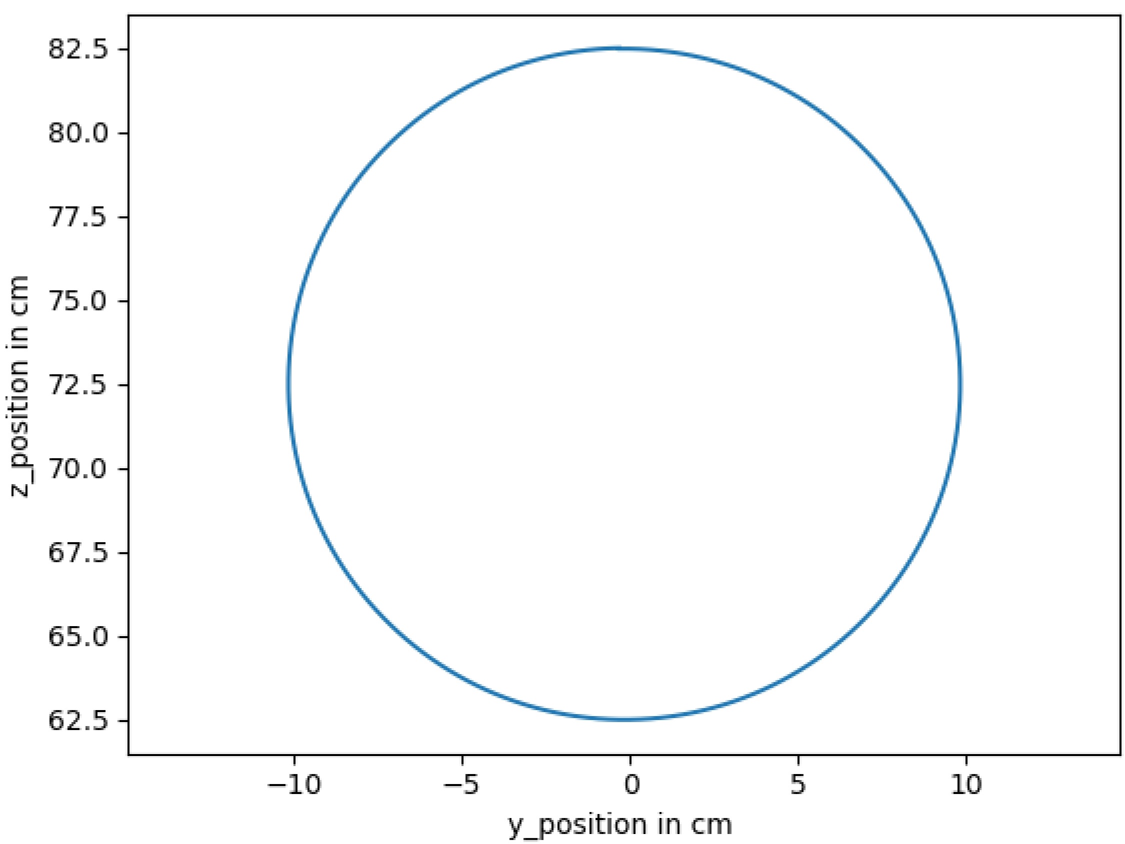
In [21]:
```python
# Plot of the y and z scatter
plt.axis("equal")
plt.xlabel("y_position in cm ")
plt.ylabel("z_position in cm")
plt.scatter(y_plt, z_plt)
```

Out[21]: <matplotlib.collections.PathCollection at 0x7f9280c5b0a0>



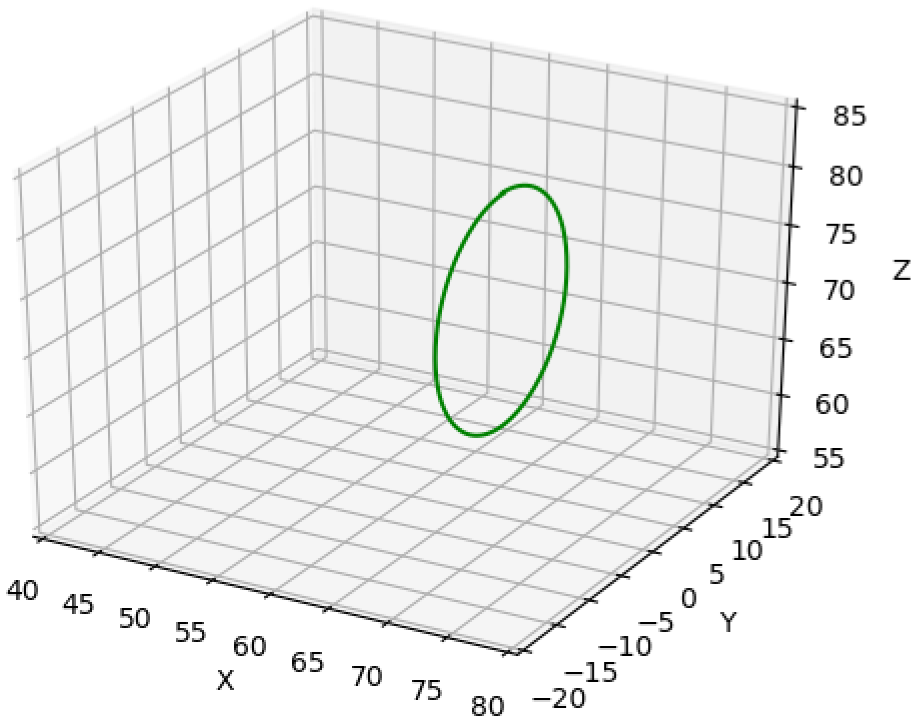
In [22]:
```
# normal plot for y and z
plt.axis("equal")
plt.xlabel("y_position in cm ")
plt.ylabel("z_position in cm")
plt.plot(y_plt,z_plt)
```

Out[22]: [<matplotlib.lines.Line2D at 0x7f9280ea47c0>]



In [23]:
```
from mpl_toolkits.mplot3d import Axes3D
```

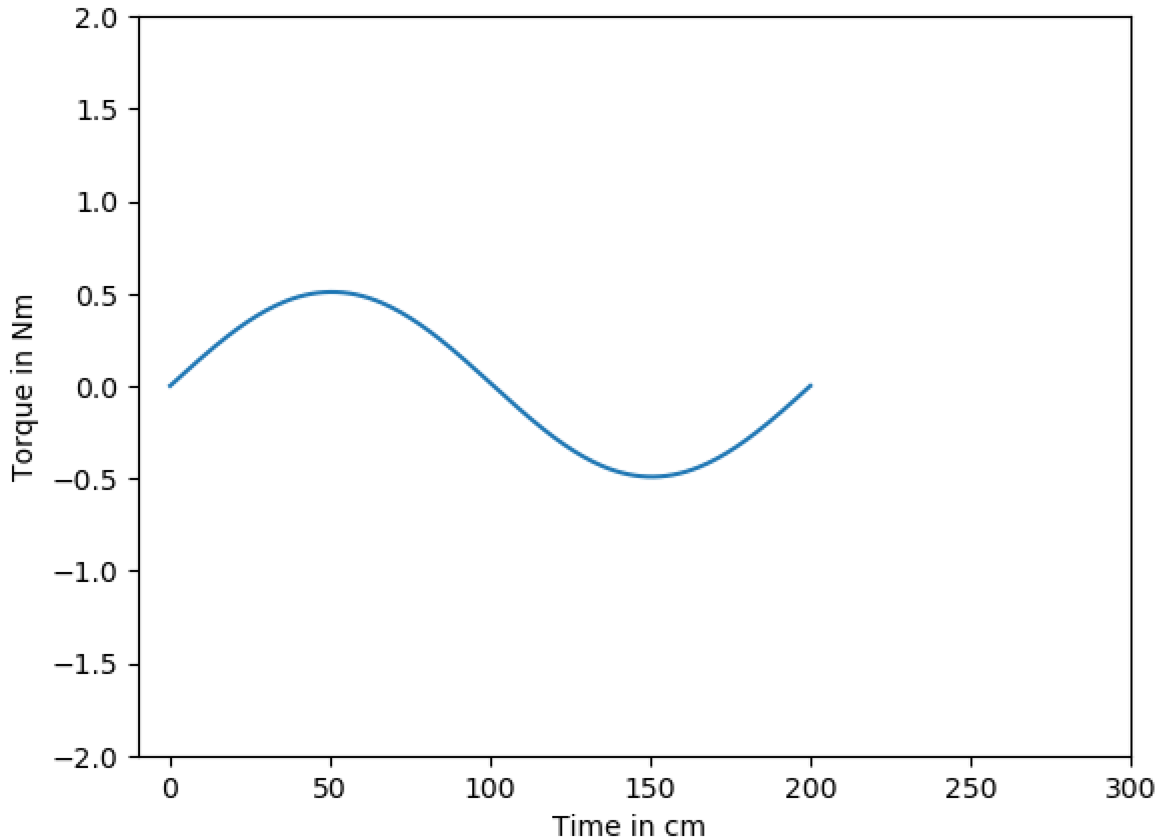
```python
from matplotlib import pyplot as plt

fig = plt.figure()
ax = fig.add_subplot(111,projection='3d')
ax.axes.set_xlim3d(left=40, right=80)
ax.axes.set_ylim3d(bottom=-20, top=20)
ax.axes.set_zlim3d(bottom=55, top=85)
ax.set_xlabel('X')
ax.set_ylabel('Y')
ax.set_zlabel('Z')
ax.plot3D(x_plt,y_plt,z_plt, color="green")
plt.show()
```



In [24]:
```python
time=[]
for i in range(0,201):
    time.append(i)
```

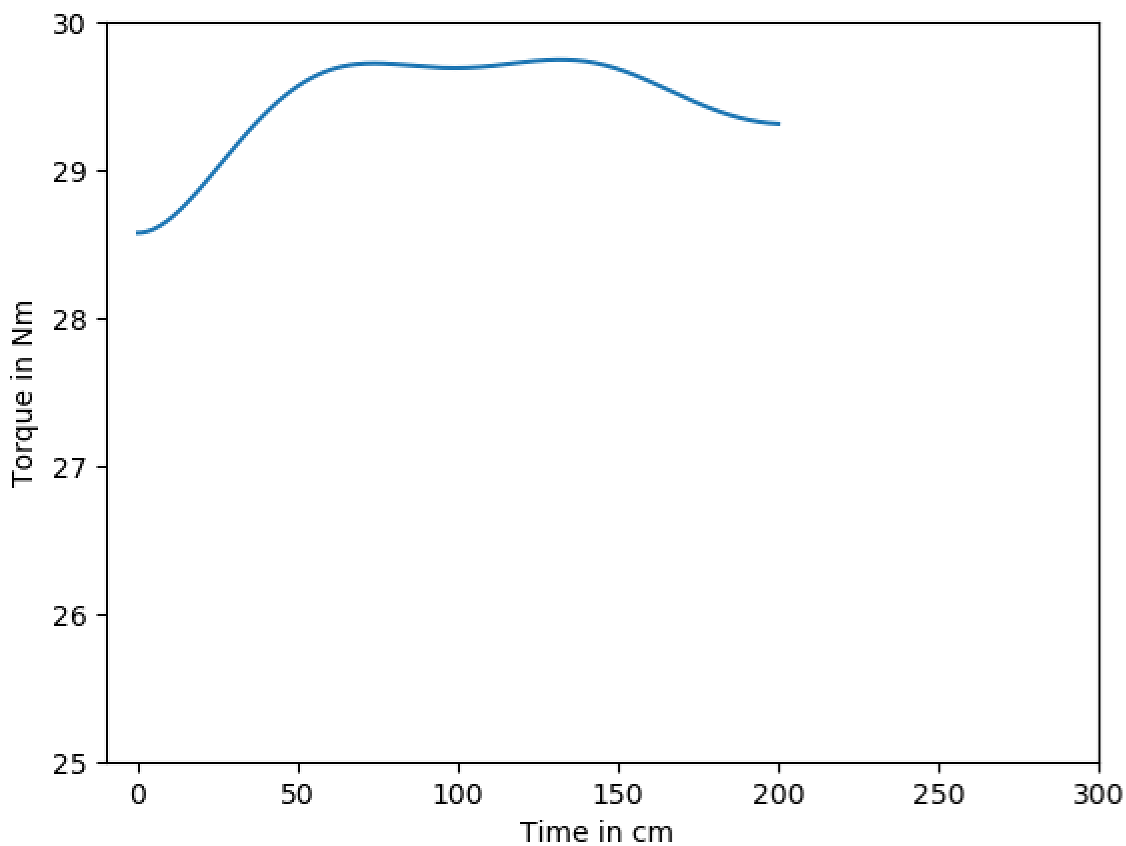
In [25]:
```python
plt.xlabel("Time in cm ")
plt.ylabel("Torque in Nm")
plt.xlim(-10, 300)
plt.ylim(-2, 2)
plt.plot(time,tau1)
```

Out[25]: [<matplotlib.lines.Line2D at 0x7f92809aa250>]



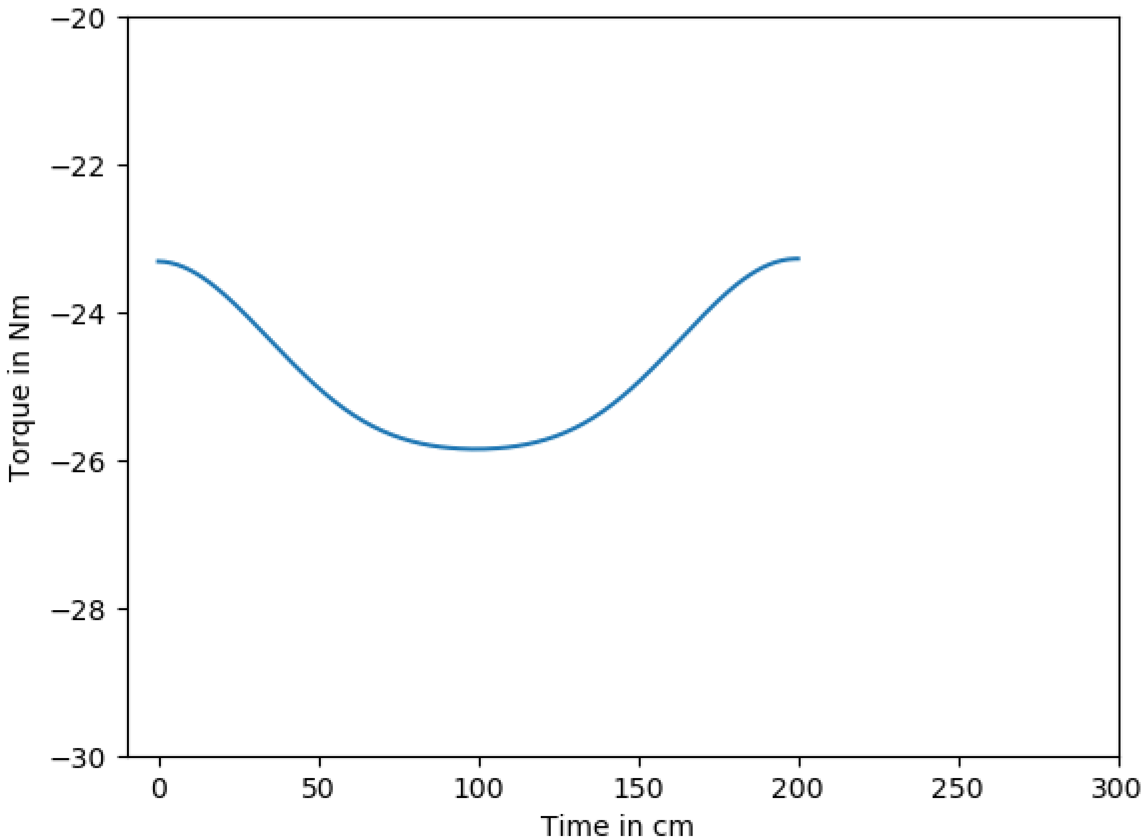
In [26]:
```
plt.xlabel("Time in cm ")
plt.ylabel("Torque in Nm")
plt.xlim(-10, 300)
plt.ylim(25,30)
plt.plot(time,tau2)
```

Out[26]: [<matplotlib.lines.Line2D at 0x7f9280976ee0>]



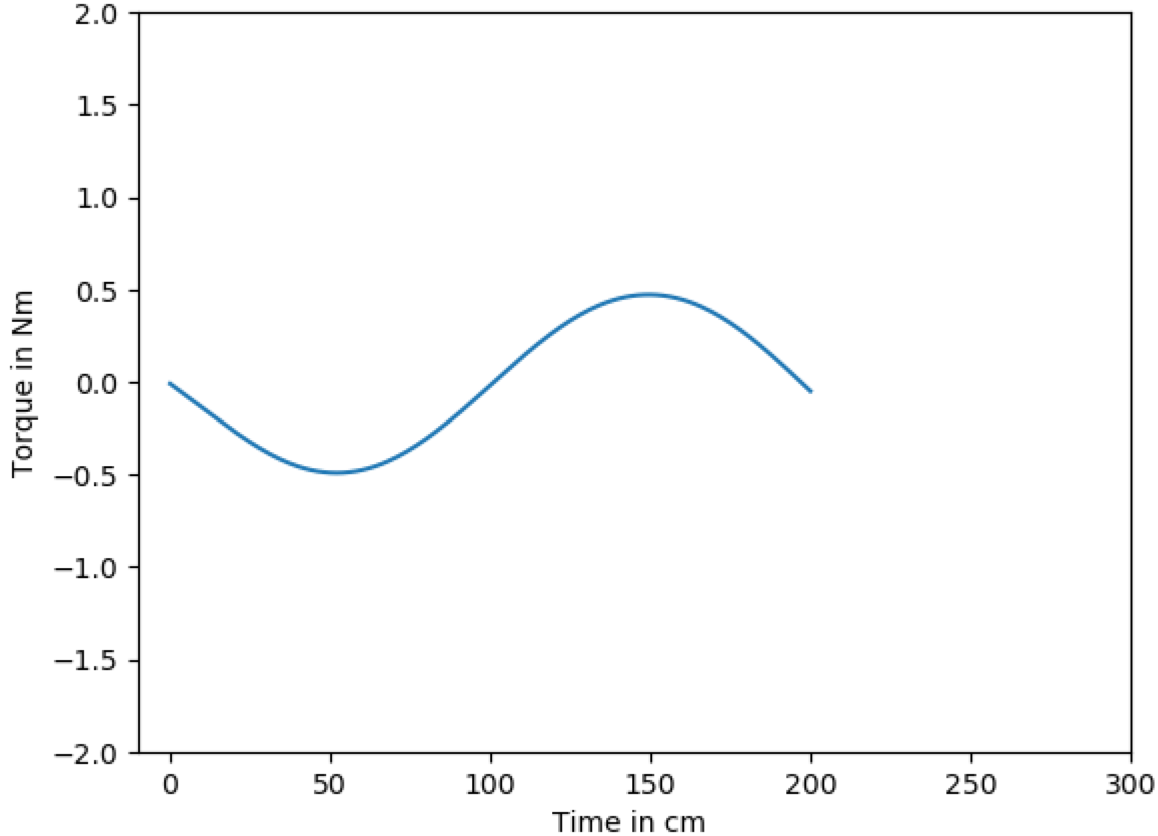
In [27]:
```
plt.xlabel("Time in cm ")
plt.ylabel("Torque in Nm")
plt.xlim(-10, 300)
plt.ylim(-30,-20)
plt.plot(time,tau4)
```

Out[27]: `[<matplotlib.lines.Line2D at 0x7f928093ca00>]`



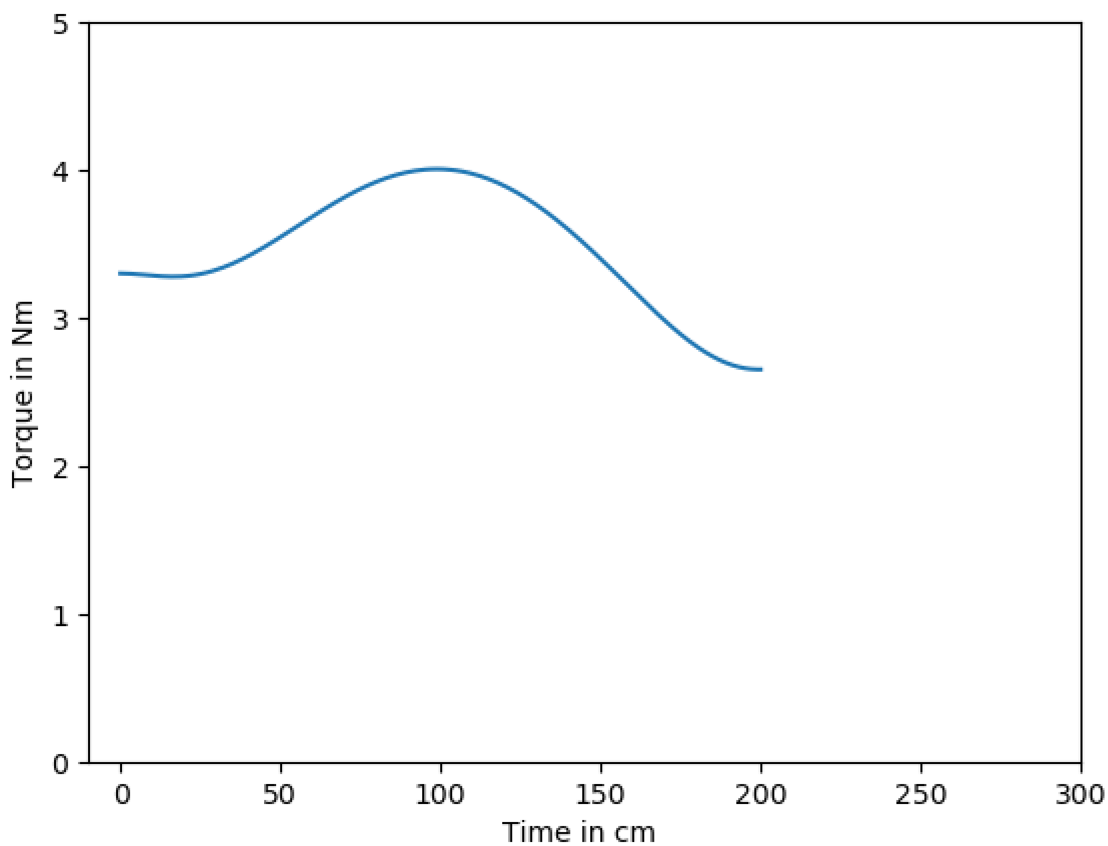
In [28]:
```
plt.xlabel("Time in cm ")
plt.ylabel("Torque in Nm")
plt.xlim(-10, 300)
plt.ylim(-2,2)
plt.plot(time,tau5)
```

Out[28]: `[<matplotlib.lines.Line2D at 0x7f92808efee0>]`



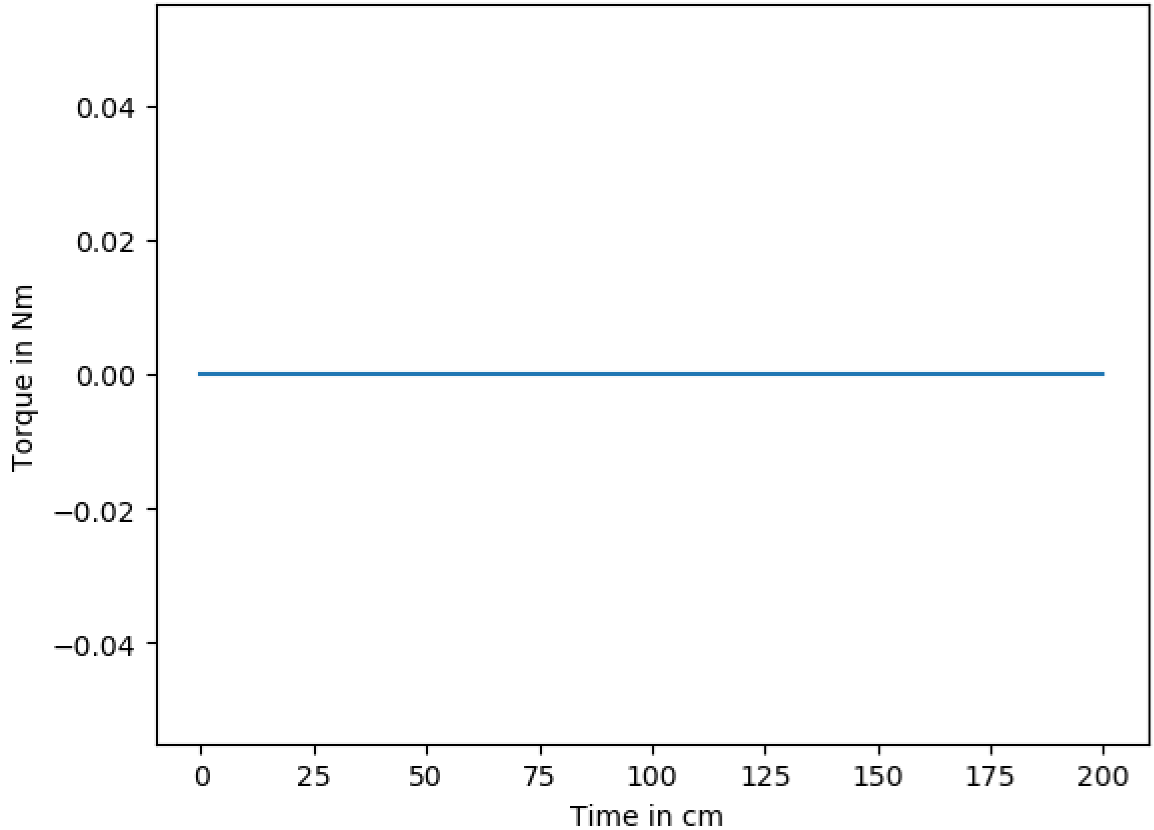
In [29]:
```
plt.xlabel("Time in cm ")
plt.ylabel("Torque in Nm")
plt.xlim(-10, 300)
plt.ylim(0,5)
plt.plot(time,tau6)
```

Out[29]: [<matplotlib.lines.Line2D at 0x7f9288140ac0>]



In [30]:
```
plt.xlabel("Time in cm ")
plt.ylabel("Torque in Nm")
plt.plot(time,tau7)
```

Out[30]: [<matplotlib.lines.Line2D at 0x7f9288f54820>]



In [ ]: