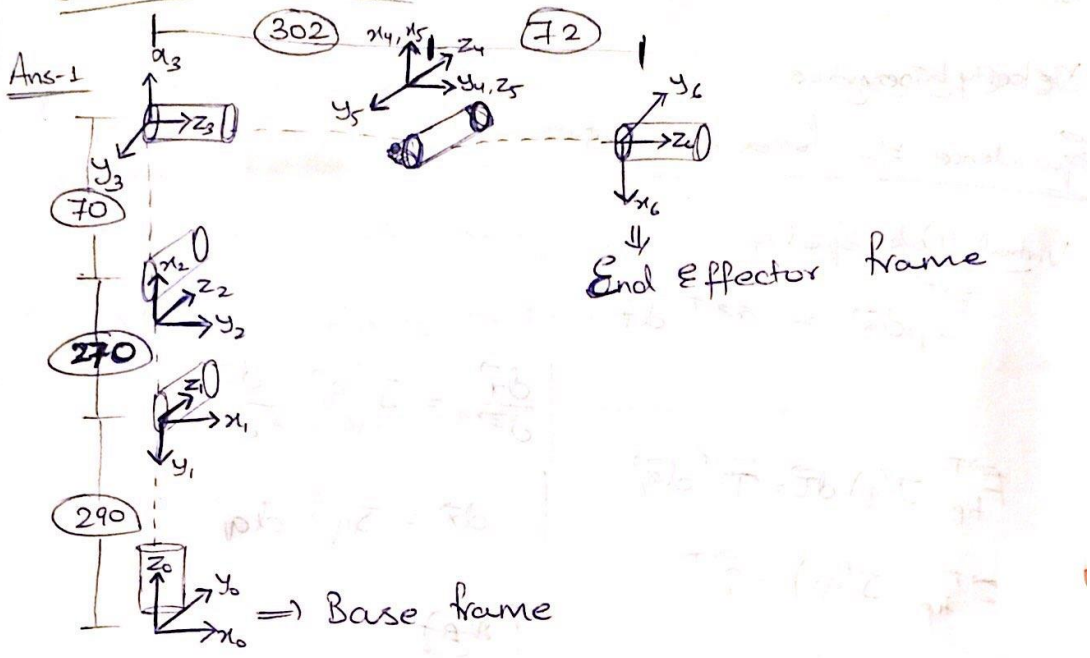
ROBOT DYNAMICS HOMEWORK- 2 ANIMESH NEMA

Dynamics homework-2

Ans-1



Ans-2 D-H parameters

n	θ (degree)	α (degree)	d (mm)	a (mm)
1	θ_1°	-90°	290mm	0mm
2	$(\theta_2 - 90)^\circ$	0°	0mm	270mm
3	$(\theta_3)^\circ$	-90°	0 mm	70mm
4	$(\theta_4)^\circ$	90°	302mm	0mm
5	$(\theta_5)^\circ$	-90°	0 mm	0mm
6	$(\theta_6 + 180)^\circ$	0°	72mm	0mm

θ => Rotation about Z_{n-1} axis

α => Rotation about X_n axis

d => Translation about Z_{n-1} axis

a => Translation about X_n axis.

PRIMARY CODE (ALL CODES PROVIDED IN A SEPARATE FILE)

```
clc,clear;

syms q1 q2 q3 q4 q5 q6


%ANSWER-2
theta = deg2rad([q1, q2-90, q3, q4, q5, q6+180]);
alpha = deg2rad([-90, 0, -90, 90, -90, 0]);
d = [290, 0, 0, 302, 0, 72];
a = [0, 270, 70, 0, 0, 0];

ANSWER-3 (The entire code for function is mentioned later)
T_M = dhparam2matrix(theta, alpha, d, a)

T_total = T_M(:,:,1)*T_M(:,:,2)*T_M(:,:,3)*T_M(:,:,4)*T_M(:,:,5)*T_M(:,:,6)
T_simplified= simplify(T_total)

T_0_6_Q5 = subs(T_simplified, [q1,q2,q3,q4,q5,q6], [0,0,0,0,0,0]);
T_0_6_Q5 = round(T_0_6_Q5)

T_0_6_Q6 = subs(T_simplified, [q1,q2,q3,q4,q5,q6], [-45,30,-30,-30,-45,180]);
T_0_6_Q6 = round(T_0_6_Q6)
%T1 = plotarm(-50,40,-30,-30,-50,180)
T_0_6_Q8_1 = subs(T_simplified, [q1,q2,q3,q4,q5,q6], [-50,40,-30,-30,-50,180]);
T_0_6_Q8_1 = round(T_0_6_Q8_1)
%T2 = plotarm(-11,-4,26,-9,-27,-16)
T_0_6_Q8_2 = subs(T_simplified, [q1,q2,q3,q4,q5,q6], [-11,-4,26,-9,-27,-16]);
T_0_6_Q8_2 = round(T_0_6_Q8_2)
%T3 = plotarm(-5,50,-36,-24,-36,0)
T_0_6_Q8_3= subs(T_simplified, [q1,q2,q3,q4,q5,q6], [-5,50,-36,-24,-36,0]);
T_0_6_Q8_3 = round(T_0_6_Q8_3)
%T4 = plotarm(-45,35,-35,-35,-40,0)
T_0_6_Q8_4 = subs(T_simplified, [q1,q2,q3,q4,q5,q6], [-45,35,-35,-35,-40,0]);
T_0_6_Q8_4 = round(T_0_6_Q8_4)
%T5 = plotarm(-10,-5,-20,-20,-10,0);
T_0_6_Q8_5 = subs(T_simplified, [q1,q2,q3,q4,q5,q6], [-10,-5,-20,-20,-10,0]);
T_0_6_Q8_5 = round(T_0_6_Q8_5)
```

ANS 3 – CODE – dhparam2matrix function

```
function T_M = dhparam2matrix(theta, alpha, d, a)
old = digits(2);
for i= 1:6
   T_M(:,:,i)= vpa([cos(theta(i)) (-sin(theta(i))*cos(alpha(i)))
(sin(theta(i))*sin(alpha(i))) (a(i)*cos(theta(i)));
       sin(theta(i)) cos(theta(i))*cos(alpha(i)) (-cos(theta(i))*sin(alpha(i)))
a(i)*sin(theta(i));
       0 (sin(alpha(i))) cos(alpha(i)) d(i);
       0 0 0 1]);

end
end
```

ANS-3-c - SYMBOLIC TRANSFORMATION MATRICES

T_M(:,:,1) = T^0_1

```
[ cos(0.017*q1), -6.1e-17*sin(0.017*q1), -1.0*sin(0.017*q1),     0]
[ sin(0.017*q1),  6.1e-17*cos(0.017*q1),      cos(0.017*q1),     0]
[             0,                  -1.0,            6.1e-17, 299.0]
[             0,                     0,                  0,   1.0]
```

T_M(:,:,2) = T^1_2

```
[ cos(0.017*q2 - 1.6), -1.0*sin(0.017*q2 - 1.6),   0, 277.0*cos(0.017*q2 - 1.6)]
[ sin(0.017*q2 - 1.6),      cos(0.017*q2 - 1.6),   0, 277.0*sin(0.017*q2 - 1.6)]
[                   0,                        0, 1.0,                        0]
[                   0,                        0,   0,                      1.0]
```

T_M(:,:,3) = T^2_3

```
[ cos(0.017*q3), -6.1e-17*sin(0.017*q3), -1.0*sin(0.017*q3), 70.0*cos(0.017*q3)]
[ sin(0.017*q3),  6.1e-17*cos(0.017*q3),      cos(0.017*q3), 70.0*sin(0.017*q3)]
[             0,                  -1.0,            6.1e-17,                  0]
[             0,                     0,                  0,                1.0]
```

T_M(:,:,4) = T^3_4

```
[ cos(0.017*q4), -6.1e-17*sin(0.017*q4),      sin(0.017*q4),     0]
[ sin(0.017*q4),  6.1e-17*cos(0.017*q4), -1.0*cos(0.017*q4),     0]
[             0,                   1.0,            6.1e-17, 300.0]
[             0,                     0,                  0,   1.0]
```

T_M(:,:,5) = T^4_5

```
[ cos(0.017*q5), -6.1e-17*sin(0.017*q5), -1.0*sin(0.017*q5),   0]
[ sin(0.017*q5),  6.1e-17*cos(0.017*q5),      cos(0.017*q5),   0]
[             0,                   -1.0,            6.1e-17,   0]
[             0,                      0,                  0, 1.0]
```

T_M(:,:,6) = T^5_6

```
[ cos(0.017*q6 + 3.1), -1.0*sin(0.017*q6 + 3.1),   0,    0]
[ sin(0.017*q6 + 3.1),      cos(0.017*q6 + 3.1),   0,    0]
[                   0,                        0, 1.0, 72.0]
[                   0,                        0,   0,  1.0]
```

ANSWER 4 - T_simplified = T^0_6 (THE CODE IS BIG DUE TO MATLAB CONSIDERING SMALL TERMS THAT CAN BE NEGLIGIBLE – SIMPLIFIED MATRIX IS ALSO SHOWN BELOW THIS GENERATED MATRIX.)

```
[                                    sin(0.018*q6 + 3.1)*(3.7e-33*sin(0.018*q1)
+ 6.1e-17*sin(0.018*q5)*(cos(0.018*q4)*(sin(0.018*q3)*(6.1e-17*cos(0.018*q2 -
1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) -
cos(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 -
1.6)*sin(0.018*q1))) + sin(0.018*q4)*(6.1e-17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 -
1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) - 1.0*sin(0.018*q1) + 6.1e-
17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 -
1.6)*sin(0.018*q1)))) + 6.1e-17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 -
1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) - 6.1e-
17*cos(0.018*q5)*(6.1e-17*sin(0.018*q1) + cos(0.018*q3)*(6.1e-17*cos(0.018*q2 -
1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) - 6.1e-
17*sin(0.018*q4)*(sin(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*sin(0.018*q1) +
cos(0.018*q1)*sin(0.018*q2 - 1.6)) - cos(0.018*q3)*(cos(0.018*q2 -
1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 - 1.6)*sin(0.018*q1))) + 6.1e-
17*cos(0.018*q4)*(6.1e-17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*sin(0.018*q1)
+ cos(0.018*q1)*sin(0.018*q2 - 1.6)) - 1.0*sin(0.018*q1) + 6.1e-
17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 -
1.6)*sin(0.018*q1))) + sin(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-
17*sin(0.018*q2 - 1.6)*sin(0.018*q1))) + sin(0.018*q4)*(sin(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) -
cos(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 -
1.6)*sin(0.018*q1))) - 1.0*cos(0.018*q4)*(6.1e-17*cos(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) -
1.0*sin(0.018*q1) + 6.1e-17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) -
6.1e-17*sin(0.018*q2 - 1.6)*sin(0.018*q1))) + 6.1e-17*sin(0.018*q3)*(cos(0.018*q2 -
1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 - 1.6)*sin(0.018*q1))) - cos(0.018*q6 +
```

```
3.1)*(cos(0.018*q5)*(cos(0.018*q4)*(sin(0.018*q3)*(6.1e-17*cos(0.018*q2 -
1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) -
cos(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 -
1.6)*sin(0.018*q1))) + sin(0.018*q4)*(6.1e-17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 -
1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) - 1.0*sin(0.018*q1) + 6.1e-
17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 -
1.6)*sin(0.018*q1)))) + sin(0.018*q5)*(6.1e-17*sin(0.018*q1) + cos(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) - 6.1e-
17*sin(0.018*q4)*(sin(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*sin(0.018*q1) +
cos(0.018*q1)*sin(0.018*q2 - 1.6)) - cos(0.018*q3)*(cos(0.018*q2 -
1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 - 1.6)*sin(0.018*q1))) + 6.1e-
17*cos(0.018*q4)*(6.1e-17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*sin(0.018*q1)
+ cos(0.018*q1)*sin(0.018*q2 - 1.6)) - 1.0*sin(0.018*q1) + 6.1e-
17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 -
1.6)*sin(0.018*q1))) + sin(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-
17*sin(0.018*q2 - 1.6)*sin(0.018*q1)))),
sin(0.018*q6 + 3.1)*(cos(0.018*q5)*(cos(0.018*q4)*(sin(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) -
cos(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 -
1.6)*sin(0.018*q1))) + sin(0.018*q4)*(6.1e-17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 -
1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) - 1.0*sin(0.018*q1) + 6.1e-
17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 -
1.6)*sin(0.018*q1)))) + sin(0.018*q5)*(6.1e-17*sin(0.018*q1) + cos(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) - 6.1e-
17*sin(0.018*q4)*(sin(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*sin(0.018*q1) +
cos(0.018*q1)*sin(0.018*q2 - 1.6)) - cos(0.018*q3)*(cos(0.018*q2 -
1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 - 1.6)*sin(0.018*q1))) + 6.1e-
17*cos(0.018*q4)*(6.1e-17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*sin(0.018*q1)
+ cos(0.018*q1)*sin(0.018*q2 - 1.6)) - 1.0*sin(0.018*q1) + 6.1e-
17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 -
1.6)*sin(0.018*q1))) + sin(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-
17*sin(0.018*q2 - 1.6)*sin(0.018*q1)))) + cos(0.018*q6 + 3.1)*(3.7e-
33*sin(0.018*q1) + 6.1e-17*sin(0.018*q5)*(cos(0.018*q4)*(sin(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) -
cos(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 -
1.6)*sin(0.018*q1))) + sin(0.018*q4)*(6.1e-17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 -
1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) - 1.0*sin(0.018*q1) + 6.1e-
17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 -
1.6)*sin(0.018*q1)))) + 6.1e-17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 -
1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) - 6.1e-
17*cos(0.018*q5)*(6.1e-17*sin(0.018*q1) + cos(0.018*q3)*(6.1e-17*cos(0.018*q2 -
1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) - 6.1e-
17*sin(0.018*q4)*(sin(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*sin(0.018*q1) +
cos(0.018*q1)*sin(0.018*q2 - 1.6)) - cos(0.018*q3)*(cos(0.018*q2 -
1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 - 1.6)*sin(0.018*q1))) + 6.1e-
17*cos(0.018*q4)*(6.1e-17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*sin(0.018*q1)
+ cos(0.018*q1)*sin(0.018*q2 - 1.6)) - 1.0*sin(0.018*q1) + 6.1e-
17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 -
1.6)*sin(0.018*q1))) + sin(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-
17*sin(0.018*q2 - 1.6)*sin(0.018*q1))) + sin(0.018*q4)*(sin(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) -
cos(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 -
1.6)*sin(0.018*q1))) - 1.0*cos(0.018*q4)*(6.1e-17*cos(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) -
1.0*sin(0.018*q1) + 6.1e-17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) -
6.1e-17*sin(0.018*q2 - 1.6)*sin(0.018*q1))) + 6.1e-17*sin(0.018*q3)*(cos(0.018*q2 -
1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 - 1.6)*sin(0.018*q1))),
sin(0.018*q5)*(cos(0.018*q4)*(sin(0.018*q3)*(6.1e-17*cos(0.018*q2 -
```

```
1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) -
cos(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 -
1.6)*sin(0.018*q1))) + sin(0.018*q4)*(6.1e-17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 -
1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) - 1.0*sin(0.018*q1) + 6.1e-
17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 -
1.6)*sin(0.018*q1)))) - 2.3e-49*sin(0.018*q1) - 3.7e-33*cos(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) -
1.0*cos(0.018*q5)*(6.1e-17*sin(0.018*q1) + cos(0.018*q3)*(6.1e-17*cos(0.018*q2 -
1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) - 6.1e-
17*sin(0.018*q4)*(sin(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*sin(0.018*q1) +
cos(0.018*q1)*sin(0.018*q2 - 1.6)) - cos(0.018*q3)*(cos(0.018*q2 -
1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 - 1.6)*sin(0.018*q1))) + 6.1e-
17*cos(0.018*q4)*(6.1e-17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*sin(0.018*q1)
+ cos(0.018*q1)*sin(0.018*q2 - 1.6)) - 1.0*sin(0.018*q1) + 6.1e-
17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 -
1.6)*sin(0.018*q1))) + sin(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-
17*sin(0.018*q2 - 1.6)*sin(0.018*q1))) - 6.1e-
17*sin(0.018*q4)*(sin(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*sin(0.018*q1) +
cos(0.018*q1)*sin(0.018*q2 - 1.6)) - cos(0.018*q3)*(cos(0.018*q2 -
1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 - 1.6)*sin(0.018*q1))) + 6.1e-
17*cos(0.018*q4)*(6.1e-17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*sin(0.018*q1)
+ cos(0.018*q1)*sin(0.018*q2 - 1.6)) - 1.0*sin(0.018*q1) + 6.1e-
17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 -
1.6)*sin(0.018*q1))) - 3.7e-33*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) -
6.1e-17*sin(0.018*q2 - 1.6)*sin(0.018*q1)),
72.0*sin(0.018*q5)*(cos(0.018*q4)*(sin(0.018*q3)*(6.1e-17*cos(0.018*q2 -
1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) -
cos(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 -
1.6)*sin(0.018*q1))) + sin(0.018*q4)*(6.1e-17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 -
1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) - 1.0*sin(0.018*q1) + 6.1e-
17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 -
1.6)*sin(0.018*q1)))) - 1.8e-14*sin(0.018*q1) - 300.0*cos(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) -
72.0*cos(0.018*q5)*(6.1e-17*sin(0.018*q1) + cos(0.018*q3)*(6.1e-17*cos(0.018*q2 -
1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) - 6.1e-
17*sin(0.018*q4)*(sin(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*sin(0.018*q1) +
cos(0.018*q1)*sin(0.018*q2 - 1.6)) - cos(0.018*q3)*(cos(0.018*q2 -
1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 - 1.6)*sin(0.018*q1))) + 6.1e-
17*cos(0.018*q4)*(6.1e-17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*sin(0.018*q1)
+ cos(0.018*q1)*sin(0.018*q2 - 1.6)) - 1.0*sin(0.018*q1) + 6.1e-
17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 -
1.6)*sin(0.018*q1))) + sin(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-
17*sin(0.018*q2 - 1.6)*sin(0.018*q1))) + 277.0*cos(0.018*q2 - 1.6)*cos(0.018*q1) -
70.0*sin(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*sin(0.018*q1) +
cos(0.018*q1)*sin(0.018*q2 - 1.6)) - 4.4e-15*sin(0.018*q4)*(sin(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*sin(0.018*q1) + cos(0.018*q1)*sin(0.018*q2 - 1.6)) -
cos(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 -
1.6)*sin(0.018*q1))) - 1.7e-14*sin(0.018*q2 - 1.6)*sin(0.018*q1) + 4.4e-
15*cos(0.018*q4)*(6.1e-17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*sin(0.018*q1)
+ cos(0.018*q1)*sin(0.018*q2 - 1.6)) - 1.0*sin(0.018*q1) + 6.1e-
17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 -
1.6)*sin(0.018*q1))) + 70.0*cos(0.018*q3)*(cos(0.018*q2 - 1.6)*cos(0.018*q1) -
6.1e-17*sin(0.018*q2 - 1.6)*sin(0.018*q1)) - 300.0*sin(0.018*q3)*(cos(0.018*q2 -
1.6)*cos(0.018*q1) - 6.1e-17*sin(0.018*q2 - 1.6)*sin(0.018*q1))]

[ - cos(0.018*q6 + 3.1)*(sin(0.018*q5)*(6.1e-17*cos(0.018*q4)*(cos(0.018*q1) -
6.1e-17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2
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- 1.6)*sin(0.018*q1)) + 6.1e-17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) +
6.1e-17*cos(0.018*q1)*sin(0.018*q2 - 1.6))) - 1.0*cos(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) -
6.1e-17*cos(0.018*q1) + sin(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6)) + 6.1e-17*sin(0.018*q4)*(sin(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) +
cos(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6)))) +
cos(0.018*q5)*(sin(0.018*q4)*(cos(0.018*q1) - 6.1e-17*cos(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) +
6.1e-17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6))) - cos(0.018*q4)*(sin(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) +
cos(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6))))) - sin(0.018*q6 + 3.1)*(3.7e-
33*cos(0.018*q1) + 6.1e-17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*cos(0.018*q1)
- 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) + cos(0.018*q4)*(cos(0.018*q1) - 6.1e-
17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 -
1.6)*sin(0.018*q1)) + 6.1e-17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) +
6.1e-17*cos(0.018*q1)*sin(0.018*q2 - 1.6))) + 6.1e-17*cos(0.018*q5)*(6.1e-
17*cos(0.018*q4)*(cos(0.018*q1) - 6.1e-17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 -
1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) + 6.1e-
17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6))) - 1.0*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 -
1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) - 6.1e-17*cos(0.018*q1)
+ sin(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6)) + 6.1e-17*sin(0.018*q4)*(sin(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) +
cos(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6)))) - 6.1e-17*sin(0.018*q3)*(cos(0.018*q2 -
1.6)*sin(0.018*q1) + 6.1e-17*cos(0.018*q1)*sin(0.018*q2 - 1.6)) +
sin(0.018*q4)*(sin(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*cos(0.018*q1) -
1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) + cos(0.018*q3)*(cos(0.018*q2 -
1.6)*sin(0.018*q1) + 6.1e-17*cos(0.018*q1)*sin(0.018*q2 - 1.6))) - 6.1e-
17*sin(0.018*q5)*(sin(0.018*q4)*(cos(0.018*q1) - 6.1e-17*cos(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) +
6.1e-17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6))) - cos(0.018*q4)*(sin(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) +
cos(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6))))), sin(0.018*q6 + 3.1)*(sin(0.018*q5)*(6.1e-
17*cos(0.018*q4)*(cos(0.018*q1) - 6.1e-17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 -
1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) + 6.1e-
17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6))) - 1.0*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 -
1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) - 6.1e-17*cos(0.018*q1)
+ sin(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6)) + 6.1e-17*sin(0.018*q4)*(sin(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) +
cos(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6)))) +
cos(0.018*q5)*(sin(0.018*q4)*(cos(0.018*q1) - 6.1e-17*cos(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) +
6.1e-17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6))) - cos(0.018*q4)*(sin(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) +
cos(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6))))) - cos(0.018*q6 + 3.1)*(3.7e-

```
33*cos(0.018*q1) + 6.1e-17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*cos(0.018*q1)
- 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) + cos(0.018*q4)*(cos(0.018*q1) - 6.1e-
17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 -
1.6)*sin(0.018*q1)) + 6.1e-17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) +
6.1e-17*cos(0.018*q1)*sin(0.018*q2 - 1.6))) + 6.1e-17*cos(0.018*q5)*(6.1e-
17*cos(0.018*q4)*(cos(0.018*q1) - 6.1e-17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 -
1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) + 6.1e-
17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6))) - 1.0*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 -
1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) - 6.1e-17*cos(0.018*q1)
+ sin(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6)) + 6.1e-17*sin(0.018*q4)*(sin(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) +
cos(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6)))) - 6.1e-17*sin(0.018*q3)*(cos(0.018*q2 -
1.6)*sin(0.018*q1) + 6.1e-17*cos(0.018*q1)*sin(0.018*q2 - 1.6)) +
sin(0.018*q4)*(sin(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*cos(0.018*q1) -
1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) + cos(0.018*q3)*(cos(0.018*q2 -
1.6)*sin(0.018*q1) + 6.1e-17*cos(0.018*q1)*sin(0.018*q2 - 1.6))) - 6.1e-
17*sin(0.018*q5)*(sin(0.018*q4)*(cos(0.018*q1) - 6.1e-17*cos(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) +
6.1e-17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6))) - cos(0.018*q4)*(sin(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) +
cos(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6))))), 2.3e-49*cos(0.018*q1) + 3.7e-
33*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 -
1.6)*sin(0.018*q1)) + 6.1e-17*cos(0.018*q4)*(cos(0.018*q1) - 6.1e-
17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 -
1.6)*sin(0.018*q1)) + 6.1e-17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) +
6.1e-17*cos(0.018*q1)*sin(0.018*q2 - 1.6))) - 1.0*cos(0.018*q5)*(6.1e-
17*cos(0.018*q4)*(cos(0.018*q1) - 6.1e-17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 -
1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) + 6.1e-
17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6))) - 1.0*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 -
1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) - 6.1e-17*cos(0.018*q1)
+ sin(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6)) + 6.1e-17*sin(0.018*q4)*(sin(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) +
cos(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6)))) - 3.7e-33*sin(0.018*q3)*(cos(0.018*q2 -
1.6)*sin(0.018*q1) + 6.1e-17*cos(0.018*q1)*sin(0.018*q2 - 1.6)) + 6.1e-
17*sin(0.018*q4)*(sin(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*cos(0.018*q1) -
1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) + cos(0.018*q3)*(cos(0.018*q2 -
1.6)*sin(0.018*q1) + 6.1e-17*cos(0.018*q1)*sin(0.018*q2 - 1.6))) +
sin(0.018*q5)*(sin(0.018*q4)*(cos(0.018*q1) - 6.1e-17*cos(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) +
6.1e-17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6))) - cos(0.018*q4)*(sin(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) +
cos(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6)))), 1.8e-14*cos(0.018*q1) +
300.0*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 -
1.6)*sin(0.018*q1)) + 4.4e-15*cos(0.018*q4)*(cos(0.018*q1) - 6.1e-
17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 -
1.6)*sin(0.018*q1)) + 6.1e-17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) +
6.1e-17*cos(0.018*q1)*sin(0.018*q2 - 1.6))) + 70.0*sin(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) -
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72.0*cos(0.018*q5)*(6.1e-17*cos(0.018*q4)*(cos(0.018*q1) - 6.1e-
17*cos(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 -
1.6)*sin(0.018*q1)) + 6.1e-17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) +
6.1e-17*cos(0.018*q1)*sin(0.018*q2 - 1.6))) - 1.0*cos(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) -
6.1e-17*cos(0.018*q1) + sin(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6)) + 6.1e-17*sin(0.018*q4)*(sin(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) +
cos(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6)))) + 70.0*cos(0.018*q3)*(cos(0.018*q2 -
1.6)*sin(0.018*q1) + 6.1e-17*cos(0.018*q1)*sin(0.018*q2 - 1.6)) -
300.0*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6)) + 277.0*cos(0.018*q2 - 1.6)*sin(0.018*q1) +
1.7e-14*cos(0.018*q1)*sin(0.018*q2 - 1.6) + 4.4e-
15*sin(0.018*q4)*(sin(0.018*q3)*(6.1e-17*cos(0.018*q2 - 1.6)*cos(0.018*q1) -
1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) + cos(0.018*q3)*(cos(0.018*q2 -
1.6)*sin(0.018*q1) + 6.1e-17*cos(0.018*q1)*sin(0.018*q2 - 1.6))) +
72.0*sin(0.018*q5)*(sin(0.018*q4)*(cos(0.018*q1) - 6.1e-17*cos(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) +
6.1e-17*sin(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6))) - cos(0.018*q4)*(sin(0.018*q3)*(6.1e-
17*cos(0.018*q2 - 1.6)*cos(0.018*q1) - 1.0*sin(0.018*q2 - 1.6)*sin(0.018*q1)) +
cos(0.018*q3)*(cos(0.018*q2 - 1.6)*sin(0.018*q1) + 6.1e-
17*cos(0.018*q1)*sin(0.018*q2 - 1.6))))]

[
sin(0.018*q6 + 3.1)*(6.1e-17*cos(0.018*q2 + 0.018*q3 - 1.6) + sin(0.018*q5)*(6.1e-
17*cos(0.018*q4)*sin(0.018*q2 + 0.018*q3 - 1.6) + 6.1e-17*sin(0.018*q4)*(6.1e-
17*cos(0.018*q2 + 0.018*q3 - 1.6) + 6.1e-17)) - cos(0.018*q5)*(6.1e-17*cos(0.018*q2
+ 0.018*q3 - 1.6) - 3.7e-33*sin(0.018*q4)*sin(0.018*q2 + 0.018*q3 - 1.6) + 6.1e-
17*cos(0.018*q4)*(3.7e-33*cos(0.018*q2 + 0.018*q3 - 1.6) + 3.7e-33) - 2.3e-49) +
1.0*sin(0.018*q4)*sin(0.018*q2 + 0.018*q3 - 1.6) - cos(0.018*q4)*(6.1e-
17*cos(0.018*q2 + 0.018*q3 - 1.6) + 6.1e-17) - 2.3e-49) - cos(0.018*q6 +
3.1)*(sin(0.018*q5)*(1.0*cos(0.018*q2 + 0.018*q3 - 1.6) - 6.1e-
17*sin(0.018*q4)*sin(0.018*q2 + 0.018*q3 - 1.6) + cos(0.018*q4)*(3.7e-
33*cos(0.018*q2 + 0.018*q3 - 1.6) + 3.7e-33) - 3.7e-33) +
cos(0.018*q5)*(1.0*cos(0.018*q4)*sin(0.018*q2 + 0.018*q3 - 1.6) +
sin(0.018*q4)*(6.1e-17*cos(0.018*q2 + 0.018*q3 - 1.6) + 6.1e-17))),
sin(0.018*q6 + 3.1)*(1.0*sin(0.018*q5)*(1.0*cos(0.018*q2 + 0.018*q3 - 1.6) - 6.1e-
17*sin(0.018*q4)*sin(0.018*q2 + 0.018*q3 - 1.6) + cos(0.018*q4)*(3.7e-
33*cos(0.018*q2 + 0.018*q3 - 1.6) + 3.7e-33) - 3.7e-33) +
1.0*cos(0.018*q5)*(1.0*cos(0.018*q4)*sin(0.018*q2 + 0.018*q3 - 1.6) +
sin(0.018*q4)*(6.1e-17*cos(0.018*q2 + 0.018*q3 - 1.6) + 6.1e-17))) + cos(0.018*q6 +
3.1)*(6.1e-17*cos(0.018*q2 + 0.018*q3 - 1.6) + sin(0.018*q5)*(6.1e-
17*cos(0.018*q4)*sin(0.018*q2 + 0.018*q3 - 1.6) + 6.1e-17*sin(0.018*q4)*(6.1e-
17*cos(0.018*q2 + 0.018*q3 - 1.6) + 6.1e-17)) - cos(0.018*q5)*(6.1e-17*cos(0.018*q2
+ 0.018*q3 - 1.6) - 3.7e-33*sin(0.018*q4)*sin(0.018*q2 + 0.018*q3 - 1.6) + 6.1e-
17*cos(0.018*q4)*(3.7e-33*cos(0.018*q2 + 0.018*q3 - 1.6) + 3.7e-33) - 2.3e-49) +
1.0*sin(0.018*q4)*sin(0.018*q2 + 0.018*q3 - 1.6) - cos(0.018*q4)*(6.1e-
17*cos(0.018*q2 + 0.018*q3 - 1.6) + 6.1e-17) - 2.3e-49),
sin(0.018*q5)*(1.0*cos(0.018*q4)*sin(0.018*q2 + 0.018*q3 - 1.6) +
1.0*sin(0.018*q4)*(6.1e-17*cos(0.018*q2 + 0.018*q3 - 1.6) + 6.1e-17)) - 3.7e-
33*cos(0.018*q2 + 0.018*q3 - 1.6) - cos(0.018*q5)*(1.0*cos(0.018*q2 + 0.018*q3 -
1.6) - 6.1e-17*sin(0.018*q4)*sin(0.018*q2 + 0.018*q3 - 1.6) +
1.0*cos(0.018*q4)*(3.7e-33*cos(0.018*q2 + 0.018*q3 - 1.6) + 3.7e-33) - 3.7e-33) -
6.1e-17*sin(0.018*q4)*sin(0.018*q2 + 0.018*q3 - 1.6) + cos(0.018*q4)*(3.7e-
33*cos(0.018*q2 + 0.018*q3 - 1.6) + 3.7e-33) + 1.4e-65,
```

```
sin(0.018*q5)*(72.0*cos(0.018*q4)*sin(0.018*q2 + 0.018*q3 - 1.6) +
72.0*sin(0.018*q4)*(6.1e-17*cos(0.018*q2 + 0.018*q3 - 1.6) + 6.1e-17)) -
300.0*cos(0.018*q2 + 0.018*q3 - 1.6) - 70.0*sin(0.018*q2 + 0.018*q3 - 1.6) -
277.0*sin(0.018*q2 - 1.6) - cos(0.018*q5)*(72.0*cos(0.018*q2 + 0.018*q3 - 1.6) -
4.4e-15*sin(0.018*q4)*sin(0.018*q2 + 0.018*q3 - 1.6) + 72.0*cos(0.018*q4)*(3.7e-
33*cos(0.018*q2 + 0.018*q3 - 1.6) + 3.7e-33) - 2.7e-31) - 4.4e-
15*sin(0.018*q4)*sin(0.018*q2 + 0.018*q3 - 1.6) + cos(0.018*q4)*(2.7e-
31*cos(0.018*q2 + 0.018*q3 - 1.6) + 2.7e-31) + 299.0]

[
0,
0,
0,
1.0]
```

Basically, if we ignore the small terms, we obtain

$$= \begin{bmatrix} 72(-c\theta_{1234}s\theta_5 + c\theta_{14}s\theta_{235} - s\theta_{145} - c\theta_{125}s\theta_3 - c\theta_{135}s\theta_2) - 302(c\theta_{12}s\theta_3 + c\theta_{13}s\theta_2) + 70(c\theta_{123} - c\theta_1 s\theta_{23}) + 270(c\theta_{12}) \\ 72(-c\theta_{234}s\theta_{15} + c\theta_4 s\theta_{1235} + c\theta_1 s\theta_{45} - c\theta_{25}s\theta_{13} - c\theta_{35}s\theta_{12}) - 302(c\theta_2 s\theta_{13} + c\theta_3 s\theta_{12}) + 70(c\theta_{23}s\theta_1 - s\theta_{123}) + 270(c\theta_2 s\theta_1) \\ 72(c\theta_{134}s\theta_{25} + c\theta_{24}s\theta_{35} + c\theta_5 s\theta_{23} - c\theta_{235}) + 302(s\theta_{23} - c\theta_{23}) - 70(c\theta_3 s\theta_2 + c\theta_2 s\theta_3) - 270(s\theta_2) + 290 \\ 1 \end{bmatrix}$$

ANS-5

```
T_0_6_Q5 =

[  0, 0, 1, 374]

[  0, 1, 0,   0]

[ -1, 0, 0, 630]

[  0, 0, 0,   1]
```

ANS-6-a

```
T_0_6_Q6 =

[ 0, -1, 1,  363]

[ 1, -1, 0, -328]

[ 1,  0, 1,  637]

[ 0,  0, 0,    1]
```

ANS 6 -b = Cartesian position = [363 mm , -328mm, -637mm]^T

ANS 6 -c = Unit vector representing approach vector = [1, 0, 1]^T

ANS 7 – plotarm function code. THE IMAGES ARE SHOWN in answer-8

```
function T = plotarm(Q1,Q2,Q3,Q4,Q5,Q6);

syms q1 q2 q3 q4 q5 q6
theta = deg2rad([q1, q2-90, q3, q4, q5, q6+180]);
alpha = deg2rad([-90, 0, -90, 90, -90, 0]);
d = [290, 0, 0, 302, 0, 72];
a = [0, 270, 70, 0, 0, 0];
T_M = dhparam2matrix(theta, alpha, d, a);

X=[0];
Y=[0];
Z=[0];

for i=1:6
    T_M(:,:,i) = vpa(subs(T_M(:,:,i), [q1, q2, q3, q4, q5,
q6],[Q1,Q2,Q3,Q4,Q5,Q6]));
end

T_0_1 = T_M(:,:,1);
T_0_2 = T_M(:,:,1)*T_M(:,:,2);
T_0_3 = T_M(:,:,1)*T_M(:,:,2)*T_M(:,:,3);
T_0_4 = T_M(:,:,1)*T_M(:,:,2)*T_M(:,:,3)*T_M(:,:,4);
T_0_5 = T_M(:,:,1)*T_M(:,:,2)*T_M(:,:,3)*T_M(:,:,4)*T_M(:,:,5);
T_0_6 = T_M(:,:,1)*T_M(:,:,2)*T_M(:,:,3)*T_M(:,:,4)*T_M(:,:,5)*T_M(:,:,6);

X = round([X, T_0_1(1,4) , T_0_2(1,4),  T_0_3(1,4), T_0_4(1,4), T_0_5(1,4),
T_0_6(1,4)]);
Y = round([Y, T_0_1(2,4) , T_0_2(2,4),  T_0_3(2,4), T_0_4(2,4), T_0_5(2,4),
T_0_6(2,4)]);
Z = round([Z, T_0_1(3,4) , T_0_2(3,4),  T_0_3(3,4), T_0_4(3,4), T_0_5(3,4),
T_0_6(3,4)]);

figure
scatter3(X,Y,Z);
hold on
plot3(X,Y,Z);
xlabel('x')
ylabel('y')
zlabel('z')
hold off
```

ANS-8

As seen from the images, the computed values match the values from ROBOT STUDIO.

Any deviations are due to the rounding off in the program.
Images have been provided in a separate file as well to crosscheck the answers.

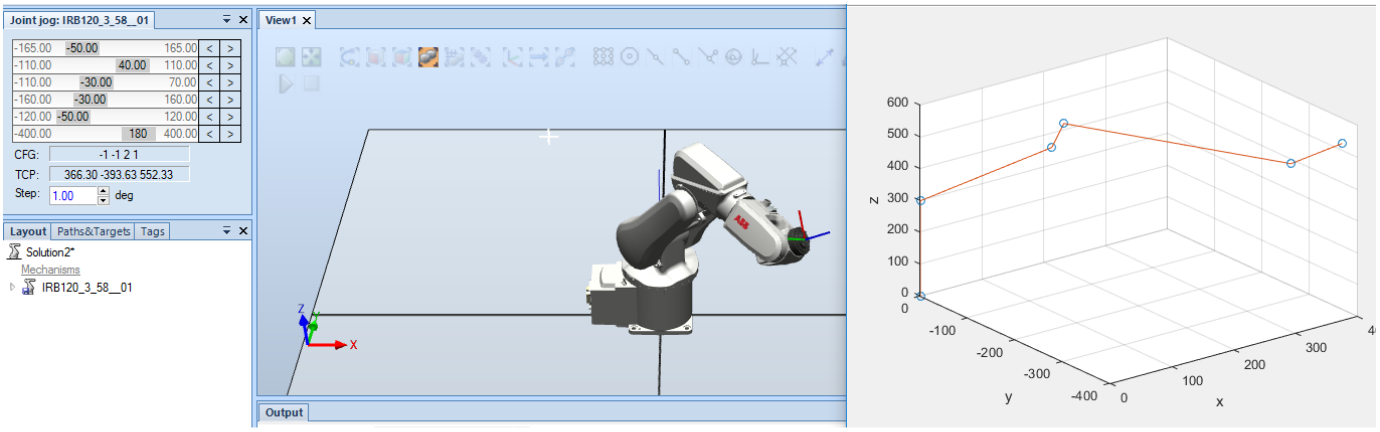
T_0_6_Q8_1 =

[0, -1, 1, 366] Tool Cartesian position w.r.t baseframe is[366mm, -395mm, 551mm]^T

[1, -1, 0, -395]

[1, 0, 1, 551]

[0, 0, 0,   1]



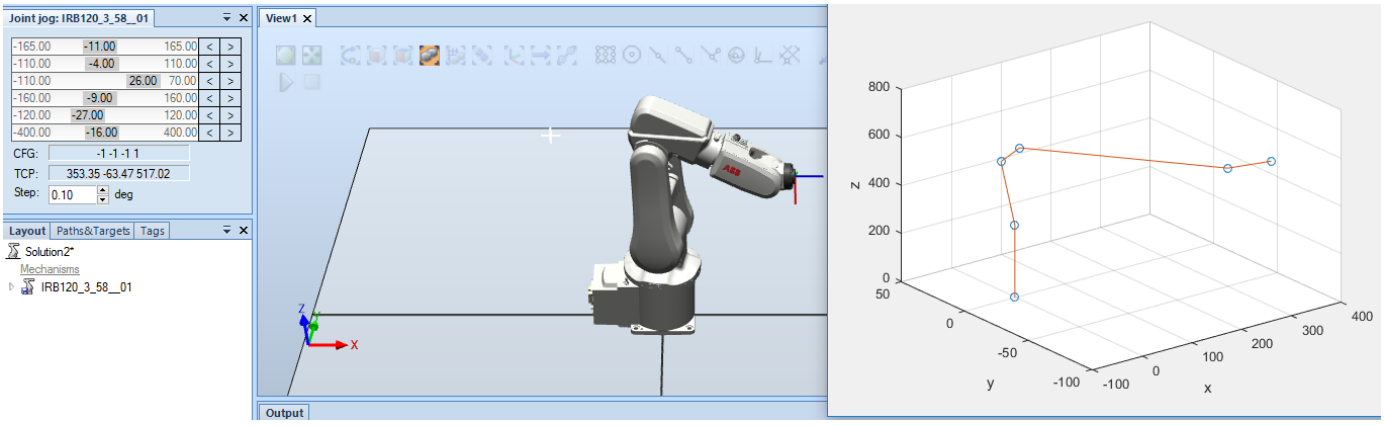
T_0_6_Q8_2 =

[0, 0, 1, 353] Tool Cartesian position w.r.t baseframe is[353mm, -64mm, 516mm]^T

[0, 1, 0, -64]

[-1, 0, 0, 516]

[0, 0, 0,   1]



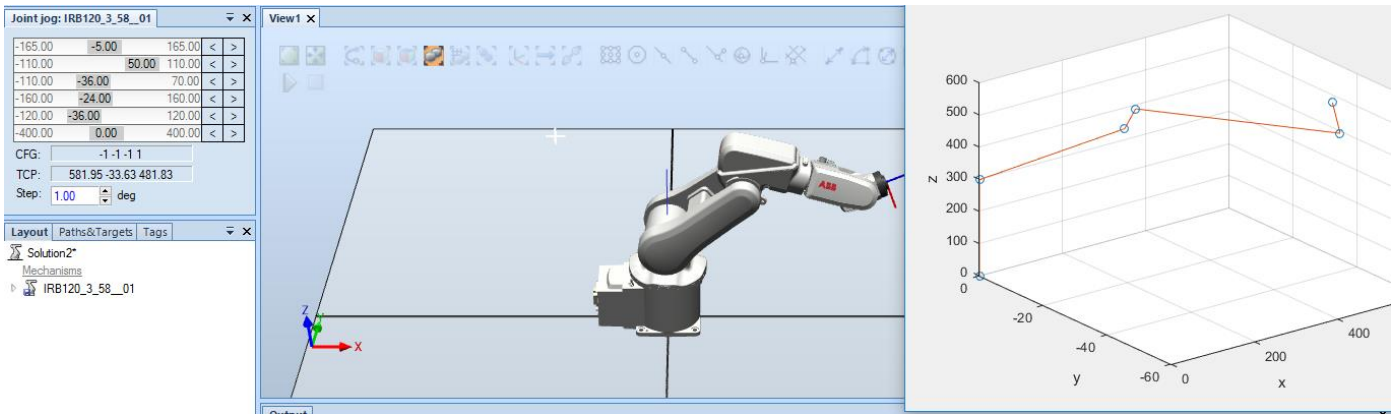
T_0_6_Q8_3 =

[0, 0, 1, 582] Tool Cartesian position w.r.t baseframe is[582mm, -34mm, 481mm]^T

[0, 1, 0, -34]

[-1, 0, 0, 481]

[0, 0, 0,   1]



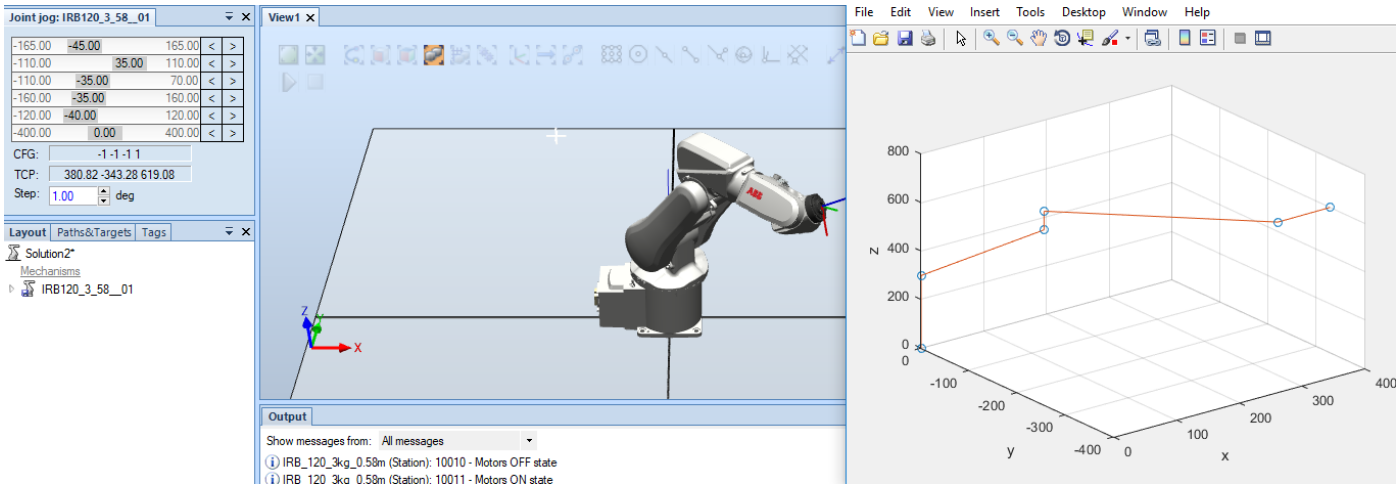
T_0_6_Q8_4 =

[0, 1, 1, 381] Tool Cartesian position w.r.t baseframe is[381mm, -344mm, 618mm]^T

[-1, 1, 0, -344]

[-1, -1, 1, 618]

[0, 0, 0,   1]



T_0_6_Q8_5 =

[0, 0, 1, 276] Tool Cartesian position w.r.t baseframe is[276mm, -45mm, 791mm]^T

[0, 1, 0, -45]

[-1, 0, 1, 791]

[0, 0, 0,   1]