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Design of 6-Axis robotic arm

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ABSTRACT

There has been an increase in the use of a robotic arm in various commercial and non-commercial sectors such as production, electronics, healthcare and assembly lines. Majorly robotic arm is used in assembly lines due to human restriction in that area. The aim of this project is the design of stationary 6-axis robotic arm for pick and place operation. For reducing the cost of stepper motors, we have achieved the speed reduction. The main context of this paper is the design of 6-axis robotic arm resembling a human arm consisting of manipulators performing various motions including pitching, rolling and yawing. The robotic arm is developed using software V-Rep for its efficient usage in Torque calculations and simulation

Keywords— *6-Axis Robotic Arm, V-Rep, Solidworks*

1. INTRODUCTION

A **robotic arm** is a type of mechanical arm, usually programmable, with similar functions to a human arm; the arm may be the sum total of the mechanism or may be part of a more complex robot. The links of such a manipulator are connected by joints allowing either rotational motion (such as in an articulated robot) or translational (linear) displacement. The terminus of the kinematic chain of the manipulator is called the end effectors and it is analogous to the human hand. The end effectors, or robotic hand, can be designed to perform any desired task such as welding, gripping, spinning etc., depending on the application.

Many times it is difficult to judge the actual working co-ordinates including the degree of freedom, work-space coordinates of the prototype in the design stage. Hence by keeping the payload of 0.5kg and maximum horizontal reach of 0.75m constant the arm was designed. Kinematic and Dynamic analysis are crucial tasks in designing, this is eased by V-Rep Software. The solid works model of the arm is inserted in the database of V-Rep along with its endpoint coordinates. V-Rep analyses the torque and feasibility of robotic arm bypassing the design and analysis procedures. Later on, the torque calculations are verified by hand calculations. The other designs such as shafts, bearings, and pulleys are handmade with interpretations and later on verified by actual working of each axis 1. Individually 2.Then combined.

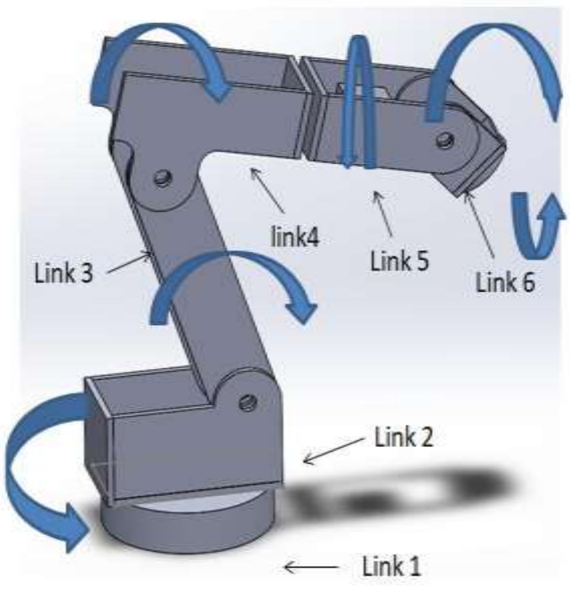

Fig. 1: Rough sketch of 6-Axis

2. METHODOLOGY

2.1 Robotic Frame Material

The frame is the main body of the arm. The complete structure of arm containing manipulators and base on which the armrests can be considered a frame. Considering the high strength and minimum cost requirement of the frame,2 options were available. They were Plain Carbon Steel, Aluminium Alloy.

Considering, Plain carbon Steel 45C8 having S_{yt}=370Mpa & Aluminium Alloy 6082 T6 having S_{yt}=270 Mpa.
Plain carbon Steel was chosen for the joint brackets because of machinability, weldability, relatively low cost, good strength-to-weight ratio, and availability.

2.2 The material of parts and their specifications

- **Metal plate:** Plain Carbon Steel 45C8
- **Shaft:** Plain Carbon Steel 45C8.
- **Belts & Pulleys:** PET Rubber for the belt. Plastic for the pulley**.**
- **Flanges:** Aluminum alloy 6082 T6.
- **Bearing Housing:** Polypropylene(PP)

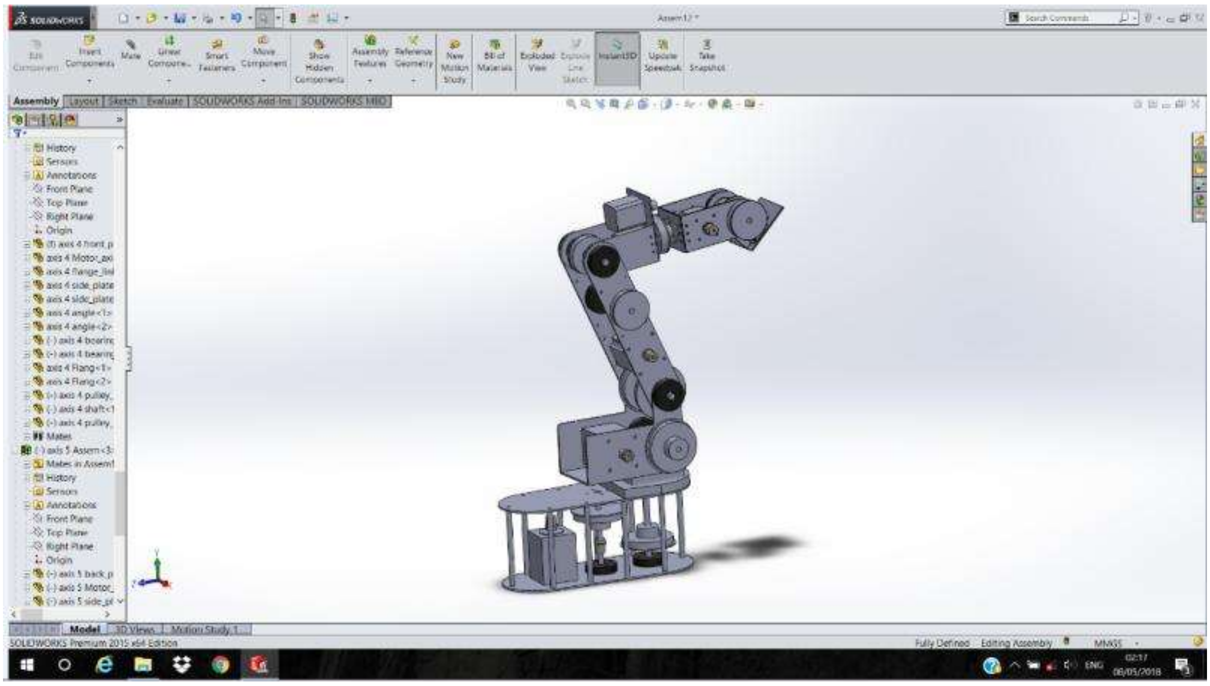

Fig. 2: Cad prototype on Solidworks

Table 1: Required Specifications of Arm:

Maximum Payload	0.6 kg
Nominal Payload	0.5 kg
Horizontal Reach	600mm
Accuracy	3mm

2.3 Torque by using V-REP Software

The V-REP allows the user to choose how to control the robot, if in inverse kinematic mode or torque/force mode. The configuration in the V-REP environment is different for each case, and sending torque to V-REP can be a little bit tricky. Now that the V-REP environment is all set up, one needs to know how to send the torque from Matlab to V-REP, in order to control the robot.

According to V-REP documentation, one needs to specify a target velocity and a maximum torque for each joint. If the current velocity is below the target velocity, the maximum torque is applied. So if you want to control the joints in force/torque, just specify a target velocity very high (e.g. that will never be reached) and then modulate the torque/force using the 'simxSetJointForce' function. One important thing is that the function that sets the maximum torque of the joints, does not accept a negative value. So in order to change the sign of the applied torque, one needs to change the sign of the target velocity and to send the absolute value of the torque.

Table 2: Torque & Output Speed based on V-Rep

Axis	Required Torque (N-m)	Output Speed (RPM)
1	16.554	10
2	10.52	10
3	5.19	13
4	1.86	13
5	0.75537	13
6	0.049	15

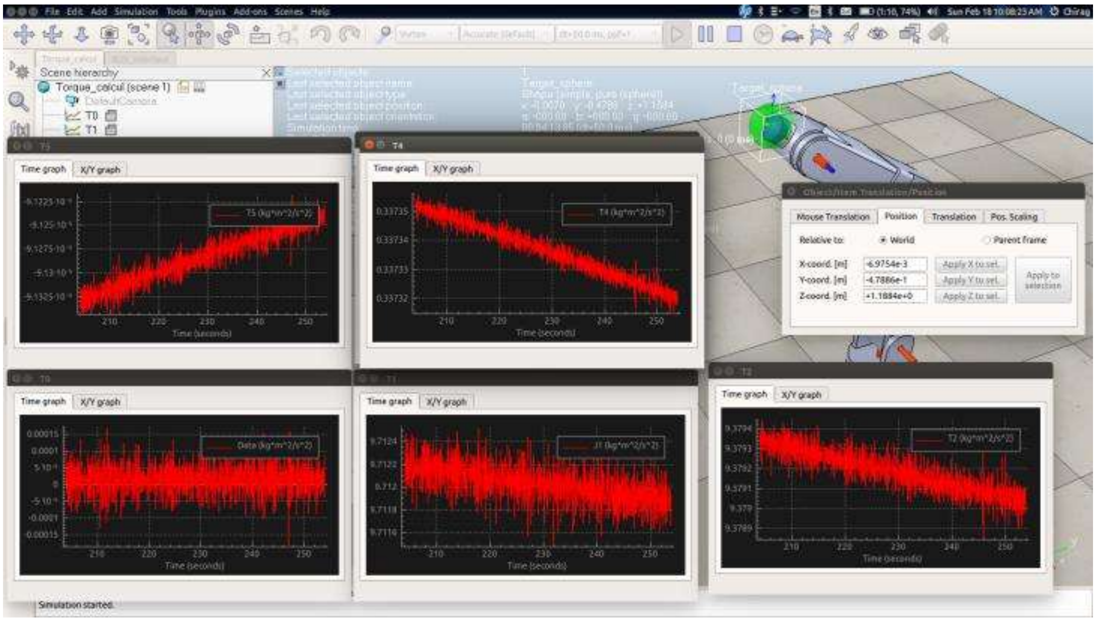

Fig. 3: Torque values calculations on V-Rep Software

2.4 Torque Calculations if each axis

Based on values of torque required from V-Rep, Each axis design was accordingly validated.

Torque (T) =F x r

Where,
F= Total load on that axis (F=m.g)
r= Length of arm
T= Torque required
m= mass of axis
g= gravitational acceleration
Here, mass of gripper+payload=0.5kg
Hence,

For Axis 6: T=0.5 x 9.81 x 0.01 = 0.049 where r = 0.01m.

For Axis 5: Consider the mass of gripper, payload, and mass of axis 6 motor, belt, and pulleys, link.
As mass of axis 6 is 0.2kg, Torque of axis 5 is: T= (0.5+0.2) x 9.81 x 0.11 = 0.75537 where r=0.11m
Similarly, other torque are calculated.

2.5 Motor Pulley & belt Selection

- Power transmitted by the motor $(P) = \frac{2\pi n T}{60}$
- Hence output Torque $(T_2) = \frac{60P}{2\pi n_2}$
- Belt length & center distance calculated by the formula $L = 2C + \frac{\pi(D+d)}{2} + \frac{(D-d)^2}{4C}$

Table 3: Axis 1 Motor & Pulley Selection

AXIS 1, 12.6 Kg-Cm, 24 VDC, 2.8 Amp				
	D1	**D2**	**D3**	**D4**
PCD	16.10	80.80	16.10	80.80
d	5,8	6,15	5,8	6,22
w	14,12.5	12.5	14,12.5	11,12
L	22	26	22	30,23
Df	19	100	19	87,85
TYPE	XL-C	XL-B	XL-C	XL-B
Reduction	5.01863354		5.01863354	
RPM	300	49.793814	49.793814	9.9217873
TORQUE	0.637	3.8378261	3.8378261	19.260643
C.D	82.665		82.665	
Belt length	13 inch		13 Inch	
Selected Pulley Designation	10XL-C	50XL-B	10XL-C	50XL-B
Required ID	6	8	8	10

Table 4: Axis 2 Motor & Pulley Selection

AXIS 2, 18.9 Kg-Cm, 24 VDC, 2.8 Amp				
	D1	**D2**	**D3**	**D4**
PCD	16.10	80.80	16.10	64.7
d	5,8	6,22	5,8	5,15
w	14,12.5	11,12	14,12.5	14
L	22	30,23	22	31
Df	19	87,85	19	68
TYPE	XL-C	XL-B	XL-C	XL-B
Reduction	5.01863354		4.01863354	
RPM	200	39.85148515	39.85148515	9.9166756
Torque	1.11	5.57068323	5.57068323	22.386534
C.D	82.6650		58.49	
Belt length	13 inch		10 Inch	
Selected Pulley Designation	10XL-C	50XL-B	10XL-C	40XL-B
Required ID	6	8	8	10

Table 5: Axis 3 Motor & Pulley Selection

AXIS 3, 12.6 Kg-Cm, 24 VDC, 2.8 Amp				
	D1	**D2**	**D3**	**D4**
PCD	16.10	61.45	16.10	61.45
d	5,8	5,15	5,8	5,15
L	22	25	22	25
Df	19	63	19	63
TYPE	XL-C	XL-B	XL-C	XL-B
Reduction	3.816770186		3.816770186	
RPM	200	52.40032547	52.40032547	13.728971
Torque	0.653	2.492350932	2.492350932	9.5127307
C.D	88.59		88.59	
Belt length	12 inch		12 inch	
Selected Pulley Designation	10XL-C	38XL-B	10XL-C	38XL-B
Required ID	6	8	8	10

Table 6: Axis 4 Motor & Pulley Selection

AXIS 4, 7 Kg-Cm, 24 VDC		
	D1	**D2**
PCD	16.10	61.45
d	5,8	5,15
L	22	25
Df	19	63
Type	XL-C	XL-B
Reduction	3.816770186	
RPM	50	13.10008137
TORQUE	0.509	1.942736025
C.D	48	
Belt length	9 inch	
Selected Pulley Designation	10XL-C	38XL-B
Required ID	5	10

Table 7: Axis 5 Motor & Pulley Selection

AXIS 5, 5.5Kg-Cm, 24 VDC		
	D1	**D2**
PCD	16.10	61.45
d	5,8	5,15
L	22	25
Df	19	63
Type	XL-C	XL-B
Reduction	3.816770186	
RPM	50	13.10008137
Torque	0.439	1.675562112
C.D	61	
Belt length	10 inch	
Selected Pulley Designation	10XL-C	38XL-B
Required ID	5	10

3. DESIGN OF SHAFT

- **Axis 3 Intermediate shaft**

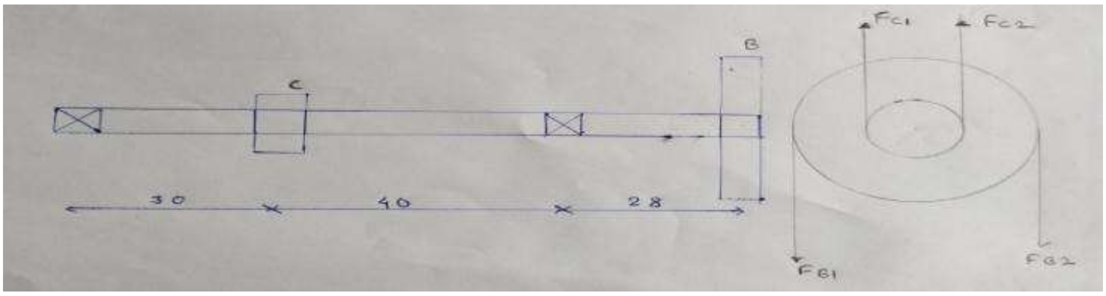

Fig. 4: Axis 3 intermediate shaft, pulley, bearing assembly

Small pulley diameter (d) = 16.10 mm
Large pulley diameter (D) = 61.45 mm
Consider tight side tension as F1 and slag side tension as F2
We know that: $\frac{F_{b1}}{F_{b2}} = e^{\mu\theta}$
Hence from the above formula, we get the equation:

$$F_{b1} - 13.735F_{b2} = 0 \quad (1)$$

Torque is calculated by the formula: $T = (F_{b1} - F_{b2})(\frac{D}{2})$

$$F_{b1} - F_{b2} = 81.367 \quad (2)$$

From equation (1) and (2),

$$F_{b1} = 87.75 \text{ N}$$
$$F_{b2} = 6.3889 \text{ N}$$
$$F_{b1} + F_{b2} = 94.1389 \text{ N}$$

Similarly calculate the tensions on small pulley:

$$F_{c1} = 334.9438 \text{ N}$$
$$F_{c2} = 24.3848 \text{ N}$$
$$F_{c1} + F_{c2} = 359.3286 \text{ N}$$

Calculate the reaction:

$$\sum(F) = 0 R_a = 242.9581 \text{ N}$$
$$\sum(M) = 0 R_b = 22.1839 \text{ N}$$

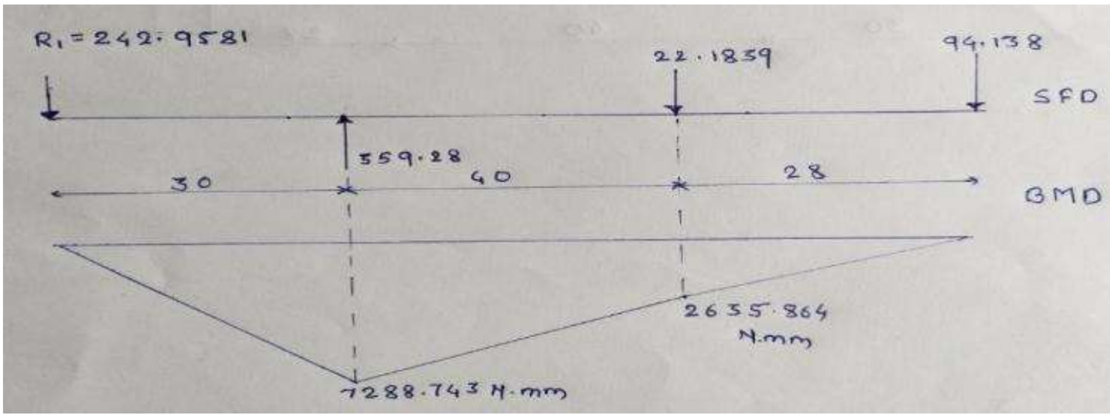

Fig. 5: Axis 3 intermediate shaft bending moment diagram

Maximum bending moment $M_{max} = 7288.743$ N
Equivalent twisting moment on shaft

$$T_e = \sqrt{(K_b M)^2 + (K_t T)^2}$$

Where, K_b = shock and fatigue factor for bending = 1.6
K_t = Shock and fatigue factor for twisting =1.2

Maximum torsional shear stress on the Shaft: $\tau_{max} = \frac{16T_e}{\pi d^3}$

Allowable shear stress on the shaft: $\tau_{all} = \frac{0.5\, S_{yt}}{N_f}$

For material plain carbon steel: $S_{yt} = 560 \ \frac{N}{mm^2}$

Considering $N_f = 1.5$

Diameter of shaft = 7.73689 ≈ 8 mm

Similarly designed all shaft are tabulated below:

Table 8: diameters of shafts

S. No.	Position of shaft	Diameter (mm)
1	Axis 1 Intermediate Shaft	10
2	Axis 1 Output Shaft	12
3	Axis 2 Intermediate shaft	10
4	Axis 2 Output Shaft	12
5	Axis 3 Intermediate shaft	8
6	Axis 3 Output Shaft	10
7	Axis 4 Shaft	10
8	Axis 5 Shaft	6

4. BEARING CALCULATION

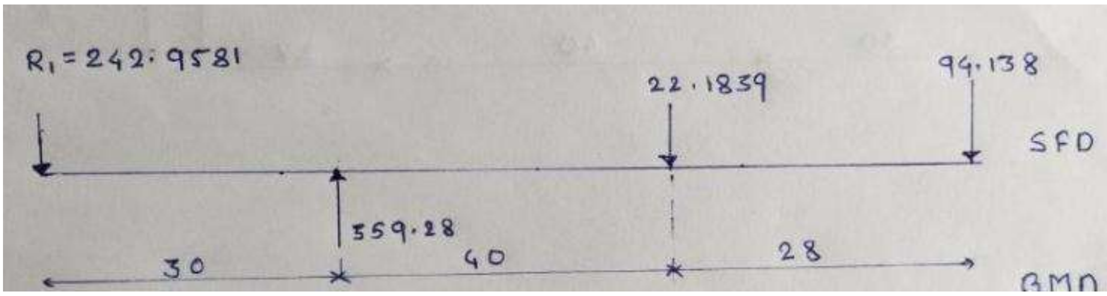

Fig. 6: Forces on axis 3 intermediate shaft

The inner diameter of bearing = 8 mm

$$R_a = 242.9581 \text{ N}$$
$$R_b = 22.1859 \text{ N}$$

Equivalent dynamic load on bearing

$$P_e = (R_a)K_a$$

Where k_a =load factor or application factor =1.2

$$P_e = 291.5497 \text{ N}$$

Consider $L_{h10} = 40000$ hr

$$L_{10} = \frac{L_{h10} \times 60 \times n}{10^6} \text{ Million revolution}$$
$$n = 52.5 \text{ RPM}$$
$$L_{10} = 32.94953 \text{ Million revolution}$$
$$L_{10} = (\frac{C}{P_e})^a \text{ Million revolution}$$

Where a =constant =3 (for ball bearing)

C = 0.934 KN

Hence selected bearing from **S.K.F** Catalogue has designation: **08**
Basic dynamic capacity for selected bearing = 3.45 KN
Selected bearing dimensions:
Bore (d) = 8 mm
Outer diameter (D) = 22 mm
Width (B) = 7 mm
similarly, we can select other bearings

Table 9: bearings designation and dimensions

Selected bearing designation	Bearing dimensions (mm)		
	Bore (d)	Outer diameter (D)	Width (B)
626	6	19	6
608	8	22	7
6000	10	26	8
6001	12	28	8

- **Design of flange**

For 10 mm diameter shaft
Inner diameter of hub = 10 mm
Outer diameter of hub (D) = 2d = 20 mm
The diameter of the bolt circle (D_1) = 3d = 30 mm
Outer diameter of the large (D_2) = 4d = 40 mm
Length of hub (l) =1.5d = 15 mm
Thickness of flange = 0.5d = 5 mm

By proportion

- **Design of hub**

Hub is subjected to torsional shear stress and it is considered as hollow shaft hence torsional shear stress induced in the hub is:

$$\tau_h = \frac{16T}{\pi d^3(1-K^4)}$$

Where, $K = \frac{d}{D}$

$$\tau_h = 6.4597248 \ \frac{N}{mm^2}$$

Allowable torsional shear stress:

$$\tau_{all} = \frac{0.5S_{yt}}{N_f}$$

The material used aluminum 6082 T6

$$S_{yt} = 270 \ \frac{N}{mm^2}$$

Consider $N_f = 3$

$$\tau_{all} = 45 \ \frac{N}{mm^2}$$

$$\tau_h < \tau_{all}$$

Hence the hub of the flange is safe.

- Design of flange

The flange is subjected to direct shear stress at the junction with the hub

$$\tau_f = \frac{2T}{\pi D^2 T_f}$$

$$\tau_f = 3.027996 \ \frac{N}{mm^2}$$

$$\tau_f < \tau_{all}$$

Hence flange is safe.

5. CONCLUSION

- The strong design has made the robotic arm functioning efficiently.
- The arm is designed with a factor of safety 1.5, hence the arm can carry payload up to 0.7kg without a change in its applications.
- Some changes can also be made to the mechanical structure of arm along with the angle of rotation.

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