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Design of articulated robotic arm using composites

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ABSTRACT

A robot is a machine, especially a programmable one by a computer, capable of carrying out a complex series of actions automatically. Most of the robots are made of metals and its alloys which make them heavy as compared to that made of composites. The aim of this project is to design and analyze the articulated robotic arm made of composites (Nylon 6 6). The study was done to design an articulated robotic arm assembly for a given work volume, analyse it for load carrying conditions and show the load, stress, and deformation results for Nylon 6 6 material.

Keywords— *Robots, Composites, Nylon, Carbon fiber, Design, Analysis, Scope*

1. A BRIEF HISTORY OF ROBOTS

Leonardo da Vinci created many robot-like sketches and designs in the 1500's. The word robot first appeared in print in the 1920 play R.U.R. (Rossum's Universal Robots) by Karl Kapek, a Czechoslovakian playwright. Robotais Czechoslovakian for worker or serf (peasant). Typical of early science fiction, the robots take over and exterminate the human race. Isaac Asimov popularized the term robotics through many science-fiction novels and short stories. Asimov is a visionary who envisioned in the 1930's the positronic brain for controlling robots; this pre-dated digital computers by a couple of decades. Unlike earlier robots in science fiction, robots do not threaten humans since Asimov invented the three laws of robotics. Joseph Englebergerand George Devoewere the fathers of industrial robots. Their company, animation, built the first industrial robot, the PUMA (Programmable Universal Manipulator Arm, a later version shown below), in 1961.

2. ROBOTS

Typically, robots are used to perform jobs that are difficult, hazardous or monotonous for humans. They lift heavy objects, paint, weld, handle chemicals, and perform assembly work for days at a time without suffering ff rom fatigue. Robots are defined by the nature of their movement. This section describes the following,

2.1 Classifications of Robots

- Cartesian
- Cylindrical
- Polar
- Articulated
- SCARA

2.2 Robot Parts

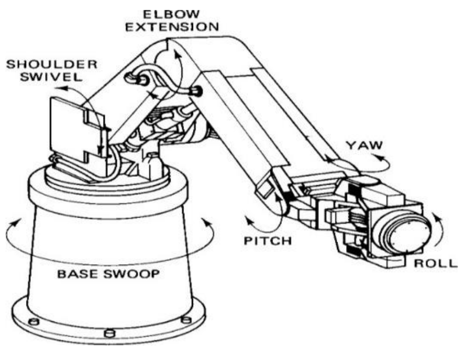

Fig. 1: Parts of Robotic Arm

2.3 Technical Robotic Terms
- Speed
- Load Bearing Capacity
- Accuracy
- Repeatability
- Work envelope
- Work cells

2.4 Robotic System Components
- Mechanical structure
- Actuator
  - Air motors
  - Hydraulic motors
  - Clutch/Brakes
  - Stepper motors
- Controller circuit

Actuator Type	Strengths	Weaknesses
Air Motor	-Low Cost -Easily Maintained -Simple to Operate	-Audible Compressor Noise -Inefficient System -Difficult to Regulate Speed
Hydraulic Motor	-High Loads Possible -Simple to Operate	-Slow System -Inefficient System -High Maintenance Requirements
Clutch/Brake	-Low Cost -Effective for Light Loads -Easy to Perform Speed Matching	-Uncontrolled Acceleration -Components Prone to Wear -Non-repeatable System
Stepper Motor	-Simple Control -Constant Load -Accurate Position	-Cannot Vary Load -Can Lose Steps -Resonance Problems
Servomotor	-High Performance -Small Motor Size -Can Operate At High Speeds	-Higher Cost System -Performance Limited by Controls -Speed Limited by Electronics

3. APPLICATIONS
As more and more robots are designed for specific tasks this method of classification becomes more relevant. For example, many robots are designed for assembly work, which may not be readily adaptable for other applications. They are termed as "assembly robots". For seam welding, some suppliers provide complete welding systems with the robot i.e. the welding equipment along with other material handling facilities like turntables, etc. as an integrated unit. Such an integrated robotic system is called a "welding robot" even though its discrete manipulator unit could be adapted to a variety of tasks. Some robots are specifically designed for heavy load manipulation, and are labeled as "heavy-duty robots".

Fig. 2

3.1 Current and potential applications include
Military robots, industrial robots, COBOTS (collaborative robots), construction robots, agricultural robots (AgRobots), medical robots, kitchen automation, robot for sport, clean-up of contaminated areas, such as toxic waste or nuclear facilities, domestic robots, nano robots, swarm robotics, autonomous drones, sports field line marking etc.

4. PROBLEM DEFINITION
The aim is to design an articulated robotic arm assembly for a given work volume using nylon 6 6, analyse it for load carrying conditions and show the load, stress, and deformation results.

5. FORMULATION
First the work volume (dimensions of the links/arms) is assumed. For the calculated arm length, the links are designed and assembled in order to check for the fit and clearances. Allowances and spaces for wiring and other operation equipments is

provided. The two bases are connected through splines and loads are applied to analyse the safety of the system. The analysis is done based on the consideration that the manipulator will be carrying a x kg payload (the value of x is calculated theoretically and then verified for safe operating conditions practically using Ansys). The mesh size is taken as 1mm and Tria (fine mesh) elements were used for meshing. The end from which another component is joined is fixed and analysis is carried out. The fatigue analysis is carried out by using Goodman's curve as the ultimate stress is taken into consideration and factor of safety is obtained.

6. METHODOLOGY

Step 1: Drawing rough fig.
Step 2: Calculating work volume
Step 3: Calculation of mass for given material
Step 4: Finding x in bending failure
Step 5: Finding x in shear stress failure
Step 6: Using these results to analyse max shear, max deformation and Factor of Safety

6.1 Rough Fig

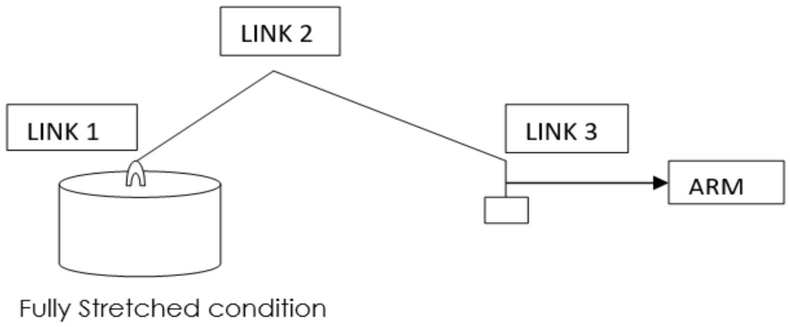

Fig. 3

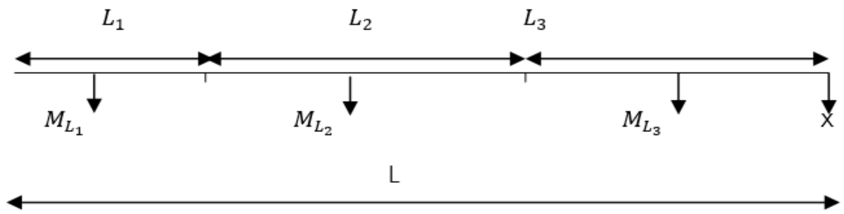

Fig. 4

6.2 Work volume

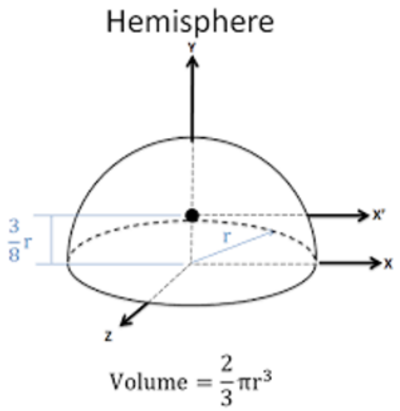

Fig. 5

Here r=L;

Total Work volume=$\frac{2}{3}\pi L^3$

Volume of the arms $=(L_1+L_2)\times bd - \frac{\pi}{4}\left(\frac{b}{2}\right)^2(L_1+L_2)+\frac{L_3 bd}{2}+\frac{\pi}{4}\left(\frac{b}{2}\right)^2 d$

Assumptions $L_1 = L_2 = 1\text{m};\ L_3\ 0.1\text{m};\ \text{b} = \text{d} = 0.1\text{m}$

On calculating we get $V = 0.016769\ m^3$

Considering $\rho = 1140 kg/m^3$

We get M = 23.6 kg

On calculating the masses, we get the total mass of the arms is 23.6kg for nylon 66.

6.3 Bending methodology

From Figure 4. Considering the masses at the centre of the lengths we get,

$$Bending\ Moment{=}M{=}\left[\left(M_{L1}\times\frac{L_1}{2}\right)+\left(M_{L_2}\times\left(L_1+\frac{L_2}{2}\right)\right)+\left(M_{L_3}\times\left(L_1+L_2+\frac{L_3}{2}\right)\right)+(X\times(L_1+L_2+L_3)\right]\times 9.81$$

$$\frac{M}{I}=\frac{E}{R}=\frac{\sigma}{y}$$

Where $E\ is\ Young's\ Modulus;\ allowable\ stress\ in\ bending = 7.5MPa\ ;\ R = \frac{d}{2};\ y = \frac{b}{2}$
Hence, we get a value of x.

Similarly, allowable shear stress is 55 Mpa, hence,

$$\text{Allowable shear stress} = \frac{F}{A} = \frac{(M_{L_1} + M_{L_2} + M_{L_3} + X)9.81}{bd}$$

But for rectangular cross section

$$\tau = \frac{1.5V}{bd};\ V = 9.81\text{M}$$

Shear stress should be within permissible limits and for this we get another value of x. On considering the least value, for X<9.576kg we get the stresses within permissible limits in both cases.

Note: masses are considered for the link only and not for the bases.

6.4 CAD models

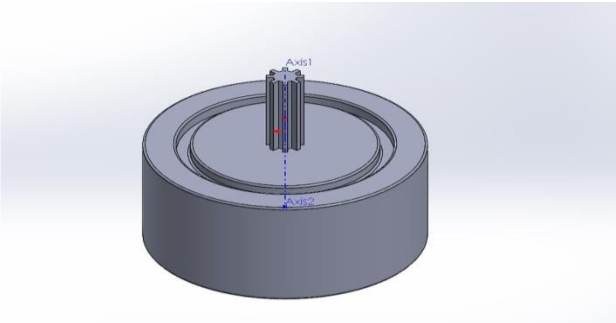

Fig. 6: Base 1

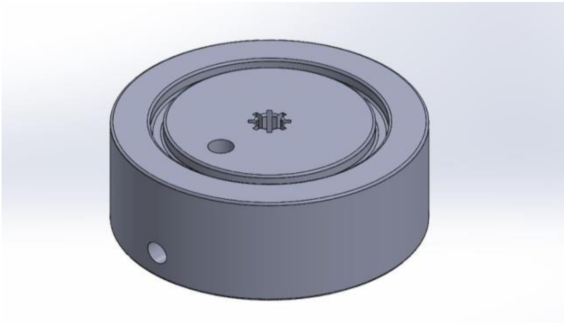

Fig. 7: Base 2

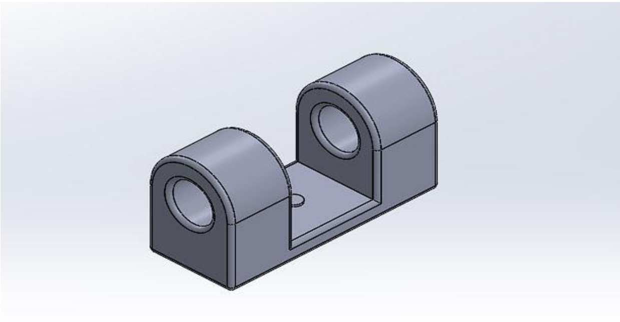

Fig. 8: Connecting link

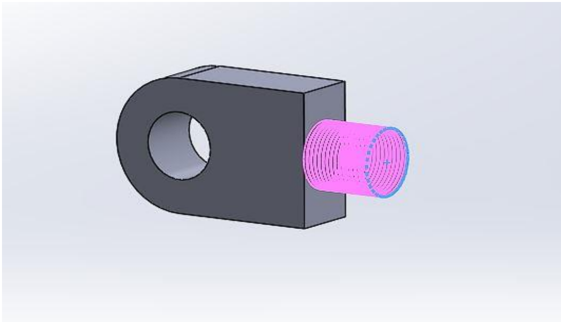

Fig. 9: End effector with threaded end

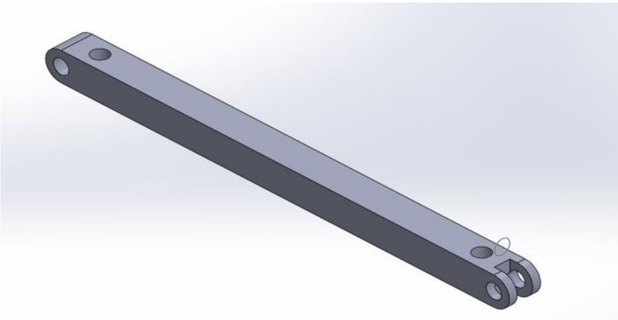

Fig. 10: link1

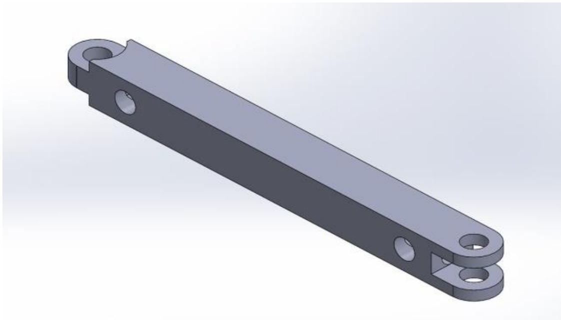

Fig. 11: link 2

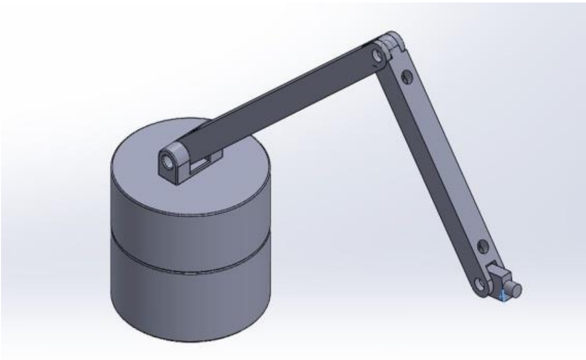

Fig. 12: complete assembly

The end effector is given with a threaded screw in order to make the robot versatile by allowing it to be interchanged based on the job to be performed. This way, the robot would be doing different tasks with the same structure.

7. ANALYSIS

- The material selected was Nylon 6 6 which has high mechanical strength, stiffness and toughness.
- Good fatigue resistance.
- High mechanical damping ability.
- Good sliding properties.
- Excellent wear resistance.

7.1 Why Nylon 6 6

The most common question we faced during our research from friends and faculty was that why not to consider Carbon Fibre as a possible choice. The answer is that carbon fibre, although 5 times stronger than steel, is very brittle and cannot take large impacts causing failure due to lack of provision of deformation.

7.2 Advantages of Nylon 6 6

(a) Nylon is a thermoplastic; hence one particular part can be re-melted and reused for a number of times.
(b) It can be repaired easily by heating the broken/damaged part and reintroducing fresh nylon material and infusing it at the damaged location. Although this may not be an ideal solution, but this is better than a complete replacement of the whole component.
(c) Lattice type alignment of the constituent nylon 66 threads gives better strength and shock absorption capacity.
(d) It is very light compared to the same size of metal and its alloys.

7.3 Disadvantages of Nylon 6 6

(a) Not all sizes can be 3D printed.
(b) These arms cannot be used in high temperature applications.
(c) Use of a certain resin is necessary and air bubbles should be removed out for better performance.

The analysis was done in Ansys Workbench. Static structural analysis was carried out for each and every part to determine the total deformation, maximum stress that the component can withstand and factor of safety of the component is found out.

The manipulator will be carrying a 9.576 kg payload and the force on the components is taken as 9.576*g + self-weight of the components. The mesh size is taken as 1mm and Tria elements are used for the meshing. The end from which another component is joined is fixed and analysis is carried out. The fatigue analysis is carried out by using Goodman's curve as the ultimate stress is taken into consideration and factor of safety is obtained.

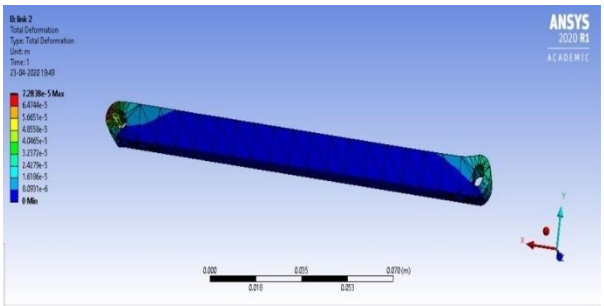

Fig. 13

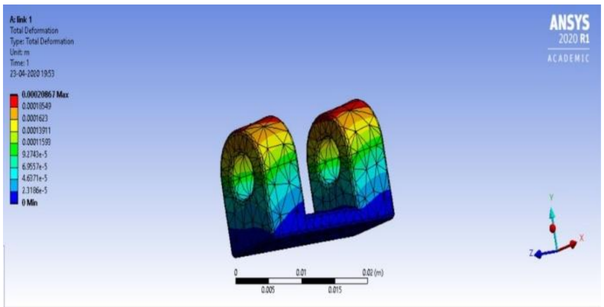

Fig. 14

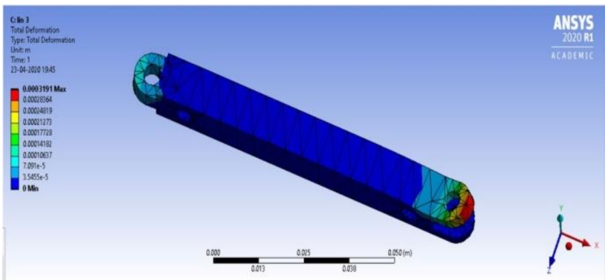

Fig. 15

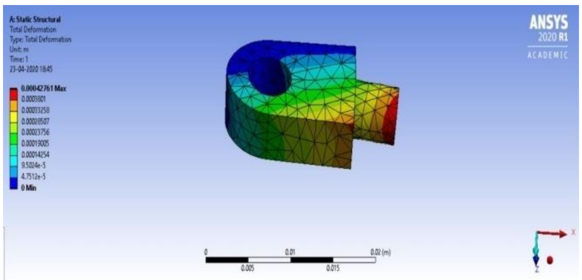

Fig. 16

8. RESULT

After conducting analysis on different parts we concluded that robots indeed be made of composites and the following results are obtained:

8.1 Total Deformation

Link 1 = 0.002 m
Link 2 = 0.007 m

Link 3 = 0.0031m
End effector = 0.04 m
(m = meters)

9. FACTOR OF SAFETY

The factor of safety for all the parts was found and the least turned out to be 1.972 which means that overall design and the material of the manipulator is considerably good and can be brought into practice.

10. CONCLUSION

The manipulator is designed using basic formulae from strength of materials. It is modelled using commercially available 3D CAD tool, SolidWorks, for further study and comparison. The model is used for analysis using a commercially available analysis tool, ANSYS, taking into account the various critical loads acting on various parts of the manipulator which has the talent to accomplish simple tasks, such as it can sense any material and capable of light material handling. The robot arm was designed and built from Nylon. After conducting the analysis it is proved that the manipulator is safe to use. The study has been in the view of developing robots which are lighter, hence more portable, can be used for various tasks and can also be recycled making it cleaner to use.

11. FUTURE SCOPE

We are presently making a 3D printed prototype in our college. With advances in technology and materials, it is highly possible to integrate nylon layers with layers of carbon fiber hence making it more strong and versatile to use. Hence we have started our study on how to integrate two different composites and increasing its refractoriness using other composites in order to be put in use in high temperature conditions also.

12. ACKNOWLEDGEMENT

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