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Design And Optimization Of A Robotic Arm Using Advanced Materials

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ABSTRACT

This Project highlights the importance of digital prototyping over traditional prototyping in manufacturing engineering. In today's fast-paced industrial era, every company strives for speed and efficiency in manufacturing to meet client demands, with the agricultural sector being a notable exception. Robots now perform tasks more quickly, cost-effectively, and accurately than humans ever could. The moving parts of a robotic arm experience significant elastic deformations and stresses, often operating at velocities comparable to the tool itself. This project focuses on the shearing operation, with the primary challenge being the design and optimization of a lightweight robotic arm component that is both durable and reliable. Through extensive study, we have developed and analysed a jointed robotic arm where the base remains fixed, and the remaining joints can move vertically and horizontally. The design and analysis were conducted using three different materials: Epoxy Carbon Woven, Steel Alloys, and AL-NI. A force of 4000N was applied to the robotic arm to evaluate its structural and thermal performance. Ultimately, the study identifies the most suitable material among these three options for use in the robotic arm.

1. INTRODUCTION

Robotic arms are pivotal in modern industries, offering precision, efficiency, and reliability in various tasks. Among these, shearing operations are particularly demanding, requiring robust, high-performance designs capable of handling significant mechanical stresses. This study focuses on the design and optimization of a robotic arm specifically engineered for shearing operations, utilizing advanced material analysis and state-of-the-art optimization techniques.

The primary objective is to create a robotic arm that combines durability, precision, and energy efficiency. Shearing operations often involve repetitive, high-force tasks that impose significant wear and tear on mechanical components. To address these challenges, this work integrates advanced material analysis, including finite element modelling (FEM), to identify materials and structural configurations that maximize strength while minimizing weight. Materials such as high-strength alloys, composites, and lightweight polymers are evaluated for their suitability in withstanding repetitive loads without compromising the arm's mobility or performance.

Optimization plays a central role in this project, targeting both structural and functional aspects of the robotic arm. The geometry of the arm is refined to achieve an optimal balance between strength and flexibility, ensuring smooth operation under varying loads. Joint configurations are carefully designed to enhance the range of motion while maintaining stability during shearing. Actuation mechanisms, such as motors and hydraulic systems, are selected and calibrated to deliver precise, energy-efficient performance.

A key component of the design process involves computational simulations. By employing advanced modelling tools, the arm's behaviour under different operational conditions is analysed, enabling the identification and resolution of potential weaknesses before physical prototyping. Stress distribution, thermal performance, and fatigue life are thoroughly evaluated, ensuring the arm meets stringent industrial standards.

The integration of intelligent control systems further enhances the arm's functionality. Real time monitoring and adaptive control algorithms enable the robotic arm to adjust its operations based on dynamic working conditions. This adaptability ensures consistent performance, even in challenging environments, and minimizes downtime due to maintenance or component failure.

In addition to functionality, cost-effectiveness is a critical consideration. The use of advanced materials and optimization techniques ensures that the robotic arm delivers high performance without excessive production costs. This makes it accessible for a wide range of industries, from small-scale manufacturing to large-scale industrial operations.

1.1 APPLICATIONS

- Assembly line automation in manufacturing industries.
- Welding tasks in automotive and construction sectors.
- Material handling and packaging in factories.
- Pick-and-place operations in electronics manufacturing.
- Precision painting and coating in industrial processes.
- Surgical assistance in healthcare and medical procedures.
- Prosthetics and rehabilitation support for individuals with disabilities.
- Laboratory automation for handling samples and experiments.
- Sorting and palletizing in logistics and warehousing.
- Inspection and quality control in production lines.
- 3D printing and additive manufacturing applications.
- Space exploration for tasks like satellite assembly and maintenance.
- Bomb disposal and hazardous material handling in defence.
- Farming and agricultural tasks such as harvesting and planting.
- Educational and research purposes in robotics and engineering.

2. LITERATURE REVIEW

Design and Implementation of Pick and Place Robotic Arm by **Ravi Kumar Mourya, Amit Shelke et.al** in International Journal of Recent Research in Civil and Mechanical Engineering (IJRRCME) 2015. This project aims to design and implement a 4-DOF pick and place robotic arm, which can be self-operable for tasks such as gripping, lifting, placing, and releasing. The project focuses on a 4-DOF articulated arm with revolute joints for angular movement between adjacent joints. Four servo motors are used to perform four degrees of freedom (4-DOF). Robot manipulators are designed to execute required movements and their controller design is equally important. The AT mega 16 Development board is used for servo motor action. The project successfully completed the design and fabrication of a 4-DOF manipulator, using computeraided designing tools like Creo 1.0 and AutoCAD. Theoretical analysis of inverse kinematics was conducted to determine the end effectors position and orientation, and FE Analysis was performed using Ansys software. The project demonstrates the importance of robotic manipulators in positioning and orienting objects for useful tasks.

Design Analysis of a Remote Controlled “Pick and Place” Robotic Vehicle by **B.O. Omijeh and R.Uhumwamgho** in International Journal of Engineering Research and Development 2014. This paper presents a design analysis of a Remote Controlled "Pick and Place" Robotic vehicle, focusing on safety precautions in the workplace and environment. The vehicle has a five-degree robotic arm with a base on top and four drive wheels that are selectively powered to propel it. The design methodology includes hardware, software, and implementation. A prototype was built to validate the design specifications, and the results were satisfactory. Robots are highly recommended for industries for safety and productivity reasons. The design of the robot makes it easier for humans to handle hazardous objects in their environment and workplace, achieving complex and complicated duties faster and more accurately.

Pick and Place Robotic Arm: A Review Paper by **Sharath Surati, Shaunak Hedaoo et.al** in International Research Journal of Engineering and Technology (IRJET) 2021. This paper presents a design analysis of a Remote Controlled "Pick and Place" Robotic vehicle, focusing on safety precautions in the workplace and environment. The vehicle has a five-degree robotic arm with a base on top and four drive wheels that are selectively powered to propel it. The design methodology includes hardware, software, and implementation. A prototype was built to validate the design specifications, and the results were satisfactory. Robots are highly recommended for industries for safety and productivity reasons. The design of the robot makes it easier for humans to handle hazardous objects in their environment and workplace, achieving complex and complicated duties faster and more accurately.

Pick and Place Robotic Arm Implementation Using Arduino by **Ashly Baby1, Chinnu Augustine et.al** in IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) 2017. A robotic arm is designed using Arduino to safely pick and place objects via user commands. The arm features a soft catching gripper that doesn't apply extra pressure to the objects. The robot is controlled using Android-based smart phones via Bluetooth, and the robot moves accordingly based on user commands. At the receiver end, four motors are interfaced with the micro controller, two for vehicle movement and the remaining two for arm and gripper movement. The Blue control app is used for controlling the robot.

Position Control Method for Pick and Place Robot Arm for Object Sorting System by **Khin Moe Myint, Zaw Min Min Htun** in International Journal of Scientific & Technology Research Volume 2016. This paper about the increasing number of industries in developing countries necessitates more labourers, leading to the need for advanced robot arms to reduce labour costs and increase manufacturing capacity. This journal aims to eliminate manual control for object sorting systems using two joints, three links, and servo motors. A microcontroller generates the required PWM signal for servo motors. The position control of the robot arm is designed using kinematic control methods, which can explain the geometry motion of the manipulator without considering forces or moments causing movements. Metal detectors are used for sorting systems.

3. METHODOLOGY

3.1 Design Specifications

DIMENSION	MEASUREMENT
Arm length	500-2000mm
Base diameter	300-600mm
Pay load capacity	1-500kg
Number of joints	7-Apr
Joint range	0-360
repeatability	0.02-0.1 mm
Maximum speed	1-10 m/s
End effector size	50-300 mm
Total weight	10-1000kg
Power consumption	100-5000 W

Table 3.1: Design specifications of robot

3.2 Modeling Procedure of Robot Components

Firstly open CATIA and click on start and choose mechanical design and open part design then we see this interface. Then open sketch part and develops circle with suitable diameter for the base of the arm and use pad command for padding the base and for the edges we padding and rectangular pattern and pocket for the edges of the step of base.

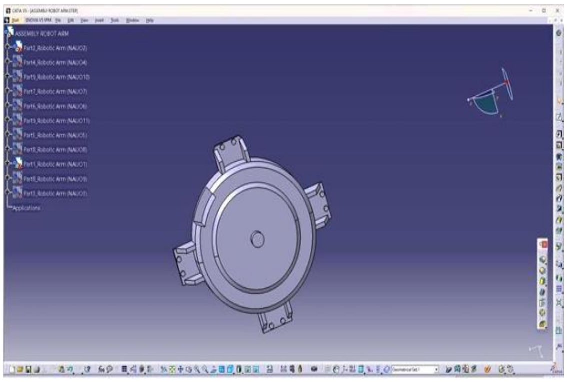

Fig 3.1 Base of the arm in CATIA

Again open part design and draw a circle and pad it by pad command and develops rectangle and uses pad and groove and fillet for obtain the wrist and shoulder as joint 1 of the arm.

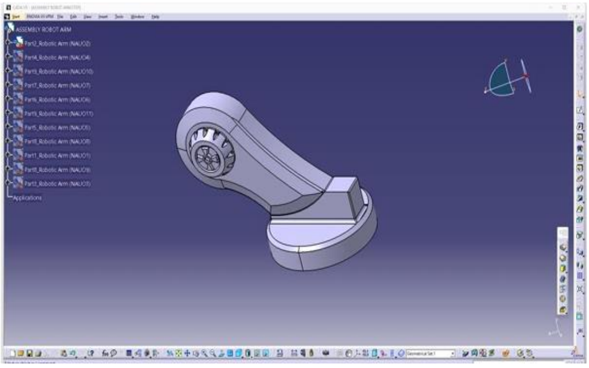

Fig 3.2: The design of Joint 1 (Waist and Shoulder) in CATIA

Then open part design again and develop the Oldham coupling by using commands as pad, pocket, groove, fillet, on developing the sketch part.

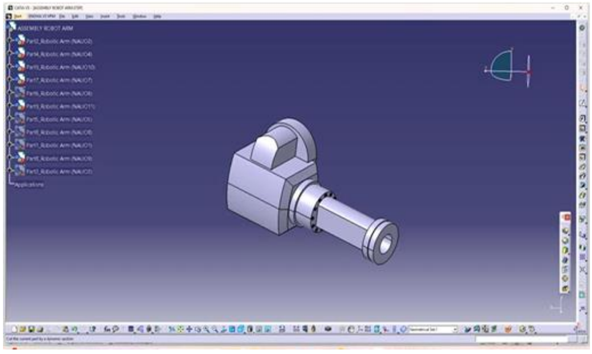

Fig 3.3: The upper part of Oldham Coupling in CATIA

Then we create wrist of the arm of robot by using pad and pocket for the sketch part that we have drawn for wrist of arm.

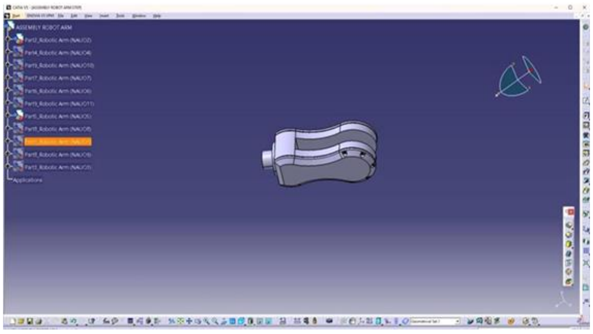

Fig 3.4: Wrist modelled in CATIA

Then we design shaft and key of Oldham coupling on padding and pocketing the material that we drawn on sketch part. By using sketch part we draw the outline and use pad command and develops the material and by using pocket command we remove the material that which is padded then we get the joint 2 of arm.

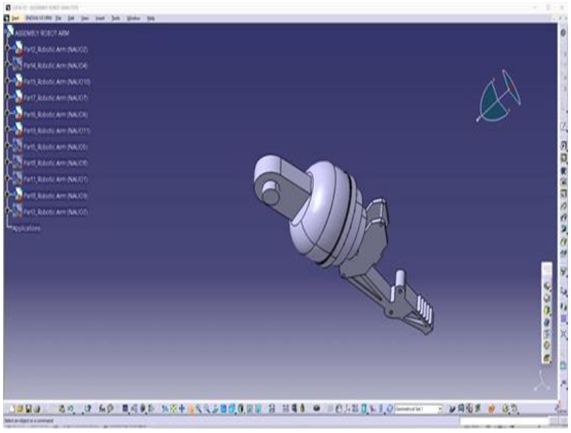

Fig 3.5: The shaft and Key of Oldham Coupling in CATIA

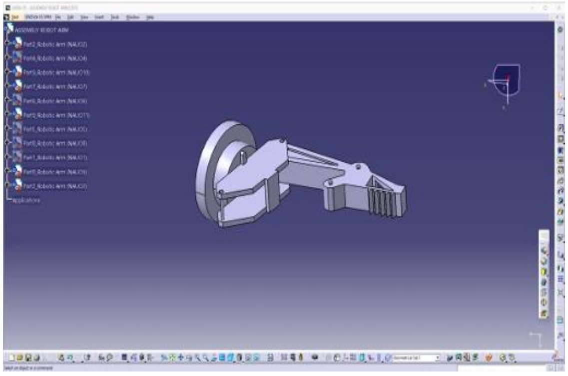

Fig 3.6: Modeling of Joint 2 in CATIA

After completing all the parts of arm individually we have assemble the parts as we go in start and mechanical design and assemble design then we choose base first and joint 1and then by selecting all the parts we assemble the parts by using snap and manipulator commands.

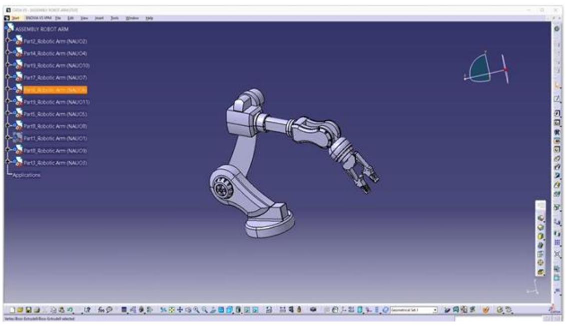

Fig 3.7: Final assembly of Robotic Armin CATIA

4. STRUCTURAL ANALYSIS OF ROBOTIC ARM IN ANSYS

The robotic arm created in CATIA software was exported in .igs format and was imported into ANSYS to make analysis.

Select Geometry from the menu - Right click - Select Import Geometry - Browse -Select
igs file – open.

After importing the geometry, material properties are applied to the model through the following steps.

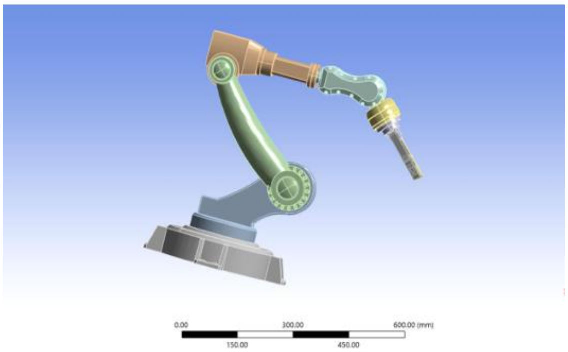

Fig 4.1: Imported model of robotic arm in ANSYS

4.1 Material properties

Material	Density (Kg/m3)	Young's Modulus (Pa)	Poisson's Ration
Steel Alloy	7850	2.e+011	0.3
Aluminium – Nickel	2770	7.1e+010	0.33
Epoxy Carbon Woven	1490	1.21e+011	0.27

Table 4.1: Material Properties

After Appling the martial properties, meshing was performed on the object using mesh option. Here tetrahedral mesh was performed.

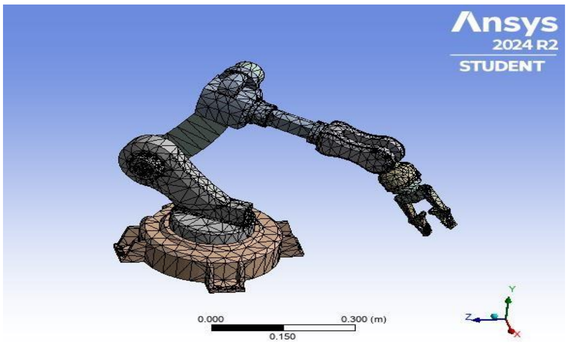

Fig 4.2: Meshed model of robotic arm

5. RESULTS

The structural analysis was performed on the robotic arm in ANSYS software with the specified boundary conditions. Initially static structural analysis was performed with three materials namely Epoxy Carbon Woven, Steel Alloy and Aluminum-Nickel. Modal analysis was also performed on the robotic arm with these materials to know vibration characteristics. The results of the analysis were listed below.

5.1 Static Analysis Results of Robotic Arm with Epoxy Carbon Woven

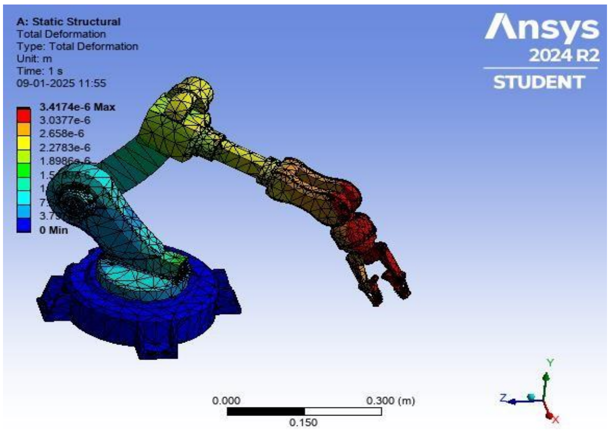

Fig 5.1: Total deformation obtained on the robotic arm with Epoxy Carbon Woven

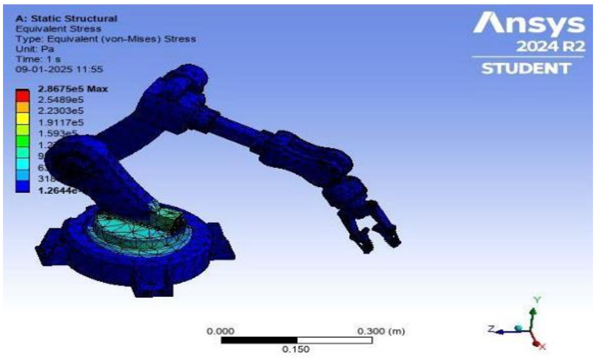

Fig 5.2: Equivalent (von mises) Stress on the robotic arm with Epoxy Carbon Woven

5.2 Static Analysis Results of Robotic Arm with Steel Alloy

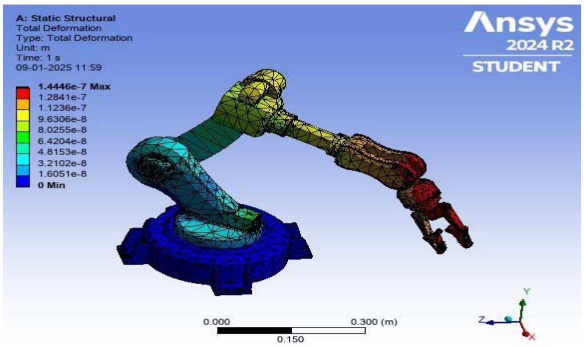

Fig 5.3: Total deformation obtained on the robotic arm with steel alloy

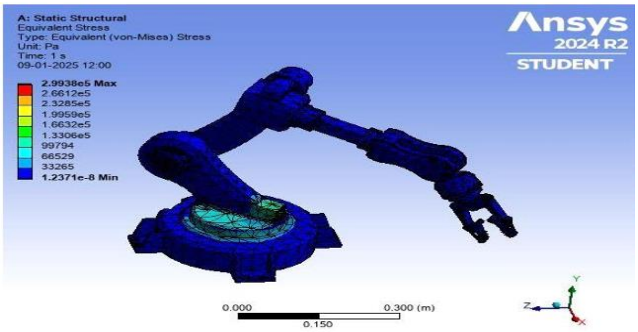

Fig 5.4: Equivalent (von mises) Stress on the robotic arm with steel alloy

5.3 Static Analysis Results of Robotic Arm with Aluminium Nickel

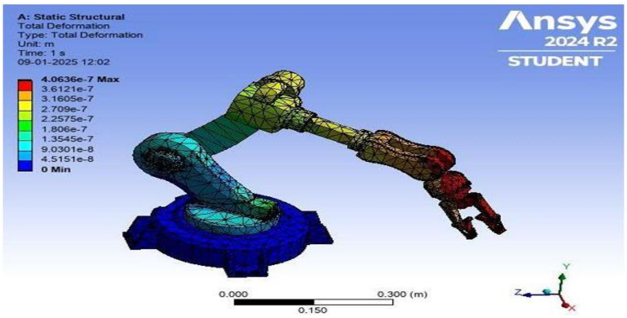

Fig 5.5: Total deformation obtained on robotic Arm with Aluminum – Nickel

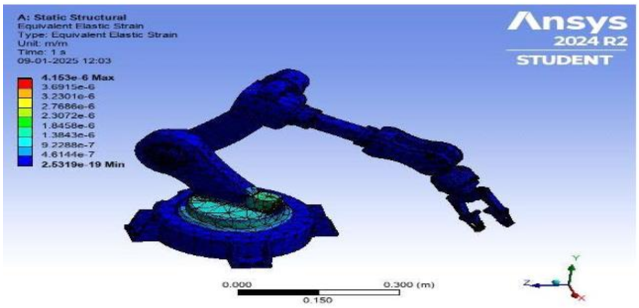

Fig 5.6: Equivalent (von mises) Stress obtained on robotic Arm with Aluminum - Nickel

5.4 Comparative Results

Material	Total Deformation	Equivalent(von-Mises) Stress
Epoxy Carbon Woven	3.4174e-006 m	2.8675e+005 Pa
Steel Alloy	1.4446e-007 m	2.9938e+005 Pa
AL-NI	4.0636e-007 m	2.9403e+005 Pa

Table 5.1: Comparative Results of Static structural Analysis

5.5 Modal Analysis Results with Epoxy Carbon Woven

Mode No	Total Deformation (mm)	Frequency (Hz)
1	0.92609	15.683
2	1.0741	29.188
3	1.2837	40.176
4	1.1958	86.666
5	1.5997	132.54
6	1.8162	225.21

Table 5.2: Modal analysis results with Epoxy Carbon Woven

5.6 Modal Analysis Results with Steel Alloy

Mode No	Total Deformation (mm)	Frequency (Hz)
1	0.42205	30.478
2	0.4713	58.709
3	0.54439	81.964
4	0.52861	168.66
5	0.71616	264.09
6	0.89086	426.07

Table 5.3: Modal analysis results with Steel Alloy

5.7 Model Analysis with Al-Ni

Mode No	Total Deformation(mm)	Frequency (Hz)
1	0.71358	30.464
2	0.79203	58.91
3	0.91462	82.18
4	0.89092	169.38
5	1.212	265.58
6	1.5354	426.5

Table 5.4: Model analysis results with AL- NI

6. CONCLUSIONS

Today's generation requires a versatile and low-cost robotic hand that mimics the human hand. An articulated robotic arm was built using CATIA V5 R20, a 3D CAD application, and then exported to ANSYS for structural analysis. This robotic arm could be utilized in a variety of sectors for operations like picking and placing, assembling, and so on. The structural analysis was shown to be correct. In the present work static and modal analysis was carried out on the robotic arm with three materials. In static analysis deformations and equivalent stress were calculated. From the results it was observed that, generated equivalent stress in robotic arm with Epoxy Carbon Woven is 2.8675e5 Pa, which is low when compared with other two materials. The obtained total deformation value is 3.4174e-6 m which is also in the considerable range. Vibration characteristics were determined through modal analysis in the robotic arm for three materials. From the results it was observed that robotic arm with Epoxy Carbon Woven is having better vibration characteristics compared to other two materials. Finally it was concluded that, the robotic arm with Epoxy Carbon Woven material is suitable for industrial application when compared with other two materials.

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