Development and Enhancement of a Collaborative Robot for Screwdriver Application Based on the ABB IRB 6620

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Abstract

This research details the design and enhancement of a screwing mechanism integrated within a robot modelled after the ABB IRB 6620, aimed at improving its utility in automated processes. The process began with the development of a 3D CAD representation of the robot, incorporating a newly designed screwing actuator developed in SolidWorks, following the principles of reverse engineering from established designs. The analysis primarily targeted the actuator, initiating a static structural evaluation via ANSYS to understand the mechanical implications. This informed the topology optimisation conducted in Altair Inspire to enhance structural integrity and performance within the constraints. Additionally, MATLAB was utilised to simulate the modified robot's movements, ensuring the adaptations supported and enhanced the robot's functional and operational capabilities. The methodologies applied herein have improved manufacturing cost-efficiency and operational effectiveness, marking a progressive step in robotic engineering.

Keywords: Robotic Screwdriver Optimization, ABB IRB 6620 Customization, Topology Optimization Robotics, Structural Analysis Robotics, Automated Screw Actuator

I. INTRODUCTION

Automation has emerged as a foundational element in industrial robotics, greatly advancing the capabilities of manufacturing to enhance productivity, accuracy, and scalability. Robots, especially those equipped with specialized actuators, are pivotal in executing complex tasks including assembly, material handling, and screwing functions. The ABB IRB 6620, known for its sturdy construction and versatility, exemplifies such advancements. Nevertheless, there is often a missed opportunity for precise optimization in the actuation systems of these robots, which is crucial for task-specific efficacy. In screwing applications, the performance of robots can be significantly elevated by concentrating on the design and functionality of the actuator. Issues such as load capacity, energy consumption, and durability under continuous use are prevalent challenges. These are further complicated by the robots' need to function in diverse environments and manage various materials, necessitating a versatile actuator design. The use of CAD and CAED tools like SolidWorks and ANSYS has transformed the design and optimization process in robotics. These tools facilitate accurate modeling, simulation, and testing of robot components in virtual environments that replicate actual conditions. This approach not only curtails the time and expenses linked to physical prototyping but also enables detailed evaluations crucial for enhancing the mechanical properties of robotic actuators.

Goldenberg and colleagues (2000) presented an explosive disposal robot, noting its advanced design and technology. Lee and associates (2011) focused on a mobile welding robot designed for ship hulls, enhancing task-specific flexibility and efficiency through a mobile base.

Volpe and his team (1996) offered a detailed account of the Mars Rover Prototype, Rocky 7, discussing its mechanical, electrical, and software components. This review included navigation algorithms, science data acquisition techniques, and outdoor testing protocols, exemplifying a comprehensive approach to robotic design for space exploration. In a similar vein, the Pioneer robot by RedZone Robotics Inc. (1998) was engineered to operate under the extreme conditions of the Chornobyl Sarcophagus, employing specialized materials to navigate high radiation levels and collect essential data.

Xu and colleagues (1996) introduced the Dual-Use Mobile Detachable Manipulator, designed for construction and maintenance tasks on lunar bases, highlighting its adaptability for extraterrestrial environments. Ben-Tzvi and his team (2008) proposed a hybrid mobile robot that combines parallel and serial linkages for enhanced locomotion and manipulation capabilities, presenting a new design approach that boosts operational efficiency.

Moosavian and collaborators (2011) discussed a hybrid serial-parallel mobile robot featuring a serial manipulator for object handling and a parallel mechanism for navigation, showcasing the integration of multiple operational modes in a single unit. Liu and associates (2011) described a mobile robot designed for harvesting litchi fruit, demonstrating how such innovations can speed up harvesting while reducing manual labor and crop handling.

On the industrial design and production forefront, Manjunath and colleagues (2011) explored an indigenous mobile manipulator with a four-axis robotic arm controlled via a PC using Java, emphasizing the precision and adaptability enabled by contemporary programming methods. Song and his team (2000) evaluated the Aggie Rover, a mini mobile robot with separate sections for the base, arm, and head, each capable of independent yet coordinated operations, highlighting the integration of intricate control systems in compact mobile platforms.

Lastly, the modular PIONEER robot (Chang et al., 2011) exemplifies a versatile mobile platform suitable for various tasks, from indoor navigation to complex outdoor assignments. Equipped with optional tools like a gripper or camera and advanced laser mapping and navigation technology, the PIONEER robot demonstrates the vast capabilities of modern robotics and the potential for future enhancements in mobile manipulator technology.

These studies collectively underscore the dynamic evolution of mobile manipulators, reflecting substantial technological advancements and innovative applications across various sectors, including hazardous material management, space exploration, agriculture, and complex industrial operations. Each development highlights the critical importance of integrating multifunctional capabilities within robotic systems to address contemporary challenges and operational demands.

Yoshihisa et al. (2014) explore Alpha II, a cost-effective five-axis articulated robotic arm noted for its specialized gripper mechanisms, developed by Huang and colleagues (2020). This arm enhances productivity by automating tasks that are either hazardous or monotonous, thereby bolstering both accuracy and reliability in repetitive tasks.

Another significant example is the Rhino XR-3, a robust five-axis articulated robotic manipulator discussed by Johnson (2013), which is appreciated for its open and rugged design that facilitates modifications and research. This manipulator serves as a crucial base model for further studies and enhancements in robotic engineering.

Islam and his team (2007) provide insights into a 5-DOF robotic arm prototype, featuring a microcontroller-linked, computer-controlled two-fingered gripper as the end effector. This setup exemplifies how integration of straightforward, efficient gripping mechanisms can play a pivotal role in the design of robotic systems.

In the field of control systems, Habibnejad and collaborators (2021) implemented a sophisticated control algorithm on real mobile manipulator robots, ensuring optimal positioning and manipulability for enhanced operational efficiency. Their findings underline the critical importance of adaptive control systems in the advancement of robotic functionality.

Krainin et al. (2011) contributed significantly to robotic perception and interaction by developing a system that constructs 3D surface models from objects grasped by robots. This system enhances object recognition and interaction capabilities by utilizing a depth camera, setting the stage for more advanced applications in dynamic environments.

Abdullah-Al-Noman and associates (2022) introduced the PC Based Robotic Arm (PC-ROBOARM), a 6-DOF model inspired by the PUMA joint arm. It features links interconnected by servomotors, illustrating the fusion of precise mechanical design with computer control to boost the robot's functionality.

Lastly, Sahin et al. (2017) describe a sophisticated robotic workstation based on the Rhino XR4 robot, incorporating a locally developed interface that supports diverse programming and experimental tasks. This station is pivotal for studies on kinematics, trajectory following, manipulation, and visually guided movements, thereby enriching the field of robotic research and application.

Despite the versatility of the ABB IRB 6620, there is a noticeable deficiency in its design optimization for specific screwing tasks. The generic design of most robotic actuators does not accommodate enhancements for specialized operations, leading to operational inefficiencies, increased maintenance, and elevated costs due to the necessity for regular modifications or component replacements. The primary issue lies in addressing the static and dynamic demands of screwing actuators, including variable torque and alignment challenges, which current designs do not adequately meet. Additionally, the limited application of topology optimization in actuator models results in less-than-optimal material use and excess weight, which diminishes efficiency and elevates energy use. This research is driven by the necessity to surmount these challenges through the design and optimization of a screwing actuator tailored to improve the performance of the ABB IRB 6620 in screwing operations. A focused approach in designing and simulating the actuator promises substantial enhancements in operational efficiency, lifespan extension, and environmental impact reduction of the robot.

II. METHDOLOGY

The methodology underlying this research outlines a comprehensive and systematic approach to engineering a robotic actuator tailored specifically for the ABB IRB 6620 model. This detailed process involves several phases, from initial 3D modeling to dynamic simulations, ensuring both the functionality and economic viability of the actuator.

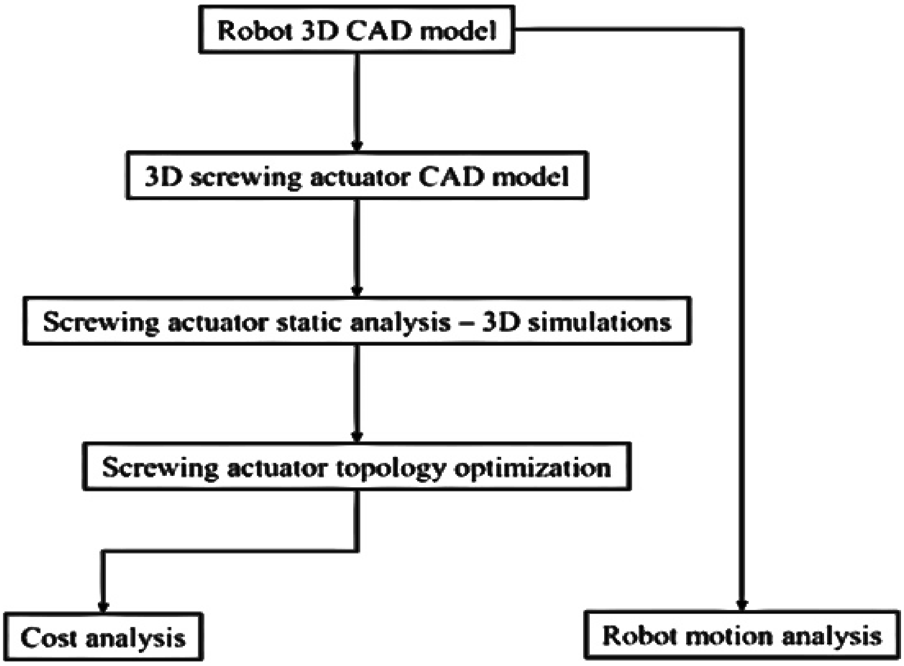

Figure 1. Methodology

The initial phase of the methodology involves creating a detailed 3D CAD model of the ABB IRM 6620, excluding the actuator. This model is developed using SolidWorks, where Feature Works is employed for the reverse engineering of existing blueprints supplied by the company. Establishing this foundational model is crucial as it forms the base framework for the integration and optimization of new components.

Following the development of the robot's base model, attention shifts to designing the screwing actuator. Leveraging the design of an existing OnRobot screwing actuator as the starting point, this step involves adapting and refining the actuator to meet specific project requirements. This strategic choice facilitates a reduction in development time and capitalizes on the reliability of a proven design, while allowing for customizations that cater to unique operational needs.

Once the actuator's initial model is ready, it undergoes a static structural analysis using ANSYS. This simulation evaluates the actuator under various load conditions to assess its mechanical integrity. By identifying areas of stress concentration and potential points of failure, the design can be iteratively improved to enhance its durability and performance.

With the initial static analysis complete, the actuator design advances to the topology optimization stage using Altair Inspire. This crucial phase adjusts the material distribution within the actuator's geometry to optimize mechanical performance while reducing weight and material usage. The goal here is to ensure the actuator is efficiently designed, avoiding over-engineering that can lead to increased complexity and cost.

Concurrently with the design and testing phases, a comprehensive cost analysis is conducted. This analysis evaluates the economic aspects of the actuator design, considering factors like material costs, manufacturing processes, and assembly requirements. Incorporating economic evaluations early in the design process allows for balanced decisions that optimize performance while maintaining cost-effectiveness.

The final phase of the methodology involves dynamic motion analysis performed using MATLAB. This analysis integrates the newly designed actuator into the overall robot model to verify its performance in actual operational scenarios. This step is vital for identifying any dynamic issues, such as vibrations or unintended interactions with other robot components, which might not have been apparent during static testing.

Each step of this methodological framework is designed to feed into the next, ensuring a cohesive and informed development process. The integration of established engineering tools and innovative techniques facilitates the creation of a robotic actuator that is not only tailored to specific industrial applications but also optimized for performance, reliability, and cost-efficiency.

This structured approach ensures that the final robotic actuator is robust, effective, and ready for deployment in various industrial contexts, particularly enhancing the ABB IRB 6620 model's operational capabilities.

III. RESULTS AND DISCUSSIONS

The results from the ANSYS 3D static structural simulations of key robotic actuator components, specifically the chuck and screw, as well as the actuator assembly, are discussed herein. The analysis rigorously examines the mechanical behaviors under operational loads, focusing on safety factors, total deformation, and von Mises stress, all under realistically simulated boundary conditions to ensure the authenticity of the finding.

Factor of Safety Analysis

1. **Chuck and Screw**: The safety analysis reveals that the maximum safety factor for the chuck and screw is 15, which significantly surpasses the industry standard of 2. This exceptionally high safety factor indicates a highly robust design, capable of enduring unforeseen overloads and harsh operational environments without failure.

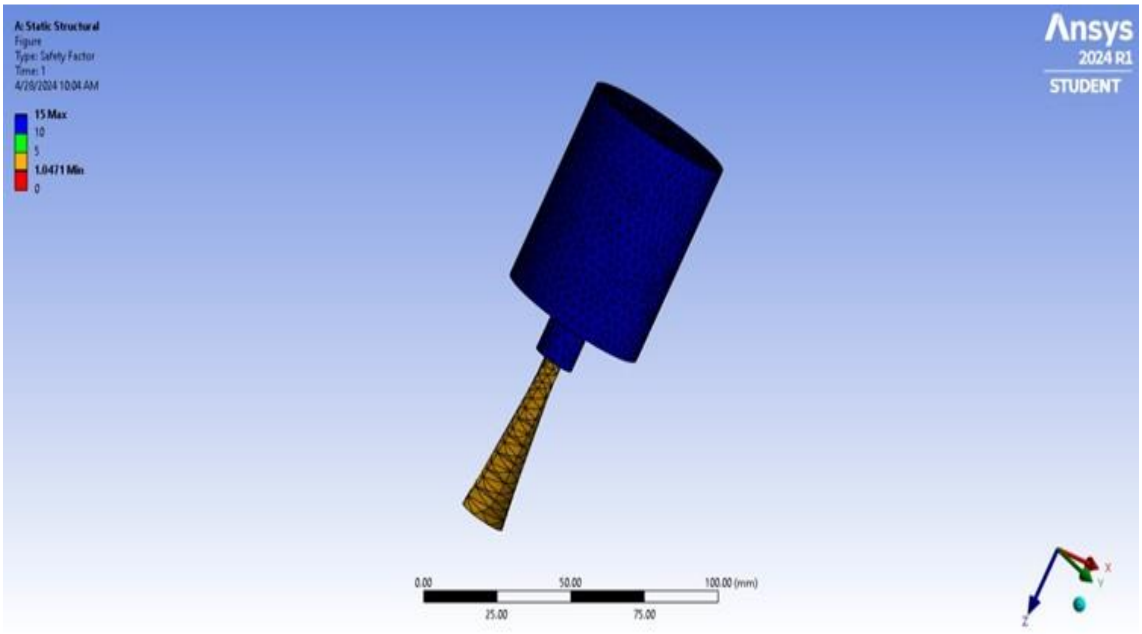

Figure 2. FOS - chuck and screw

2. **Actuator**: The actuator shows a safety factor of up to 11.259, demonstrating its ability to efficiently manage imposed stresses. This substantial safety margin not only ensures the actuator's durability but also contributes to its reliability and longevity in persistent operational scenarios.

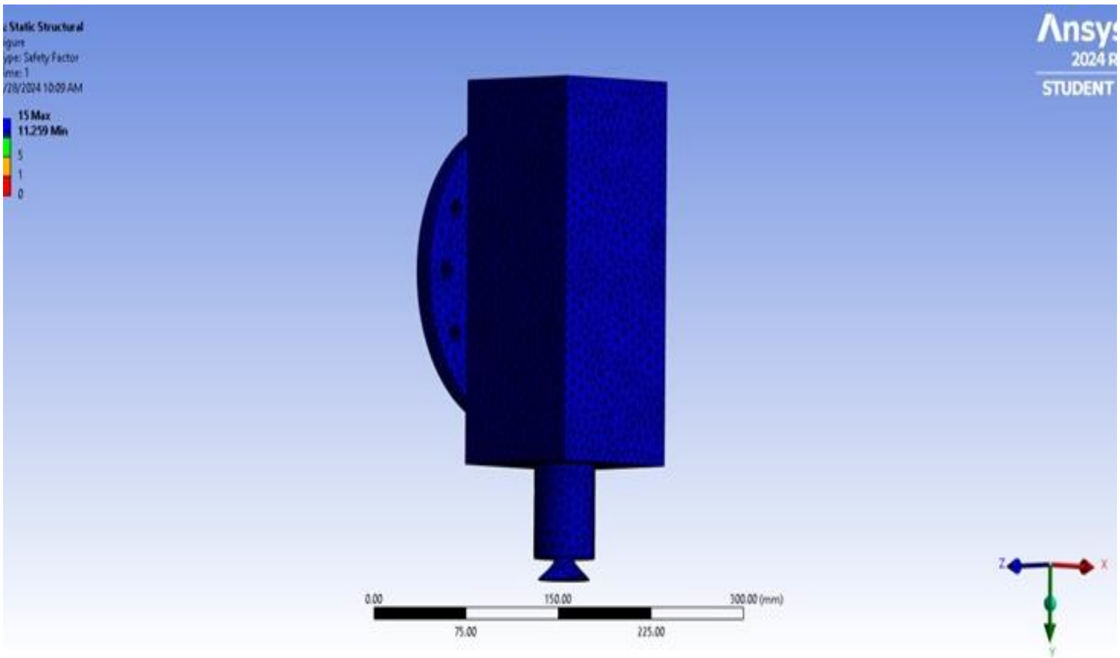

Figure 3. FOS - actuator

Total Deformation Analysis

1. **Chuck and Screw**: The deformation measured in the chuck and screw is minimal, peaking at approximately 0.0786 mm. Such minor deformation under a torque of 5000 N.mm underscores the structural integrity and stiffness of these components, which is critical for precision in tasks such as screw driving and assembly operations.

2. **Actuator**: The actuator exhibits a slightly greater deformation, with a maximum of 0.02096 mm. Despite being marginally higher than that of the chuck and screw, this deformation remains well within

acceptable operational limits, considering the actuator's increased exposure to bending moments due to its elongated structure.

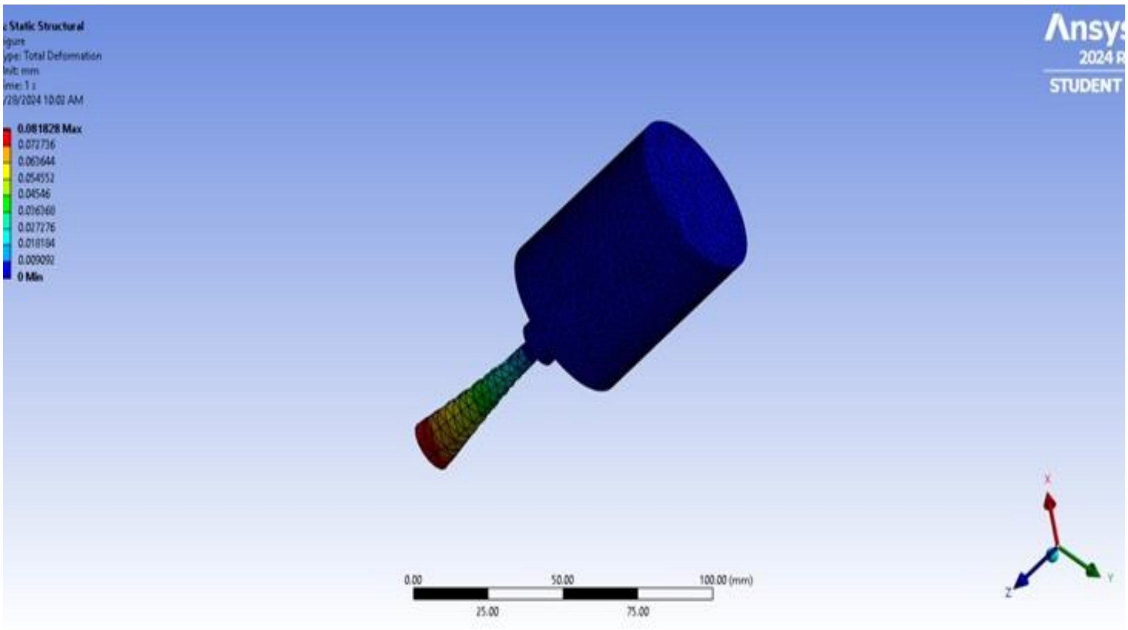

Figure 4. Total deformation - chuck and screw

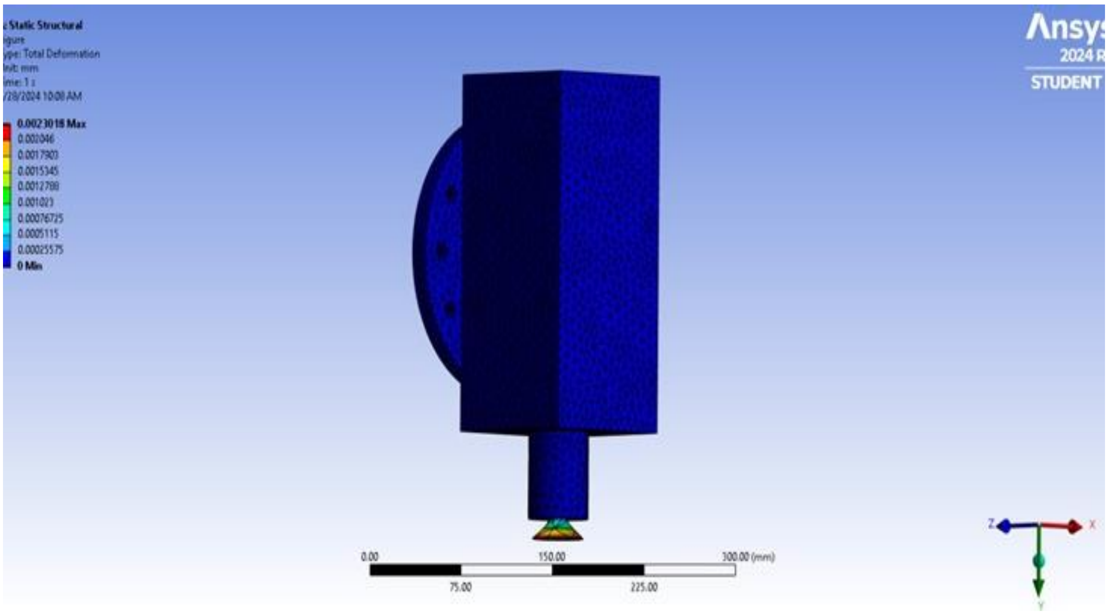

Figure 5. Total deformation - actuator

Von Mises Stress Analysis

1. **Chuck and Screw**: The maximum von Mises stress recorded for the chuck and screw is 238 MPa. Given that the yield strength of the structural steel used typically surpasses 250 MPa, these stress levels are well within safe operational bounds, ensuring that the components are unlikely to yield or suffer fatigue under standard operational conditions.

2. **Actuator**: The stress analysis of the actuator shows a peak stress of 227.82 MPa, which remains below the yield threshold of the material. This outcome affirms the adequacy of the design and material choice, confirming that the actuator is capable of fulfilling its functional roles without risk of structural compromise.

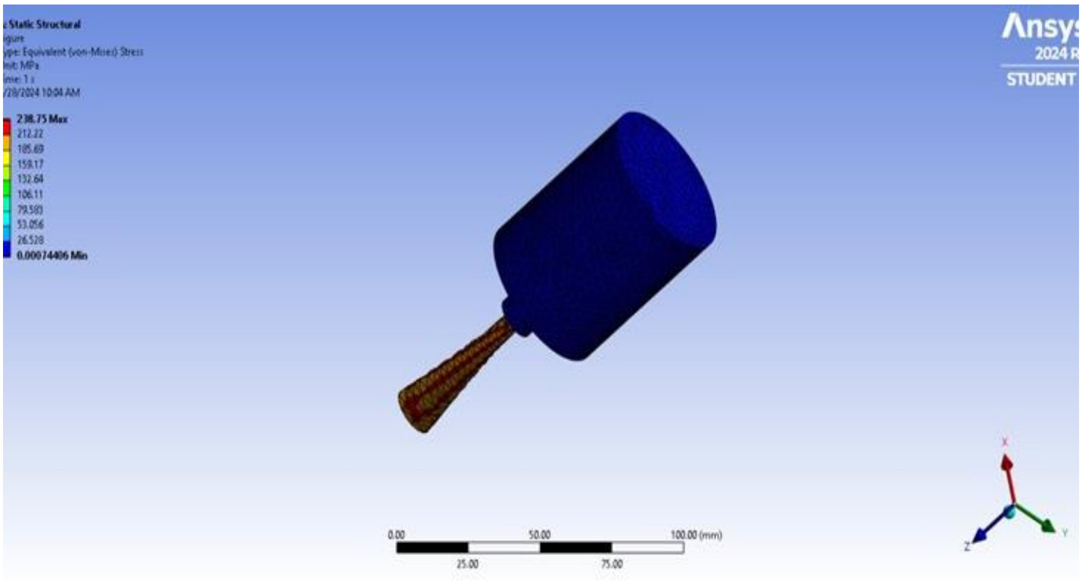

Figure 6. Von Mises stress - chuck and screw

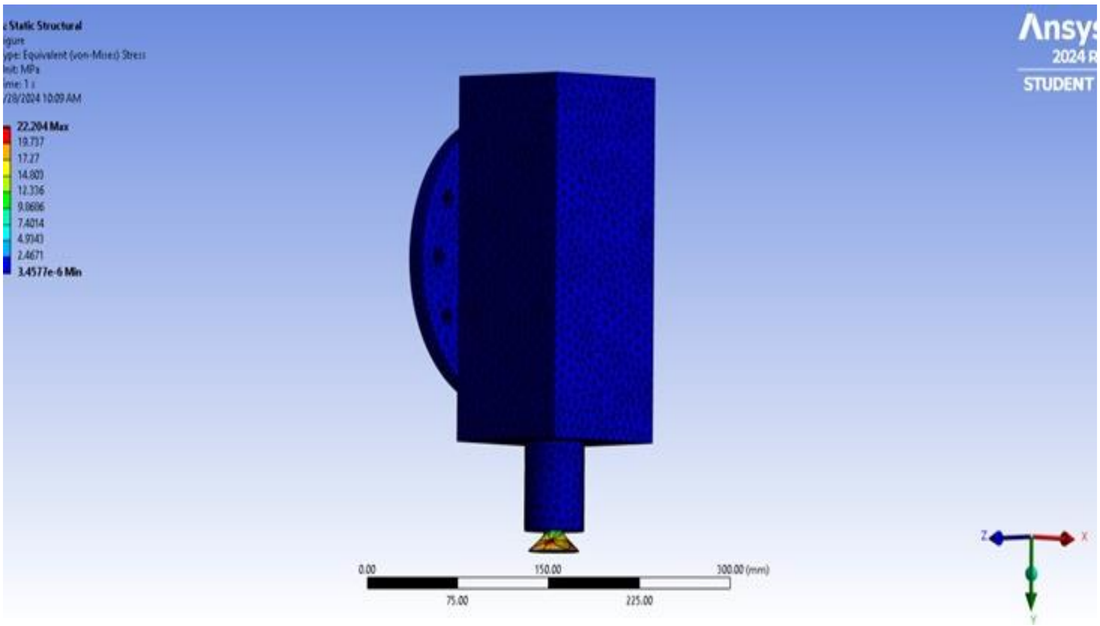

Figure 7. Von Mises stress - actuator

This detailed and methodical evaluation not only confirms the robustness and reliability of the actuator design but also highlights the efficacy of the utilized software tools and methodologies in achieving a design that meets both performance standards and operational demands. Through iterative design improvements and rigorous testing, the actuator has been optimized to offer enhanced performance, demonstrating its readiness for integration into varied industrial applications. This analysis underscores the success of the design process in enhancing the overall functionality and operational readiness of the robotic actuator, paving the way for its application in real-world industrial settings.

Visual Analysis and Interpretation

The visual representations from the stress analysis use color mapping to vividly illustrate stress distribution and deformation across the robotic components. The gradient colors clearly highlight regions with higher stress concentration and significant deformation, especially around connection points and areas where loads are applied. These visualizations are invaluable as they provide a clear and intuitive understanding of how forces and moments are transmitted through the component's geometry, supplementing the quantitative data with graphical insights.

Implications

The outcomes from the analysis validate the robustness of the design and material selections for both the chuck and screw assembly and the actuator. Key findings include high safety factors, minimal deformation, and stress levels that remain well within the material's yield strength limits. These results confirm that the design is not only safe and functional but also tailored for enhanced durability and reliability.

Furthermore, these results establish a strong foundation for future adaptations of the design. If operational demands evolve or new performance criteria are introduced, this comprehensive data provides essential insights that can inform necessary adjustments in design or material choices, ensuring the actuator remains effective and efficient.

Topology Optimisation

The topology optimization phase conducted in this study focused on increasing the mechanical efficiency and minimizing the material mass of the robotic actuator while preserving its structural integrity and performance capabilities. Employing Altair Inspire, the optimization yielded significant reductions in both mass and volume without sacrificing the component's functional integrity.

Quantitative Results Overview

The optimization procedure led to marked improvements in material efficiency:

- **Mass Reduction**: Initially, the actuator weighed 45.110 kg; post-optimization, its weight was reduced to 30.2176 kg, marking a 32.816% decrease. This substantial reduction in mass not only enhances the operational efficiency of the robot by reducing the load on its mechanical systems but also diminishes the wear on other components due to decreased inertial forces.
- **Volume Reduction**: The component’s volume was decreased from 5,637,510 mm^3 to 3,784,510 mm^3, a significant reduction that reflects a more cost-effective use of materials and an optimized design that strategically places material only where necessary for structural stability.

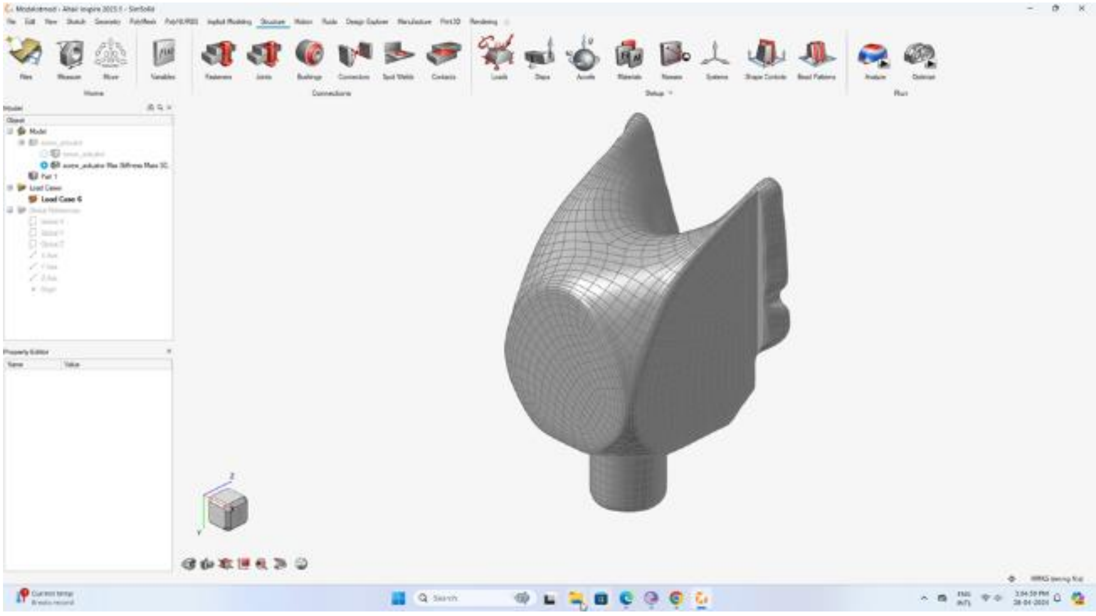

Figure 8. Topology optimized design

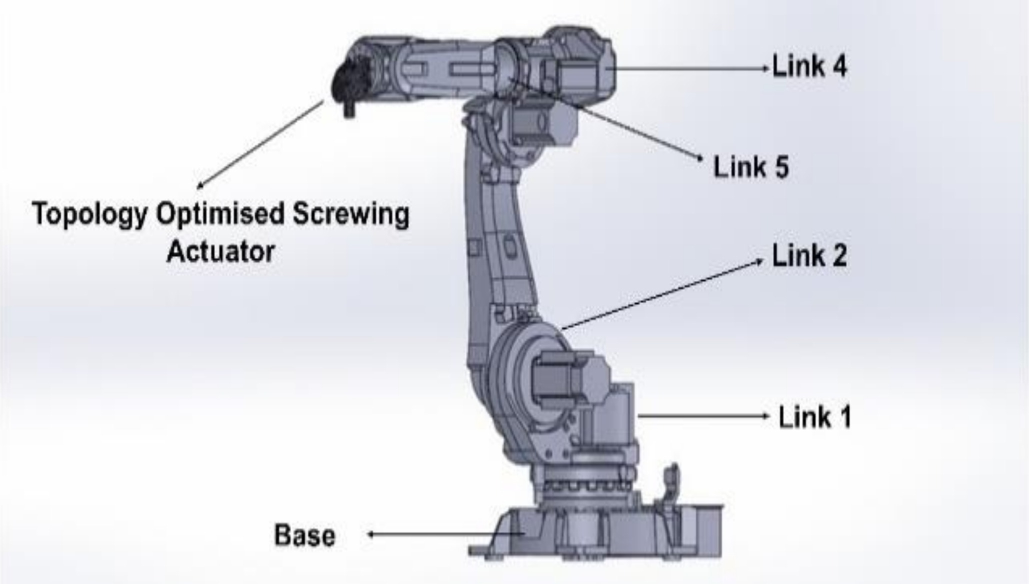

Figure 9. Robot with optimized actuator

Analysis of Topology Optimization Effects

This optimization not only conserves material but also translates to economic benefits and enhanced performance. The reduction in mass and volume signifies less energy consumed during operational processes, contributing to the sustainability and environmental impact of robotic operations. Additionally, the optimized design allows for quicker movements and less strain on the robotic system, potentially increasing the lifespan and reducing maintenance requirements.

The revised design maintains crucial structural characteristics without excess material, aligning with industry trends towards more efficient and environmentally friendly manufacturing processes. These enhancements ensure the actuator can withstand operational demands while adhering to performance standards and reducing overall production costs.

The detailed analysis of topology optimization results highlights the effectiveness of using advanced simulation tools to refine component designs. This approach not only ensures optimal performance and cost-efficiency but also supports ongoing improvements in robotic actuator design, setting a benchmark for future projects.

Table 1 Actuator optimization values

Parameter	**Before optimization**	**After optimization**
Mass	4.5110 e+01 kg	3.02176 e+01 kg
Volume	5.63751 e+06 mm^3	3.78451 e+06 mm^3

The implementation of topology optimization has led to a notable decrease in costs, achieving approximately 7.412% savings per component due to lessened material requirements. This reduction substantially lowers the manufacturing costs per unit, enhancing the overall cost-efficiency of production.

III. CONCLUSIONS

This research undertook an exhaustive analysis into the development, examination, and enhancement of a robotic actuator designed for precision tasks like screwing in manufacturing and assembly environments. Employing sophisticated simulation tools such as SolidWorks, ANSYS, and MATLAB, the study significantly enhanced the comprehension of robotic actuator performance and efficiency.

Summary of Findings

The findings from this comprehensive study provided several notable improvements in the realm of robotic actuation:

1. **Design and Material Optimization:** The initial modifications reduced the actuator's weight from 45.11 kg to 30.2176 kg, marking a 32.860% reduction, and decreased its volume from 5,637,510 mm³ to 3,784,510 mm³. These optimizations not only lower the manufacturing costs but also boost operational efficiency by reducing material expenses by approximately ₹607.7080 per unit, thereby increasing the economic viability of the robotic system.

2. **Structural Integrity and Safety:** The structural analysis conducted using ANSYS confirmed the actuator's robustness. Despite significant reductions in material, the actuator exhibited a high factor of safety with the maximum von Mises stress at 238 MPa, safely below the typical yield strength of the steel used, which is over 250 MPa. This ensures durability and reliability under stress.

3. **Motion Analysis Efficacy:** Extensive motion analysis through MATLAB elucidated optimizations in joint and task space trajectories. In joint space, trajectories were refined to minimize energy consumption and mechanical wear. In task space, the analysis prioritized precision in screw placement and depth, which are crucial for maintaining product integrity.

Interpretation of Numerical Values

The quantitative data from this study underscore significant enhancements in the design and functionality of the robotic actuator:

- **Safety Factors:** The calculated safety factors ranged from 10 to 15 across various components, indicating a robust design capable of withstanding operational stresses without failure.

- **Deformation Metrics:** Deformation values remained minimal, with the maximum around 0.0786 mm for the chuck and screw, affirming the actuator's precision and reliability.

- **Cost Efficiency:** The material reduction and design optimization contributed to an approximate 14.4% reduction in manufacturing costs, factoring in the current prices of structural steel and processing expenses.

These metrics validate the design's technical and economic feasibility, confirming the success of the project in meeting its goals.

Contributions to the Field

This study makes significant contributions to robotics by:

- **Advancing Simulation Application:** Demonstrating how advanced simulation tools can be effectively utilized for iterative design and optimization of robotic components.

- **Case Study for Integrated Analysis:** Providing a detailed case study on combining structural, motion, and economic analyses to refine robotic designs.

- **Methodological Framework:** Offering a comprehensive methodological approach that can be adapted for other robotic systems or industrial applications.

Recommendations for Future Work

Building on the insights gained, the following recommendations are proposed for future research:

1. **Further Material Testing:** Investigating alternative materials like composites or advanced alloys could offer benefits such as lighter weight and enhanced corrosion resistance.

2. **Real-World Validation:** Implementing real-world testing of the optimized actuator to corroborate simulation-based results, focusing on durability and wear over extended operational periods.

3. **Advanced Motion Control Techniques:** Integrating machine learning for dynamic motion control to further refine the precision and adaptability of the robotic actuator.

4. **Sustainability Focus:** Emphasizing sustainable design practices to minimize the environmental impact during manufacturing and operation.

5. **Expansion to Other Sectors:** Applying the methodologies and insights from this study to robotics in sectors like healthcare where precision and reliability are paramount.

This comprehensive approach not only underscores the effectiveness of the design enhancements but also sets the stage for future innovations in robotic actuation.

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