

Design and Analysis of Pick and Place Robot Gripper in the Fertilizer Industry

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ABSTRACT

The large-scale fertilizer industry faces challenges in the material handling process, especially in moving heavy and repetitive fertilizer sacks. The manual process used not only burdens the workforce physically but also risks causing work injuries, time inefficiencies, and inconsistent handling quality. Therefore, an automation-based solution is needed to improve productivity and work safety. This study aims to design and analyze a pick-and-place robot that can be used in the fertilizer industry to enhance the efficiency of the production process, especially in moving fertilizer sacks weighing up to 50 kg. The design method used is the French Method, which consists of the stages of problem analysis, conceptual design, schematic form, and detailing. The design was carried out using Autodesk Inventor for 3D modelling and ANSYS for simulation of loading on the robot gripper. The gripper was designed using a pneumatic system with an 18-fork structure and validated through mesh simulations to ensure its strength and stability. This study also involved design selection based on expert validation and mesh element quality analysis. The study results show that the gripper design has an average skewness value of 0.49, which is included in the "outstanding" category, indicating that the design is feasible for implementation in the fertilizer industry automation system. This pick-and-place robot's implementation is expected to replace manual processes, reduce human workload, and increase industrial effectiveness and productivity.

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1. Introduction

The process of moving objects is a task humans perform every day. Work that must be completed quickly and accurately is often done in the industrial field. Therefore, as industry's needs and automation increase, human resources must balance expertise with technological advances (Woo et al., 2025). Automation is a technology that combines mechanical, electronic, and computerised systems through processes or procedures, usually implemented according to instructional programs, and is combined with automatic feedback to ensure that all instructions are executed correctly (Parra-López et al., 2025). Industry automation systems are critical for increasing productivity, flexibility, and efficiency, and for reducing industrial costs (Balaha et al., 2025).

The development of science and technology is increasingly rapid; almost all industries already use tools that are created and controlled automatically. Automation's ability to produce and transfer energy for the operating process is fundamental. The technology currently under development can improve performance and perform work accurately (Diana et al., 2021). The industry uses many automated tools to support human work, including robots. Robots are tools that help humans in performing tasks that are difficult for humans, and their presence can speed up the work process. The development of robots is currently very rapid, moving in only one direction. However, current technological developments have a great capacity to be given orders to control work, so that many robots can replace human labour. Robots are defined as equipment operated without human assistance, so robots can be said to be artificial devices that can be automated (Kariuki et al., 2024; Wienbruch et al., 2025). So, the fertilizer industry requires high efficiency in the production and distribution process to meet increasing demand. The application of automation technology is the leading solution to increase productivity and reduce operational costs (Jeba Kumar,

2024; Minchala et al., 2020; Spreen et al., 2025).

With robots, humans no longer need to do monotonous work, as robots can replace human labour and optimise small-scale industries. A robot according to RIA (Robot Institute of America), a robot arm or robot manipulator is a multifunctional robot designed to move materials, equipment, or devices. This robot has a Degree of Freedom (DoF) of linear motion on the axis. This robot only has one hand, similar to a human hand used to hold and move objects (Chen et al., 2025). Robot manipulators consist of rigid bodies connected by joints and links. Each joint position is determined by one variable, so the number of joints is equal to the number of degrees of freedom. One type of robot the author will discuss is the pick-and-place robot found in industry, which can move materials from one place to another without changing its position. Pick-and-place robots can automate picking operations by selecting objects and placing them in different areas. Therefore, this procedure helps increase industry production and handles tedious work (Nguyen et al., 2025; Prabhakar et al., 2021). The purpose of this research is to design and analyse a pick-and-place robot gripper for the fertiliser industry using the French method.

2. Materials and Methods

This study uses a quantitative approach to support the design process of picking and placing robots in the fertilizer industry by applying the French method, which is considered more appropriate and easier to use. This method begins with a problem analysis to identify the specific needs of the fertilizer industry related to the material pick and place process. Furthermore, a concept design is carried out to produce several solutions that meet the predetermined criteria. Simulations were carried out to obtain the values of von Mises stress, displacement, and safety factor. The simulation results are analyzed quantitatively to ensure the design meets operational needs. The final stage is the preparation of working drawings based on the designed design so that the resulting model can be implemented optimally. Quantitative data from the analysis is used as a basis for evaluation and validation to support design decisions based on the French Method.

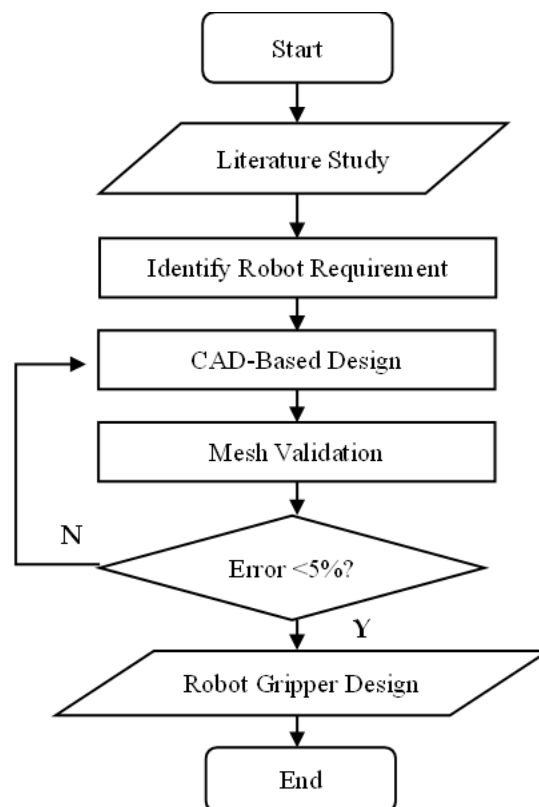


Figure 1: Research Flow Diagram

This activity design was carried out for three months from January to March 2025. The design and analysis of the pick-and-place robot were carried out at the Integrated Computer Laboratory of the Faculty of Engineering, Universitas Negeri Semarang (Figure 1).

3. Results and Discussion

3.1 Result

3.1.1 Design Needs

Identification was carried out by observing the fertilizer industry. The identification results showed that the fertilizer production process must be more efficient. This is especially true for the handling process of 50 kg fertilizer sacks, which still use manual labor. Due to limited lifting capacity and worker speed, this manual process can cause congestion in the production flow and ergonomic problems for workers. One way to increase productivity is to implement an automated system with pick-and-place robots.

3.1.2. Morphology Matrix

Each block diagram is described in a morphology matrix to determine the mechanical components to be used in the concept design.

Table 1: Gripper Mechanism Morphology Matrix.

Function	Mechanics
a. Driver	1. Hydraulic 2. Pneumatic
b. Chuck Type	1. None 2. scratch
c. End of Arm Tool	1. Fork 2. Vacuum 3. Fingers
d. Number of Forks	1. 18 Forks 2. 10 Forks
e. Sensor	1. Vision 2. Pressure

Based on Table 1, the design concepts can be grouped into variants. The following are concept variants based on the morphological matrix. The design concept synthesis process uses a morphology matrix to generate several representative alternative solutions. The resulting combination of design parameters produces three main concept variants: Variant 1 (A1–B2–C1–D1–E1), Variant 2 (A2–B2–C1–D2–E1), and Variant 3 (A2–B1–C2–D3–E2). Each variant represents a different combination of functional and technical characteristics, allowing a comparative evaluation of performance, efficiency, and the design's suitability to system requirements. This morphology matrix approach provides a systematic and objective basis for the initial design decision-making process and supports the selection of the best concept for further analysis and development.

3.1.3. Gripper Concept Design Creation

Based on the variants composed of the morphological matrix, the concept design for each variant is developed into a 3D sketch to make the design shape easier to imagine.

3.1.3.1 First Concept Design

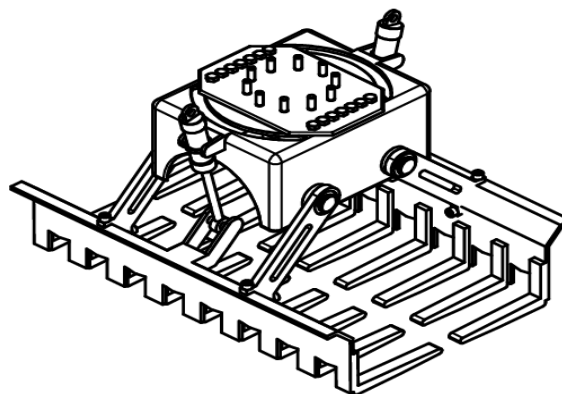


Figure 2: First Concept Design using Hydraulics

This first concept design features 18 right- and left-hand forks that enhance object grip and help prevent objects from falling. Then, this first concept design uses hydraulics as its primary driver, providing greater power and force because the object being gripped weighs 50 kg. Then, this first concept design features a relatively straight, blunt oval fork to prevent the object from being damaged or slipping (Figure 2).

3.1.3.2. Second Concept Design.

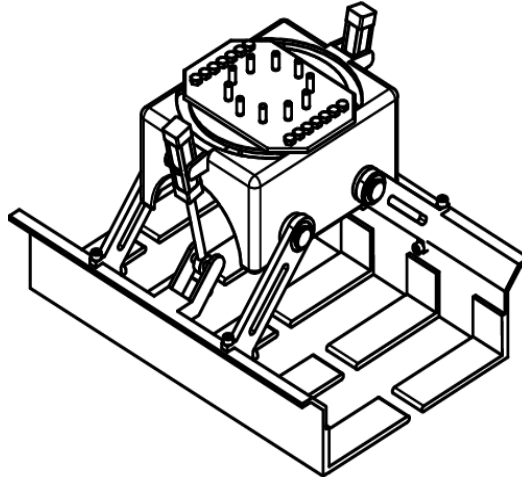


Figure 3: The Second Concept Design uses Pneumatics

This second concept design uses pneumatic drive because it is energy efficient in the industry. Then it has 10 right- and left-hand forks, each 100 mm wide. Then, for the fork tip, it has an oval shape or a fillet that allows the object to be gripped safely. And the load of this second concept design is heavier than that of the first because the fork is quite broad (Figure 3).

3.1.3.3. Third Concept Design

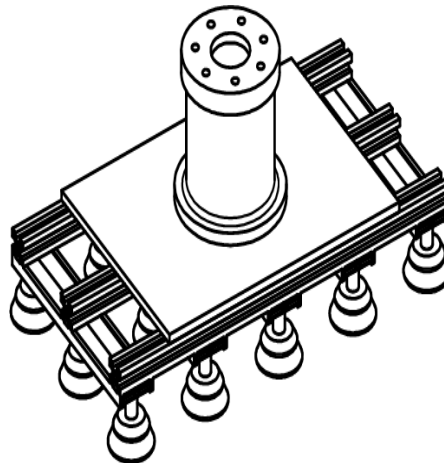


Figure 4: The Third Concept Design using a Vacuum

This third concept design uses a vacuum to lift the fertiliser sacks. Vacuum energy is obtained from pneumatics, which is added to the pneumatic ejector component, which is filled with fluid, so that it has great power. This design also allows easy integration with collaborative robots, facilitating efficient and accurate handling of objects in the fertiliser industry environment (Figure 4).

3.1.4. Selection of Concept Design

The selection of the concept design was done through an assessment by a Lecturer in Mechanical Engineering at Semarang State University, an expert in Computer Aided Design (CAD), and a practitioner from Industry, an expert in Mechanical and Robotic Design. The assessment procedure involved providing a questionnaire containing concept

designs and selecting the best design. Based on the selection results, the gripper concept is the first concept.

3.1.5 Mesh Validation

Mesh Validation is a process to ensure that the mesh, or network of elements, required for numerical simulations, such as FEA, is valid. This can yield stable, accurate simulation results. Mesh validation has several aspects of element quality, one of which is Skewness. Skewness is a measure of how far the slope or non-ideality of an element is from its ideal position. The lower the skewness value, the closer the aspect is to a perfect shape. Based on the mesh reference using skewness elements. The results of the mesh skewness have a good or bad category according to table 2.

Table 2: Skewness Mesh Metrics

Criteria	Value
Excellent	0-0.25
Very Good	0.25-0.5
Good	0.5-0.80
Acceptable	0.80-0.94
Bad	0.94-0.97
Unceptable	0.98-1.00

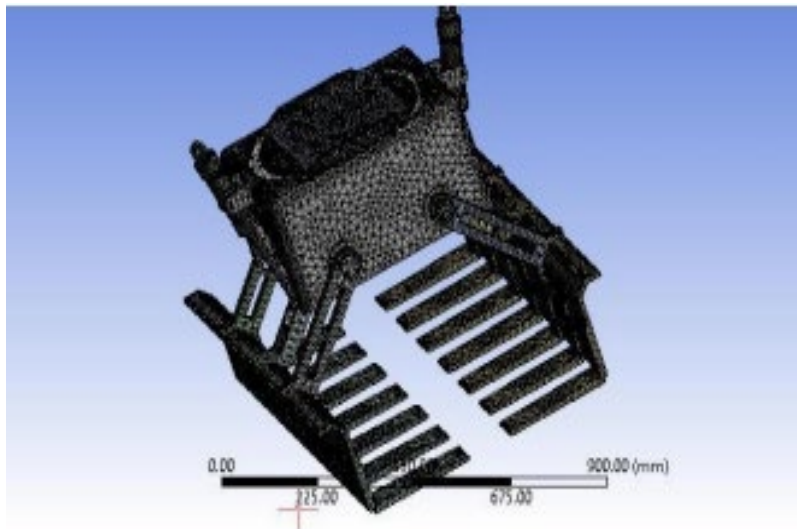


Figure 5: Results of Mesh Gripper 14 Forks

The quality of the elements is carried out based on the values in table 2, these values ensure that the mesh has good quality and is accurate if it will be analyzed further. Then, for the mesh results with skewness elements in table 3, which means very good, because with an element size of 10mm, it will have an average of 0.49 in the 14-fork gripper design (Figure 5).

Table 3: Mesh Results of Skewness Gripper 14 Fork Elements

Element Size (mm)	Average Mesh	Max. Von Misses (MPa)
10	0.491	8.098
10.5	0.500	7.772
11	0.514	7.669
11.5	0.519	7.587

Based on the data in Table 3, the relative error calculation between the voltage results on the size elements in Table 3 is carried out using Equation (1):

$$\text{Error (\%)} = \frac{H1-H2}{H2} \times 100\% \tag{1}$$

1. Error between mesh 10 mm and 10.5 mm

$$\text{Error (\%)} = 8.0984 - 7.7722 / 7.7722 \times 100\% = 4.20\%$$

2. Error between mesh 10.5 mm and 11 mm

$$\text{Error (\%)} = 7.7722 - 7.669 / 7.669 \times 100\% = 1.34\%$$

3. Error between mesh 11 mm and 11.5 mm

$$\text{Error (\%)} = 7.669 - 7.5879 / 7.5879 \times 100\% = 1.06\%$$

Based on the simulation results of the maximum von misses stress with variations in element size of 10 mm, 10.5 mm, 11 mm, and 11.5 mm, a gradual decrease in error values was obtained, namely 4.20%, 1.34%, and 1.06%. The smaller the decrease in error, the closer the simulation results are to a stable value. Because the difference in simulation results between the 11 mm and 11.5 mm meshes is below the 4% tolerance, it can be concluded that the simulation has reached mesh convergence. The 11 mm mesh size was chosen as the final result because it provides a balance between accuracy and simulation stability.

3.1.6. Fork Variation Analysis

Table 4: Results of Analysis of Variation in the Number of Forks on the Gripper.

Number of Forks	Mass (kg)	Material	Von Misses Stress	Displacement (mm)	Safety Factor
10	50.328	Alumunium Alloy 6061	6.271×10^{-5}	0.134	9.379
14	50.159	Alumunium Alloy 6061	1.141×10^{-4}	0.332	10.217
18	51.464	Alumunium Alloy 6061	8.224×10^{-5}	0.226	10.060

Fork with 14 shows the best structural performance among the variants. This is indicated by the highest safety factor of 10.217, which suggests that the structure is safer against possible failure. Although it has the most significant displacement (0.33202 mm), it is still within the tolerance limit and acceptable, as a decrease in strength does not accompany increased flexibility. In addition, the Von Misses stress value averages 1.1418×10^{-4} MPa and does not pose a risk of material failure. With a combination of high safety factors and very low working stress, fork 14 is the most balanced choice between strength, safety, and budget efficiency, making it superior to forks 10 and 18 (Figure 6).

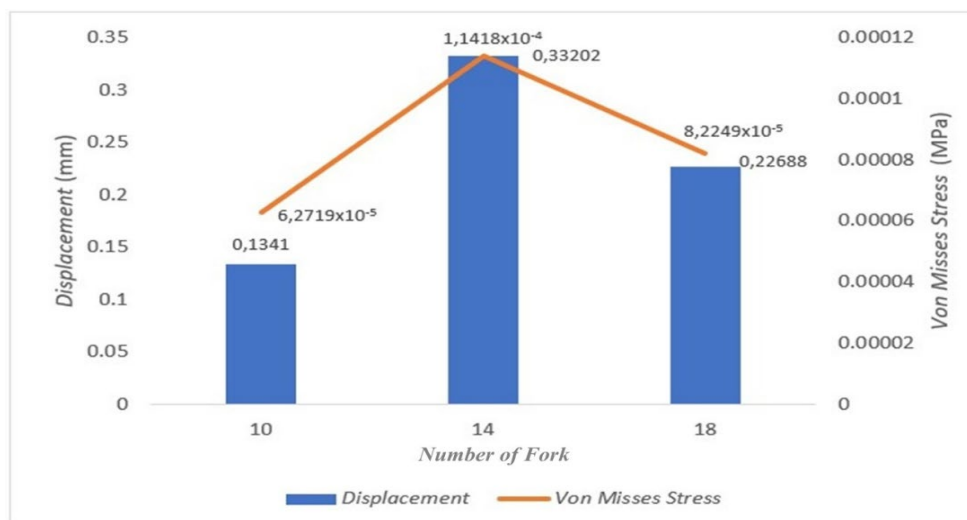


Figure 6: Displacement and Von Misses Variation Graph

3.1.7. Concept Design Analysis

With the concept design selected, the next step is to analyse the components to be used. The analysis is carried out

using numerical methods, literature reviews, and software simulations to obtain appropriate component specifications.

3.1.7.1 Gripper Components

3.1.7.1.1. Gripper Housing

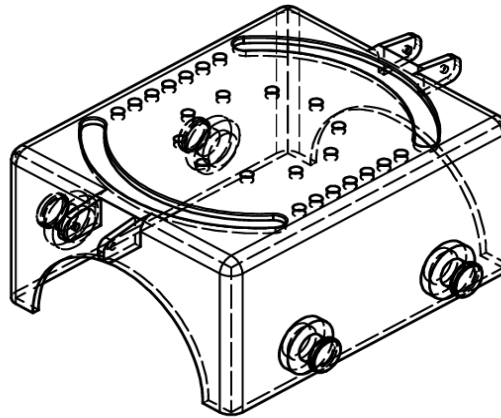


Figure 7: Gripper Housing

The gripper house serves as the main structure supporting all components of the gripper. The gripper house uses steel material. This component has a length of 500mm and a width of 400mm, 2 hydraulic connecting brackets, 10 upper holes with each \varnothing 16mm for connecting to the robot, and connecting axles for 4 arms. This is designed to ensure the stability and structural strength of the gripper, as this component is the initial connection to the robot. The results of the gripper safety factor analysis are 19.005, indicating it is powerful and can withstand a load of 50kg of sack objects (Figure 7).

3.1.7.1.2. Hydraulic



Figure 8: Hydraulic

The hydraulic system serves as the primary actuator for gripper movement via fluid pressure (Figure 8). This Hydraulic Cylinder has a lifting capacity of 2 tons, a 40mm diameter, a 250mm stroke, and a 45 mm piston diameter. The gripper uses hydraulics to lift a 50kg load, and, based on these specifications, produces a hydraulic calculation in Table 5.

Table 5: Hydraulic Pressure Calculation Variables

Variable	Value
Force (N)	490.5
Stroke (m)	0.25
Diameter Cylinder (m)	0.045
Diameter Rod (m)	0.040

From these variables, the calculations for the hydraulic piston's cross-sectional area, hydraulic pressure, and gripper movement time are obtained. The calculation variables are presented in Table 6. The gripper has two hydraulic actuators for its movement mechanism.

Table 6: Hydraulic Calculation Variables

Variable	Value
Piston Area (Forward) (m ²)	1.590×10^{-3}
Piston Area (Backwards) (m ²)	3.336×10^{-4}
Pressure (P)	0.31 MPa
Time (s)	2

This system produces clamping force via the gripper fork's open-close mechanism. This mechanism works in an integrated manner with the Hydraulic Solenoid Cartridge Valve component.

3.1.7.1.3. Gripper Arm

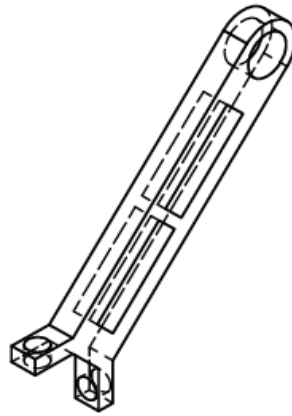


Figure 9: Gripper Arm

The gripper arm is one of the actively moving clamping components. This arm has a length of 300mm and a width of 60mm to reach the gripper fork bar and is made of 6061 aluminium alloy. The arm has a cavity in the middle to reduce the load from the gripper. Then the hydraulics become the controller of the gripper arm as it moves open and closed, adjusting its position to the dimensions of the sack or the object's shape (Figure 9).

3.1.7.1.4. Fork Gripper

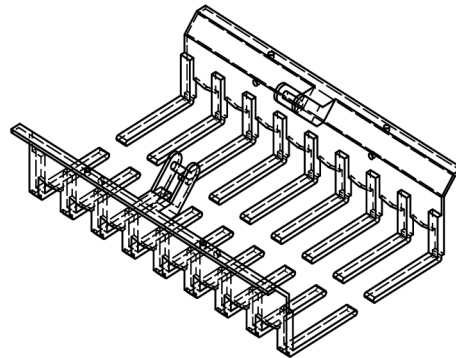


Figure 10: Fork Gripper

The fork or prong on the gripper is in direct contact with the sack object when clamping or moving it. The total length of the fork is 1000mm, and the width is 600mm, according to the sack object, which has a width of 60cm. There are 18 forks, each 250mm long and 35mm wide (Figure 10). The load force per fork is 27.22 N. The fork provides additional support at the bottom of the sack object to increase stability and reduce damage to the object during placement and arrangement. The fork is given an anodising layer because the fork material is aluminium alloy 6061, which is easily corroded when exposed to chemicals. The anodising layer helps minimise corrosion caused by

chemicals in fertilisers.

The results of the gripper analysis using aluminium alloy 6061 material, which was tested for pressure from above, assuming the weight of the sack was the same as the maximum pressure of 111 lb-force or 490 Newtons, can produce the following (Figure 11);

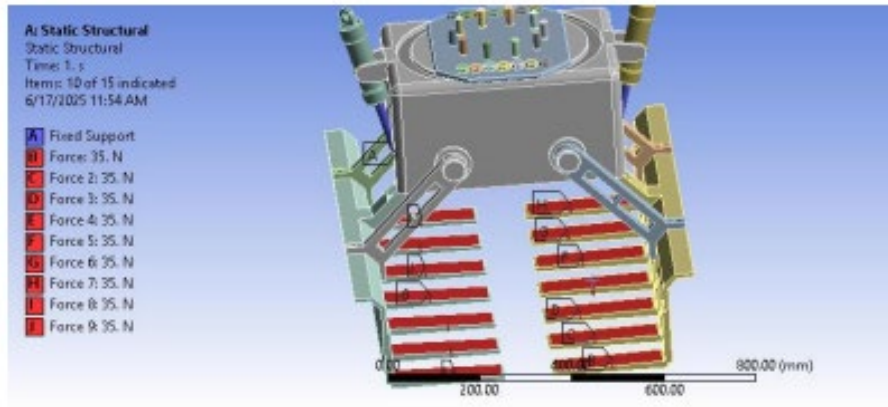


Figure 11: Direction of 50 kg pressure

Table 7: Results of Concept Design Analysis of 14-Fork Hydraulic Gripper

Parameter	Value
Mass (kg)	50.159
Yield Strength (MPa)	275
Displacement (mm)	0.332
Von Misses Stress (MPa)	7.772
Safety Factor	10.217

Static structural analysis of the 14-fork hydraulic gripper concept design was performed using the Static Structural solver in ANSYS 2021 R2, with Aluminium Alloy 6061 assumed to be homogeneous, isotropic, and linearly elastic, with a yield strength of 275 MPa. Boundary conditions were applied in the form of fixed supports at the connection area of the gripper with the actuator arm to represent a perfectly bonded condition without displacement and rotation. A working load of 50 kg was modelled as a static force evenly distributed over the contact surface of each fork, acting in the downward vertical direction, thus reflecting the actual operational conditions during the clamping process. The contact assumption between components was set to bonded contact, which assumes no slip or separation and represents a rigid connection under maximum loading conditions. The discretisation process was carried out using three-dimensional solid elements (tetrahedral elements) with a compacted mesh size in critical areas to improve the accuracy of the results. In contrast, the numerical solution method used ANSYS's default sparse solver to obtain the stress response, deformation, and safety factor of the structure.

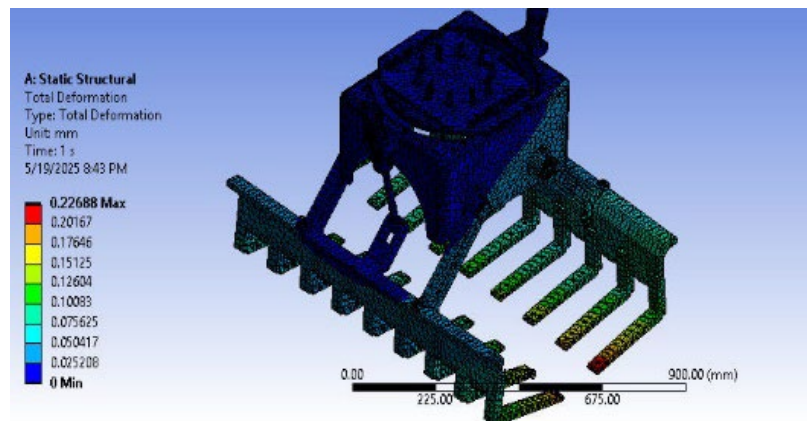


Figure 12: Displacement Analysis

The simulation results show that the gripper part experiences a maximum displacement of 0.33202 mm. This indicates that the gripper structure remains sturdy and does not undergo significant deformation, enabling it to maintain stability and precision of movement when lifting a 50 kg load (Figure 12).

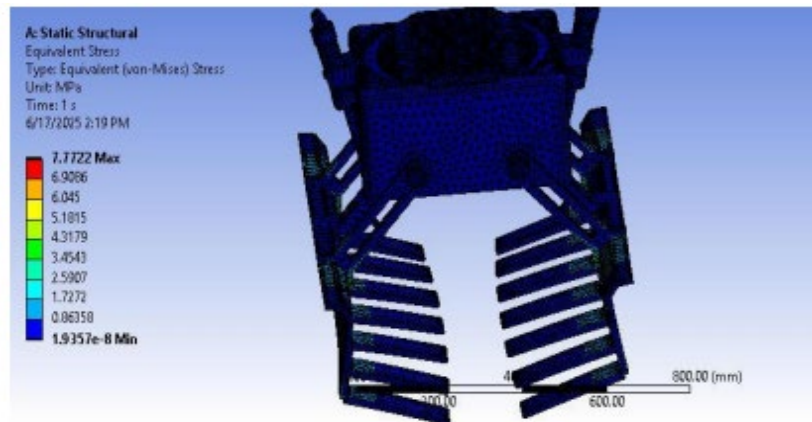


Figure 13: Von Misses Stress Analysis

The average Von Misses stress value of 14,873 MPa was found in the gripper component during simulation using the finite element method (FEA). This value shows the distribution of internal forces due to loading, especially in areas experiencing clamping forces or interacting directly with the load. These values indicate that the stress distribution in the gripper structure is even and not excessively concentrated at any point (Figure 13).

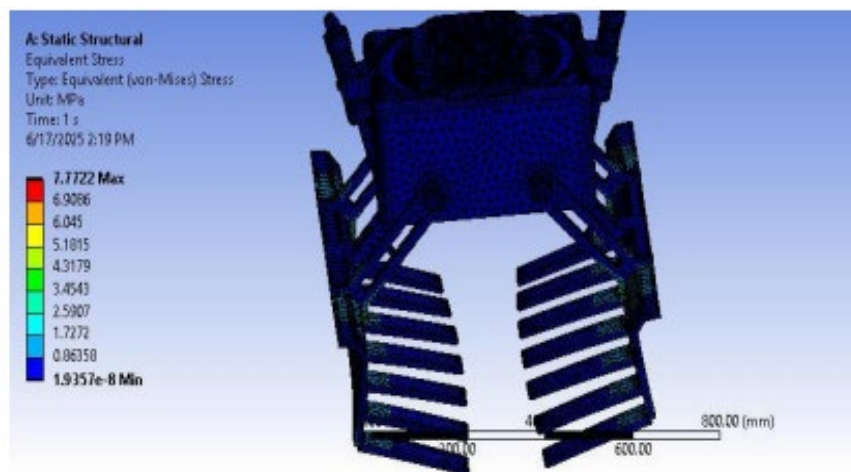


Figure 14: Safety Factor Analysis

The simulation results show that the minimum safety factor is 10.217. From this value, the gripper component can withstand loads up to five times the actual working load before reaching the material's yield strength limit. This safety value indicates that the gripper design is very safe and very resistant to loading variations, manufacturing errors, or material imperfections. In addition, the safety factor value provides users with confidence that the structure will not experience permanent damage or failure during routine operations (Figure 14).

3.1.8. Validation of Design Results

Design validation was conducted by design experts to ensure a rational machine design that functions as intended. Validation was carried out by providing a questionnaire to the validator to assess the machine design. Based on the validation results, the gripper design is feasible for use.

4. Discussion

Based on the results of the concept design selection conducted by the validator, the chosen concept design for the

pick-and-place robot gripper is the first. This concept design was chosen because it has a simple design, uses hydraulic components for a stable work response, and has 14 forks. This concept design was chosen because it has 14 forks, allowing the gripper to lift sacks optimally and minimising the risk of sacks falling. The results of the Finite Element Analysis (FEA) simulation with Ansys 2021 software on the fork in the gripper that receives the load when the gripper is working. The analysis results show that the safety factor value on 14 forks is 10.217. However, the safety factor value of 10.217 is still relatively safe, considering that the 61 safety factor values for designs with static loads range from 1.25 to 2. This shows that the components tested have met the safety factor.

Based on the results of numerical calculations on the gripper hydraulic system, it is obtained that the force required to lift a load of 50 kg is 490.5 N. By using a hydraulic cylinder with a piston cross-sectional area of 0.00158962 m², the pressure needed to produce this force is 0.31 MPa or equivalent to 3.1 bar. This pressure value indicates that the designed hydraulic system operates at a relatively low pressure, making it safe to use and requiring no high-pressure components. In addition, this pressure remains within the safe limit for most standard hydraulic components, thereby supporting the efficiency and reliability of the gripper system in pick-and-place operations. The results of the design cost estimation calculation show that the manufacturing cost for the gripper product is 19,034,000.00, and the cost of purchasing an ABB-brand robot with a 50 kg payload is 288,000,000. The total cost to build a pick-and-place robot is IDR 307,034,000. This value is efficient because the 14-fork gripper has the lowest mass among other gripper forks.

Based on the validator's validation of the design results, the gripper product design can be declared feasible for production. This is based on the results of component specification calculations, software simulation results, design cost estimates, and working drawings for the product to be produced.

5. Conclusion

The analysis was conducted using hydraulic force calculations, stress distribution simulations, and finite element method (FEA) deformation evaluations. Lifting a 50 kg sack of fertiliser was used as a workload simulation. The analysis results showed that a 10-fork design yielded a minimum safety factor of 9.3791, while a 14-fork design yielded 10.217. Meanwhile, the 18-fork design had a minimum safety factor of 10.06. The 14-fork design is recommended as the preferred gripper fork due to its highest safety factor and lowest mass, ensuring efficient budget planning. The 14-piece fork exhibits the best structural performance among the variants, as evidenced by its highest safety factor of 10.217. This fork design is robust and safe for use in the harsh, abrasive environment of the fertiliser industry.

Future research on pick-and-place robot design should focus on integrating mechanical systems. Intelligent controls, such as weight and position sensors, are recommended to improve gripper precision and safety. The size and strength of the gripper are also crucial for handling load variations in industrial processes. Furthermore, robots can be applied to other industries, such as transporting rice sacks (agriculture).

6. Funding

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