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Loading and Unloading for Thread Rolling using Automation

Mr.Aniruddha Nawale
Dept. of Mechanical Engineering
JSPM RSCOE, Tathawade,
Pune, India.

Ms. Chaitrali Rangade
Dept. of Mechanical Engineering
JSPM RSCOE, Tathawade,
Pune, India.

Mr. Onkar Shelke
Dept. of Mechanical Engineering
JSPM RSCOE, Tathawade,
Pune, India

Mr.Sourabh Pawar
Dept. of Mechanical Engineering
JSPM RSCOE, Tathawade,
Pune, India.

Prof. S.J. Jagtap
Dept. of Mechanical Engineering
JSPM RSCOE, Tathawade,
Pune, India.

***Abstract*— This thesis presents a general automation strategy for large diameter fastener production using a work cell concept. The system consists of an automatic loading and unloading system for a thread rolling machine, based on a transport system using workpiece racks. This method is successful in moving fasteners fully oriented throughout the production process and eliminates part-to-part contact during transit.**

The system architecture includes a universal fastener gripping system that can accommodate a wide variety of fastener sizes and styles. A special gripping model is created to forecast the gripper's performance, and the prototyped gripping system's error tolerance is examined to validate the model results.

The automation system is demonstrated to be a practical way to load and unload large diameter parts onto a thread rolling machine. It also demonstrates the gripping mechanism producing a firm grasp on all parts and resisting contact degradation after multiple grasps of jagged edges.

Keywords—Workcell plan; transport system; part loading & Un-loading; thread rolling process; gripper design;

I. INTRODUCTION

Historically, many fastener forming and machining processes were manually fed by aerospace fastener makers, especially when working with large diameter workpieces. Many facilities are implementing automatic machine loading and unloading due to trends in production towards more highly automated operations. This tendency is a direct effect of rising competitiveness, which calls for more productivity and lower operational costs. Additionally, ever-tighter safety standards are reducing the amount of hand feeding that operators may do into potentially dangerous processes. In order to avoid incurring expensive downtime as a result of new rules, manufacturers need continue to be ahead of the curve when it comes to safety.

Manufacturers are under more pressure than ever to automate their production processes in today's cutthroat global economy. As a result, during the system development process, automation system designers must overcome a number of obstacles, some of which may have far-reaching effects that are not immediately apparent. This thesis's objective is to assess these design choices and convey them in a way that is generic and transferable to different applications and systems. The design of an automatic loading and unloading system for a thread rolling machine—used to make aerospace fasteners—is specifically covered in this thesis. In Figure, a common fastener is seen.

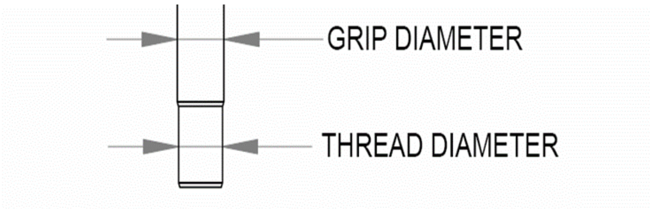

Fig. 1.1 Typical Fastener

A. Objective

The goal of this thesis is to create an automated part loading and unloading system for a common thread rolling process used in the manufacture of fasteners. First, a plan for workcell automation that will act as a guide for this and subsequent automation projects.

Second, a workcell plan must be taken into consideration while developing the mechanical design of an automatic loading system for a thread rolling machine. A universal gripping device that can hold a range of part styles and sizes characteristic to this thread rolling process is to be created as part of the thread rolling automation system. The performance and error tolerance of the gripper should be predicted using modelling approaches, and the output of this model should be utilized to validate the operation of the suggested automation system. The following is a summary of the study's goals:

1. Create a comprehensive automation plan for the manufacturing of aerospace fasteners. This strategy should be

built on the idea of a workcell and include a set of guidelines for automating both current and future machines.
2. Automate the loading and unloading of components from a thread rolling process in accordance with the large-scale workcell plan to demonstrate the concept developed in step 1.
3. Create a universal gripping mechanism for a wide range of fastener sizes and types as part of the thread rolling automation system development.
4. Use models based on fundamental engineering concepts to predict how well the created gripping system's error tolerance will function.
5. Prototype and test both the automation system and gripping system, comparing expected results with experimental data.

A universal fastener grasping system that can be utilized in any application where fasteners are handled automatically will be made possible thanks to the automation system's architecture. Despite the fact that gripping headed fasteners are a fairly common problem, research in the literature and interactions with industry revealed that very little information is available. Finally, this thesis will introduce a fresh method for understanding modelling. The machine design engineer was taken into consideration when developing this model, despite the fact that the majority of the work in grasping and automated fixture planning is theoretical rather than applied. The model will be developed generally to make it easier to adapt to different grasping scenarios, with the direct application to this case being demonstrated.

II. LITERATURE REVIEW

A. *Survey on the thread cutting*

Since a large portion of this thesis will focus on automating a thread rolling machine, it is important to comprehend the rolling process in and of itself. Additionally, a review of the most recent developments in thread rolling technology is carried out before creating any specific mechanical designs.

This chapter gives an overview of a few of the frequently used automated thread rolling technologies. Recent innovations in process monitoring technologies as well as various rolling machine designs are included in the discussion of recent advancements in thread rolling machine development. The thread rolling process will be briefly described in this chapter, followed by a study of the technologies used in the sector. We'll look at the most recent developments in handling fasteners in automated operations. Finally, a summary of the study on parts orientation and grasping will be given.

24TH international symposium on automation and robotics in construction, M. Muthukkaruppan and K. Manoj, is arc. An online case study comparing the productivity of a component utilising a real-time multi-stationed automated rotational transfer line used for drilling and tapping shows how low-cost automation employing electro-pneumatic system may be done.

Shiv G. Kapoor, Richard E. Devor, Sameer Chowdhary, O. Burak Ozdoganlar, and Urbana, Illinois, 61801 in the United States internal thread formation modelling and analysis In this study, a mechanistic model is presented for the prediction of the thrust and torque that a forming tap will experience throughout an internal thread formation procedure.

Journal of mechanical and civil engineering published by Darshith, Ramesh Babu, and Manjunaths (IOSR-JMCE).The procedure of cutting and rolling specific threads is the subject of this study. There is discussion of the various thread rolling and cutting processes.

Wagner Matthew - The manufacture of aerospace fasteners involves numerous machining and shaping processes, including heading, centerless grinding, and thread rolling. Many of these operations have traditionally been fed by hand, especially for big diameter parts. The production processes for big diameter fasteners can be automated using the general automation plan presented in this project, which is based on the idea of a work cell. To demonstrate the general work cell concept, a thread rolling machine's automatic loading and unloading system is built and prototyped.

B. *Methodology*

Depending on the particular application and requirements, numerous approaches can be used to automate thread cutting. A general approach that can be used to automate thread cutting procedures is as follows:

Analyze the Conditions: Recognize the particular specifications needed for the thread cutting procedure, such as the thread specifications (such as pitch, diameter, and type), material characteristics, tolerances, and manufacturing volume. This will assist in determining the required level of automation and direct following actions.

Choose the thread cutting technique: Based on the application and specifications, choose the thread cutting technique that is most appropriate. Single-point threading, tap and die sets, thread milling, and thread rolling are examples of common techniques. Think about things like the type of material, manufacturing speed, desired thread quality, and tooling accessibility.

The automation equipment should be chosen: Based on the thread cutting technique you choose, select the required automation equipment. This could involve robotic systems, CNC (Computer Numerical Control) machines, or specialised thread cutting equipment. Make that the chosen equipment is able to carry out the necessary thread cutting operations precisely and effectively.

Program the automation equipment with the necessary orders and settings to carry out the thread cutting operation, if you're utilizing CNC machines or robotic systems. Set up the necessary tooling, such as taps, dies, or milling machines, and make sure everything is placed and aligned properly.

Establish a methodical procedure for loading workpieces into the automation system. Material handling and setup of the workpieces. Conveyor systems, robotic arms, and other handling devices can be used to handle the workpieces securely and precisely. For accurate thread cutting, the workpiece's setup, alignment, and clamping must be perfect.

Execute the Automation Process: Start the automation process by carrying out the scripted instructions and directives. According to the given parameters, the automation system will carry out the thread cutting operations on the workpieces. To maintain accuracy and quality control, keep an eye on the procedure.

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Implement inspection procedures to ensure that the threaded components are of a high standard. Tools for dimensional measurement, vision systems, and other quality control procedures can be used in this. Make that the automated thread cutting procedure continuously complies with the necessary requirements and quality standards.

Maintenance and optimization: Conduct routine preventive maintenance on the automation equipment and address any potential problems. For increased effectiveness, precision, and productivity, continuously assess and enhance the automated thread cutting procedure.

III. WORKCELL CONCEPT SELECTION

This research project's primary objective, as stated in the first chapter, was to develop the framework for an automation plan for the standard aircraft production process. The manufacturer had been considering the notion of a work cell for some time and wanted to determine the best way to adopt it for their procedures and goods. A collection of machines was identified that should be considered for the cell plan, and products with high production volumes and comparable size limits were chosen as the parts to be created in the cell.

A. *Discrete Time Analysis of Current Method of Production*

At each station, pieces are manually fed by operators as part of the existing production procedure. Each machine processes parts until the entire batch is finished, at which point they are moved to the following machine to continue processing. Since on the factory floor different projects frequently take priority over one another and batch size can vary with each work, it can be challenging to simulate this process accurately. Assumptions were made that any parts in the queue will be handled as first in/first out, meaning that batches of parts will be processed in the order they are received at each machine, in order to simplify and replicate this process. Additionally, it will be assumed that batch size is constant, which is an acceptable assumption for the sake of an initial study in the instance of this manufacturer.

The underlying concepts of this approach become readily apparent after running Arena with the specified cell arrangement. Production initially lags when product enters the processes as the first batch passes through each machine and the cell achieves steady state. After this, the batch of parts is finished at regular intervals according to the process's slowest cycle time.

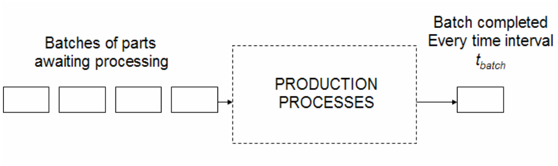

Fig.3.1 Schematic of current method of production

B. *Sequential Cell Discrete Time Analysis*

Next, Arena received the sequentially operated, highly automated cell model. In contrast to the earlier mentioned and depicted approach, which moves batches through the process, this one move individual parts.

Fig 3.2 Schematic of sequential cell

C. *Reduced Automation Batches Cell Discrete Time Analysis*

Finally, Arena analyses the batch transfer cell with less automation. As batches of parts rather than individual parts are transferred between machines in this cell, it is extremely comparable to the already discussed methodology in terms of analysis. The research reveals that for both production time and work in progress, the batch transfer cell is likewise governed by the same equations that control the current operation. The results of the study of the current method match the results obtained utilizing sample cycle periods.

D. *Discrete Time Analysis Conclusions*

Several inferences can be made after the discrete time analysis is complete.

First off, just automating product transfer between machines won't boost the process' productivity. Reducing the cycle time of the slowest process or using additional machines to do the slowest process simultaneously are the only ways to boost productivity.

E. *Selecting a Workcell Concept*

The conclusions are as follows after looking at two overarching cell conceptions and four design objectives. The manual batch transfer cell is chosen primarily due to its adaptability and simplicity. The manual batch transfer cell is definitely superior in this regard. These two design goals were determined to be the most significant in the process selection.

	Highly Automated Sequential Transfer Cell	Manual Batch Transfer Cell
Reduced Labor (vs. current one operator per machine)	One operator per workcell	One operator for every 3-4 machines
Increased Throughput / Productivity (vs. current)	Reduced work-in-progress, productivity gains from reduced operator fatigue / breaks needed	Productivity gains from reduced operator fatigue / breaks needed
Flexibility and Adaptability	LOW	HIGH
Ease of Implementation	LOW	HIGH

Fig.3.3 Comparisons of cell performance criteria

The manual batch transfer cell can work unattended for a set amount of time, which can be arranged to coincide with the operators' breaks, and will also benefit from a reduction in human error in loading. Additionally, by removing the operator's hands from the loading and unloading operation, an enhancement in operator safety is achieved.

IV. MOTION PLANNING

The system would process two transport trays of parts at once and will include a dual heating coil, according to earlier portions that established the issue at hand.

Additionally, the system will have a post-processing section where bolts will be drained of any leftover oil after rolling. The

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next step is to decide how these spaces will be organized and what kind of equipment will be used to transfer parts between them.

The two degree of freedom strategy needs more planning but yields a more straightforward system, all pick and place points in this architecture are positioned to fall on a plane of motion. The placement points in the thread roller, both heating coils, three post-processing locations, one row of tray holes, and all four are coplanar. The end effector only requires two degrees of freedom to move in this concept: vertically and horizontally. In order for the end effector to reach every tray site, the trays will need to index under this plane of motion.

Due to the requirement that all end effector motion be kept separate from the worker, this strategy also decreases the area that needs to be guarded. By doing this, the worker will be able to stay near to the thread roller and carefully observe the procedure. The two degrees of freedom with a tray indexing drive was selected as the concept to be developed due to its simplicity and small protective envelope.

A. Moving in the Developed Workspace

One can move around a two-dimensional workstation in a variety of ways. If the pick and place points were few and constant, hard automation might be used, but this application demands that a robotic solution be used. Although a SCARA or articulated arm robot could be employed, a pick-and-place robot was preferred in order to benefit from the concept of restricted degrees of freedom. Based on the design requirements encountered, an automation integrator was chosen to create the robotic system.

It is anticipated that the longest part that will be processed has a length of 10". A maximum velocity of 2.5 m/s is assumed and acceleration values of 1g are employed. These values are well within the range of what CA Motion's machines can physically do.

V. GRIPPING SYSTEM DESIGN

The details of the system's mechanical design can now be discussed as the cycle and procedure have been approved. The design of the end effector in this system presents the greatest design challenge. It must be dependable and damage-tolerant, and it must be able to handle a wide range of fastener sizes and types. The maximum size for some features will also be limited by many clearance concerns because the gripper needs to fit between components in the trays as well as between dies and die hangers in the thread roller.

A. Moving in the Developed Workspace

Setting design criteria for the grasping system is helpful, just as it is for the entire system. The following is a list of these rules.

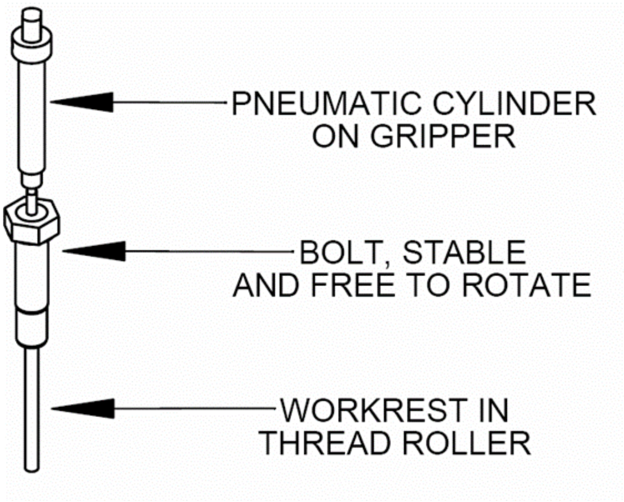


Fig. 5.1 Gripper pneumatic cylinder concept

B. Calculations

When it comes to thread cutting, there are several calculations involved to determine the dimensions and parameters of the thread. Here are some key calculations commonly used in thread cutting:

Pitch Diameter:

The pitch diameter (D) is the diameter of an imaginary cylinder that intersects the thread crests at the same radial distance as the thread roots.

It is calculated using the formula:

D = Major Diameter - (1.08253 * Pitch)

Major Diameter:

The major diameter (d) is the largest diameter of the thread.

It can be calculated using the formula: d = Pitch Diameter + (2 * 0.64952 * Pitch)

Minor Diameter:

The minor diameter (Dm) is the smallest diameter of the thread.

It is generally calculated as: Dm = Major Diameter - (2 * Thread Depth)

Thread Depth:

The thread depth (h) is the radial distance between the crest and the root of the thread.

For external threads, it is typically 0.6134 * Pitch, and for internal threads, it is typically 0.5413 * Pitch.

Thread Helix Angle:

The thread helix angle (α) is the angle formed by the helix of the thread with the axis of the cylinder.

It is calculated as: α = tan^(-1)(Pitch/Lead)

Lead:

The lead (L) is the axial distance traveled by the thread in one complete revolution.

It is the reciprocal of the thread pitch (P): L = 1/P.

Number of Thread Turns:

The number of thread turns (N) is the total number of thread rotations required to complete the thread.

It is calculated as: N = Length of Thread / Lead

These calculations provide the basic parameters for thread cutting. It's important to note that there are different thread standards (such as metric, unified, and others), each with its own specific formulas and parameters.

If the major diameter of the thread is 80mm, you can use that information along with the thread pitch (14 TPI) to calculate additional parameters for the thread. Here's how you can proceed:

Thread Pitch (P): Given that the thread pitch is 14 TPI, the pitch can be calculated by dividing 1 inch (25.4 millimeters) by 14, which equals approximately 0.0714 inches (1.814 millimeters).

Minor Diameter (miD): The minor diameter can be calculated by subtracting the thread depth from the major diameter. Assuming a thread depth of 0.6 times the pitch, which is approximately 0.0429 inches (1.089 millimeters), you can calculate the minor diameter as follows:

miD = Major Diameter - 2 * Thread Depth

miD = 80mm - 2 * 1.089mm

miD ≈ 77.822mm

Material Selection-

EN 8 is a commonly used engineering steel grade in Europe that conforms to the European standard EN 10083-2. It is also known as 080M40 in the United Kingdom and SAE 1040 in the United States. EN 8 is a medium carbon steel with good tensile strength, toughness, and wear resistance. It is often used in applications such as gears, axles, shafts, and machine components.

The chemical composition of EN 8 typically includes the following elements:

Carbon (C): 0.36% - 0.44%

Silicon (Si): 0.10% - 0.40%

Manganese (Mn): 0.60% - 1.00%

Phosphorus (P): Maximum 0.050%

Sulfur (S): Maximum 0.050%

The mechanical properties of EN 8 depend on factors such as heat treatment and the desired strength and hardness. As a general guideline, EN 8 can have the following mechanical properties after appropriate heat treatment:

Tensile Strength: 550 MPa (MegaPascals) - 700 MPa

Yield Strength: 280 MPa - 420 MPa

Elongation: 14% - 22%

Orange TT555 12V 15RPM Rectangular gearbox DC motor for DIY Project Encoder Compatible

Fig.5.2 DC Motor

1. Rated current (mA): ≤1400.
2. Rated power (W): 3.960.
3. Rated Torque (N-m): 315.6
4. Rated speed: 15 RPM.
5. Shaft length (mm): 27.
6. Shaft diameter (mm): 8.
7. Base motor RPM: 3000.

SMPS

Fig 5.3 SMPS

Input Voltage: AC 90 - 264V 50 / 60Hz

Output Voltage: 12V DC, 2A, and 24Watt

Output Voltage: Adjustment range: ±20%

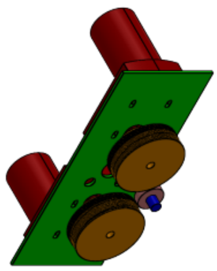
Output Voltage Type - DC Current

Shell Material: Metal Case / Aluminum Base

Color: Sliver

Weight: 200g Approx

Dimension: 88 x 60 x 32 mm Approx



C. Manufacturing Drawing

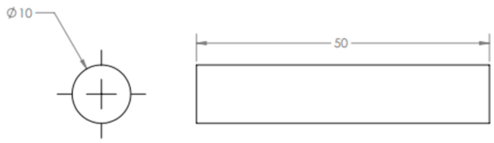


Fig 5.4 10 mm Bolt

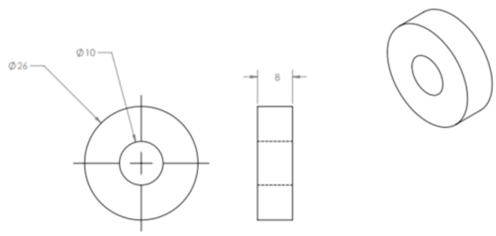


Fig 5.5 Bearing

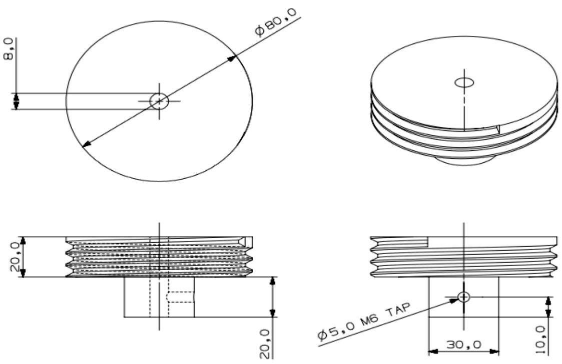


Fig 5.6 Thread Blank

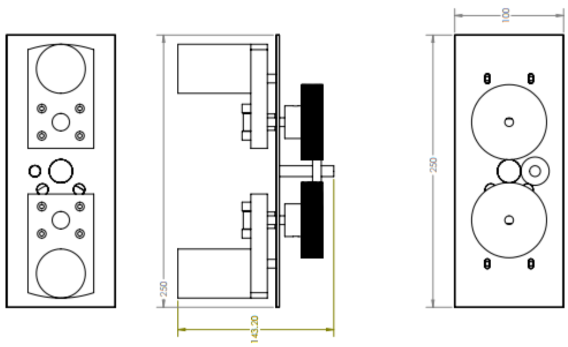


Fig. 5.7 Assembly

D. Static Structural analysis

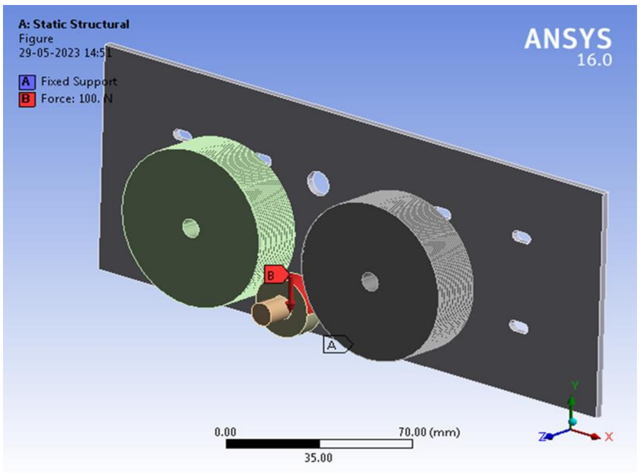


Fig .5.8 Boundary Conditions

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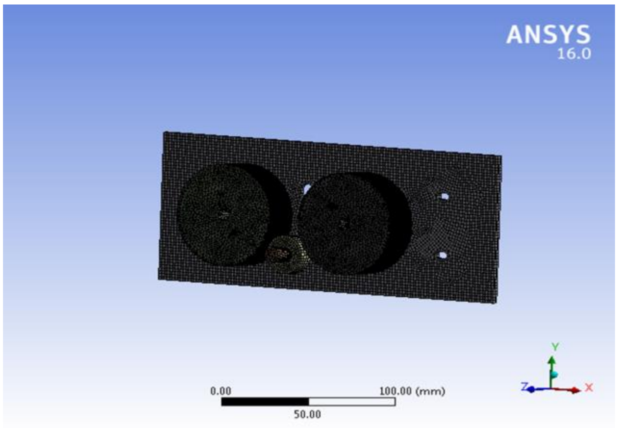


Fig 5.9 Mesh Configuration

Result

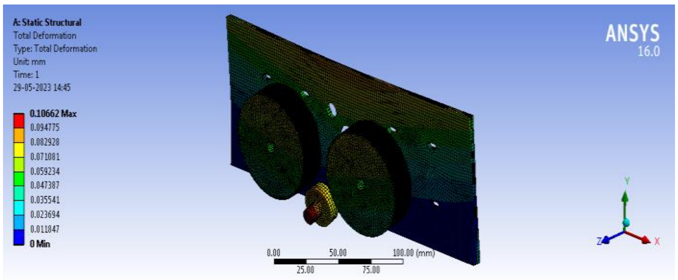
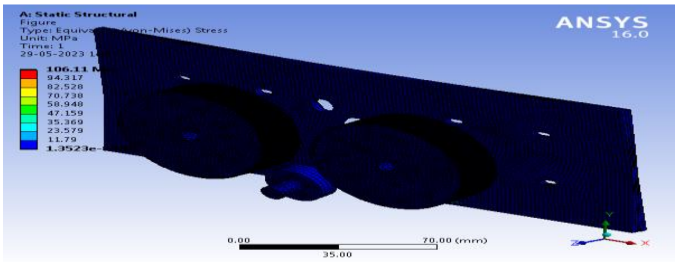


Fig. 5.10 Total deformation in mm



5.11 Stress generated

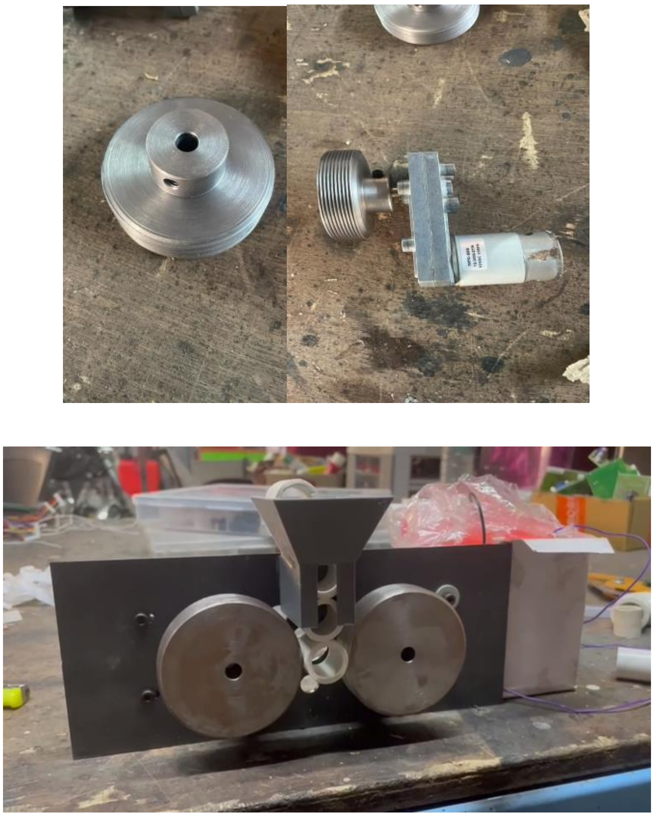


Fig 5.12 development images

VI. CONCLUSION & RECOMMENDATION

The design of an automatic part loading and unloading system for a thread rolling machine used in the manufacture of aerospace fasteners was tracked in this thesis from the basic concept to the prototyping and testing stages. A thorough analysis of the manufacturing processes and the need to create a workcell idea served as the foundation for the design process. Using this information, a workcell automation plan was developed, which served as the foundation for the creation of the automation system. A universal gripping system that can support a range of fastener sizes and types was designed for the automation system, and the development of the gripping system resulted in the creation of a model that forecasts gripper error tolerance.

A. CONCLUSION

In this thesis, the following subjects were especially covered:

- A highly automated workcell was disregarded in favour of a more straightforward strategy for the issue at hand through the use of discrete time analysis and the consideration of design goals. The less complicated method requires moving batches of parts manually between automated systems. A work-cell that is created using this technology is more adaptable and suitable for creating small batches of specialized parts.
- To move components between machines with automated part loading and unloading, a transport tray system was put into place. It was demonstrated that the transport tray idea is a practical way to swiftly offer a

batch of parts to an autonomous loading system and is also a secure mode of transport that prevents part-to-part contact.

- In collaboration with CAMotion, Inc., a thread rolling machine's automatic part loading and unloading system was created and prototyped. The robot that was chosen was a modified version of the pick-and-place robot CRP-1000 from CAMotion. The peg-in-hole problem of inserting bolts into oversized destination holes was solved by the machine, which was found to hold appropriate placement tolerances.
- A-2 tool steel gripping faces with a semicircular gripping face profile were used to create a universal fastener gripping system. A wide range of fastener sizes and types could be reliably grasped by the gripping system, and it was discovered that the gripping faces were resistant to wear even after 10,000+ cycles.
- To determine what kinds of faults the suggested gripper can withstand, a grabbing model was created. The gripper's ability to self-align a workpiece with a specific set of angular faults in its jaws was predicted by the model.

B. RECOMMENDATION

This study identifies a wide range of potential areas for future academic and applied research. To implement the decreased automation workcell concept, the system's practical element entails producing several transport trays. However, because of the small production run produced, prototyping the trays was costly. Although conventional machining techniques were employed, alternative techniques, such as water jet cutting, might be examined. It should be thought about whether it's possible to machine more than one tray at a time. The trays may be machined or water jet cut in batches and stacked on top of one another. The two steel locating elements also increased the price of each tray. The trays might be used by only focusing on the tray material.

Initial tests indicated that the system performed satisfactorily in terms of the automation component of this thesis, and all design objectives were met. More testing is advised for the system, though, as any long-term mechanical problems might not show up during prototype testing. The gripping mechanism is a good example of this; although early wear characteristics were satisfactory, a longer test time would be helpful in analyzing the design and material selections.

The compelling self-alignment model highlights areas that need more research in the academic world. For the model verification, only one gripper-workpiece material combination was examined. To more fully validate the model, material pairs with various coefficients of friction should be tested. Additionally, a wider range of part head forms ought to be evaluated for additional confirmation.

There is potential for growth with the grabbing model as well. The gripper in the automation system's gripper has semicircular grabbing faces, which the model as it is currently provided only supports.

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