Erowa Robot Integration

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requirements for the degree of

Bachelor of Science

in Mechanical Engineering Technology

by

Tre Brennan
Blake Ross
Jake Davolio

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Thesis Advisor:

Professor Moise Cummings

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ABSTRACT

The integration of an Erowa Compact 80 Pallet Changer Robot onto a Yasda Precision Mill at Dayton Reliable Tool Mfg Co (DRT) presents a solution to enhance parts output without requiring a second shift, addressing challenges posed by a skilled labor shortage. This project focuses on designing and fabricating components such as subplates, programs (macros), and a standard tool kit to seamlessly integrate the robot with existing manufacturing processes. The primary objective is to develop a robust and efficient solution that optimizes production processes, maintains, or improves product quality, and ensures compatibility with current equipment. This primary focus on optimizing the process is due to customer preference and time constraints. Key considerations include safety, cost-effectiveness, ease of maintenance, and ease of use. The successful implementation of this project is expected to boost production capacity, reduce human intervention, and increase overall efficiency in manufacturing operations.

PROBLEM DEFINITION AND RESEARCH

PROBLEM STATEMENT

The objective of this project is to enhance the output of parts in the manufacturing processes at Dayton Reliable Tool Mfg Co (DRT). Our project focus is on integrating an Erowa Compact 80 Pallet Changer Robot onto a Yasda Precision Mill to keep up with the influx of jobs going to the machine and without the use of a second shift. To achieve this, the project team must design and fabricate suitable components such as subplates, programs (macros), and a standard tool kit that will enable seamless integration of the robot with the current manufacturing setup. The key challenge lies in developing a robust and efficient integration solution that optimizes the production process and ensures compatibility with the existing equipment while maintaining or improving product quality. Additionally, the team must consider factors such as safety, cost-effectiveness, ease of maintenance, and ease of use throughout the design and implementation phases. The successful completion of this project will significantly boost production capacity, reduce human intervention, and lead to higher productivity and efficiency in the manufacturing operations.

BACKGROUND

The problem revolves around the challenge of finding skilled workers, a persisting issue that has plagued the industry for many years. In the manufacturing sector, numerous job vacancies exist, yet as highlighted in a recent Deloitte study, the skills gap poses a substantial threat. The study predicts that between 2018 and 2028, approximately 2.4 million positions may remain unfilled, potentially resulting in a staggering economic impact of 2.5 trillion dollars (1). Faced with this alarming situation, many manufacturers have been compelled to act. Some are enhancing their training programs, while others are embracing automation as a cost-effective alternative to human labor. This shift towards automation is primarily driven by its cost-efficiency compared to traditional labor expenses.

RESEARCH

SCOPE OF THE PROBLEM

At present, the work center deals with approximately 100 distinct parts. These parts are allocated in orders ranging from 1 to 4 parts each, leading to significant setup times for each job. (2) However, with the introduction of a robot, the initial setup can be efficiently managed by the first-shift worker before leaving, allowing for overnight operation. Given the absence of a second shift, the current maximum work output is capped at 10 hours (3). Nevertheless, the incorporation of the robot introduces the potential for overnight production, thereby enhancing overall productivity. Moreover, during daytime operations, the robot's ability to manage other tasks after setting up the pallets in the machine will further contribute to increased efficiency (4).

CURRENT STATE OF THE ART

The current solutions at DRT are inadequate due to a persistent labor shortage for the second shift. This shortfall arises from challenges in finding willing and qualified workers for overnight shifts, along with scheduling conflicts and limited incentives for late-night work. Consequently, the company faces a pressing need to address this issue to maintain operational efficiency and meet customer demands.

To fill this crucial gap, the proposed senior design project involves the integration of a robot pallet changer that DRT has selected to replace the need for the second shift workers. A robot pallet changer is a device that can automatically change pallets on a machine tool. It is used to improve the efficiency of manufacturing processes by reducing the time required to change pallets manually. Pallet changers also offer several advantages over human workers, including the ability to work tirelessly and consistently without fatigue, reduced operating costs overall, increased output through faster and more precise work, improved product quality, enhanced workplace safety, and operational flexibility (5). By leveraging robotics technology, the company aims to not only bridge the labor shortage but also achieve a more sustainable and efficient production process that can meet the demands of the market effectively.

There are numerous existing robot pallet changer solutions available for comparison with the Erowa Compact 80. One such alternative is the AX-Series Pallet Delivery System, jointly manufactured by American Machine & Engineering Co and Trinity Automation. The AX1 model boasts an integrated Fanuc M-10iD Robot and a streamlined design to maximize floor space efficiency. The AX1 System is capable of handling payloads of up to 17 lbs., accommodating a maximum part size of 12” in diameter and 9” in height, and offers a choice of either 14 or 28 pallet locations to suit specific requirements. The pallet system is equipped with pallets designed for a single clamping module and a single-pallet operator station with a rotating receiver. Additionally, the CNC table setup incorporates a rotating receiver with a single clamping module and air knife blow-offs for cleaning contact surfaces (6).

Another existing alternative solution is the System 3R Workpal 1, which is manufactured by GF Machining Solutions. The Workpal System can be adapted for various applications, including Precision Milling, Laser Cutting, and Wire EDM. Workpal 1 features a maximum payload of 50 Kg (110 lbs.) and has a compact footprint, requiring minimal floor space. It supports flexible magazine configurations and accommodates one tooling system in the magazine. There are 20 different tooling systems that can be prepared in the magazine. The Workpal 1 provides maximum access to the magazine, facilitating the loading and unloading of pallets (7).

END USER

This problem has significant implications for both DRT and its customer base. To address it, implementing a second shift or incorporating robotic assistance could enhance DRT's capacity, leading to increased profits by accommodating a larger workload and the production of new parts. However, failure to resolve this issue could result in DRT struggling to meet delivery deadlines, potentially causing customer dissatisfaction, and driving them to explore alternatives among competitors. Additionally, the introduction of a robot will directly impact the operators. They will need to acquire knowledge of the robot's programming language and understand how the robot integrates with the machinery. The design of fixtures will also play a crucial role in efficiency, minimizing unnecessary setup time.

CONCLUSIONS AND SUMMARY OF RESEARCH

In summary, the research highlights the persistent challenge of finding skilled workers in the manufacturing industry, exacerbated by an impending skills gap. Manufacturers are turning to automation, like robot pallet changers, as a cost-effective solution to the labor shortage issue. These systems offer benefits such as consistent operation, reduced long-term costs, increased output, improved quality, and enhanced safety.

A variety of robot pallet changer solutions are at hand, encompassing the AX-Series Pallet Delivery System, the System 3R Workpal 1, and the Erowa Compact 80, with each being tailored to meet distinct manufacturing requirements. Remarkably, in the course of the research, it was uncovered that DRT has opted for the Erowa Compact 80 as their robot pallet changer. This choice is predicated on their history of integrating the same machine with various units on the production floor.

Addressing this challenge is vital for DRT and its customers, as it can lead to increased profits and customer satisfaction. Operators will need to adapt to the introduction of robots and efficient fixture design to minimize setup time. In conclusion, the integration needs to increase productivity while still keeping precision.

CUSTOMER FEATURES

The customer features are:

- Efficiency
    - DRT wants the robot to be more efficient than the current operator’s system and as efficient as possible.

- Ease of operation
    - DRT wants to be able to have any operator to operate the robot and not spend hours trying to learn how to use it. DRT also wants the installation of the pallets to be as quick as possible.

- Precision
    - DRT must hold plus or minus 0.0002-inch profiles on the Yasda. Therefore, the pallets must be precise to be able to machine good parts.

- Cost effective
    - DRT wants to keep the fixturing and other costs as low as possible, but understands that precision must also be kept.

- Movable Pallets
    - DRT wants the operators to be able to take the pallets from the machine to a quality check station without removing the part to check it.

PRODUCT OBJECTIVES

- Parts Output (Hours of work/Day) (Weight Importance = 11.82%)
    - To measure how efficient the robot is, we will compare the cycle time accomplished in a day compared to the run time the machine was getting without it.

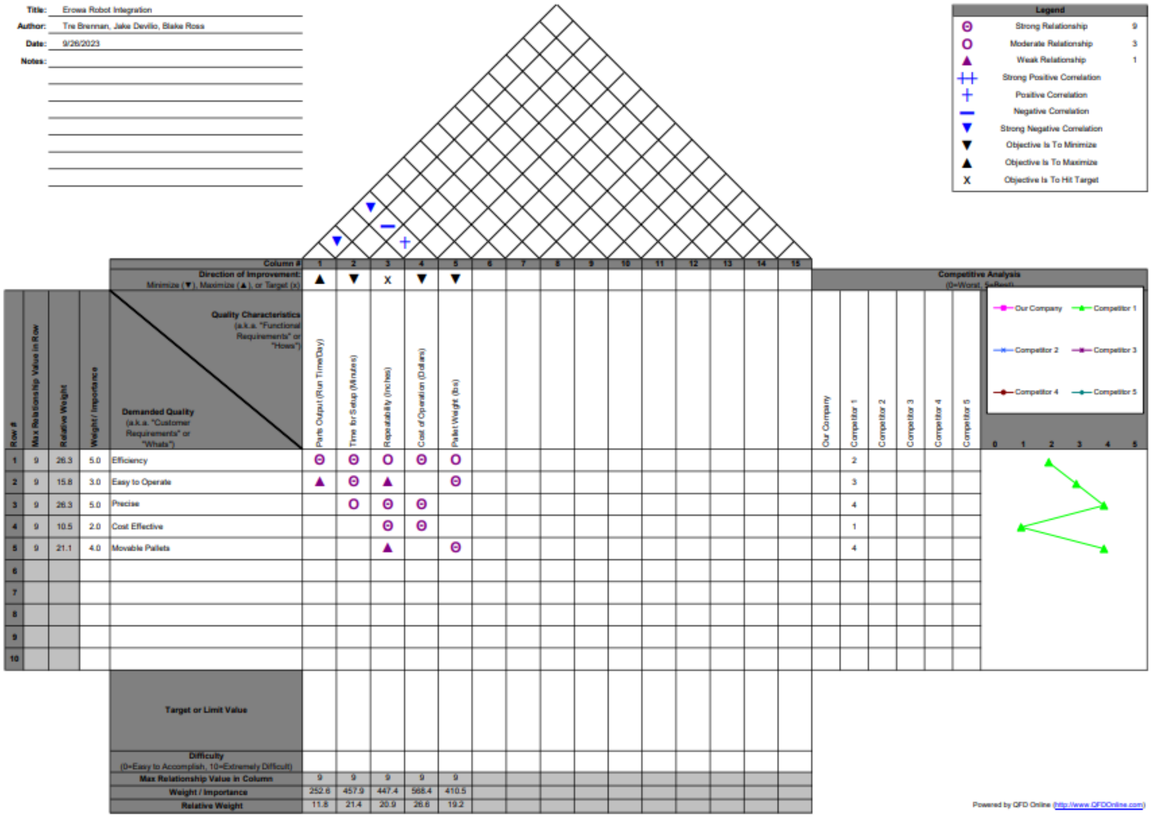
- Time it takes to setup (Minutes) (Weight Importance = 21.42%)
    - To measure how easy it is to run the machine we will be looking at how long it takes the operators to set the pallets and machine up to run parts.

- Repeatability (Inches) (Weight Importance = 20.96%)
    - To measure the precision of the setup a set of test parts will be released to have the machine run back-to-back and then the difference between the test parts is the machines repeatability

- Cost (Dollars) (Weight Importance = 26.59%)
    - To measure the cost effectiveness of adding the robot, we need to calculate the amount of time the robot will save compared to not having the robot. This will serve as a baseline to estimate the reduction in operator costs, thus determining the overall cost effectiveness of incorporating the robot.

- Pallet Weight (lbs.) (Weight Importance = 19.21%)
    - To measure if the pallet is too heavy to be moved to a different station, we must measure the pallets weight with the subplate and average fixture and part weight.

QUALITY FUNCTION DEPLOYMENT



Title: Erowa Robot Integration
Author: Tre Brennan, Jake Devilio, Blake Ross
Date: 9/26/2023
Notes:

Legend		
Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
X	Objective Is To Hit Target	

				Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	▼	x	▼	▼										
Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Parts Output (Run Time/Day)	Time for Setup (Minutes)	Repeatability (Inches)	Cost of Operation (Dollars)	Pallet Weight (lbs)										
1	9	26.3	5.0	Efficiency	Θ	Θ	O	Θ	O										
2	9	15.8	3.0	Easy to Operate	▲	Θ	▲		Θ										
3	9	26.3	5.0	Precise		O	Θ	Θ											
4	9	10.5	2.0	Cost Effective			Θ	Θ											
5	9	21.1	4.0	Movable Pallets			▲		Θ										
6																			
7																			
8																			
9																			
10																			
				Target or Limit Value															
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)															
				Max Relationship Value in Column	9	9	9	9	9										
				Weight / Importance	252.6	457.9	447.4	568.4	410.5										
				Relative Weight	11.8	21.4	20.9	26.6	19.2										

Competitive Analysis
(0=Worst, 5=Best)

Row #	Our Company	Competitor 1	Competitor 2	Competitor 3	Competitor 4	Competitor 5
1		2				
2		3				
3		4				
4		1				
5		4				
6						
7						
8						
9						
10						

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Figure 1: House of Quality

From the house of quality, the key design features are light weight, cost effective, efficient, and very repeatable.

DESIGN

PALLET DESIGN CONCEPTS

Design 1 (Mounting Pattern in Pallet)

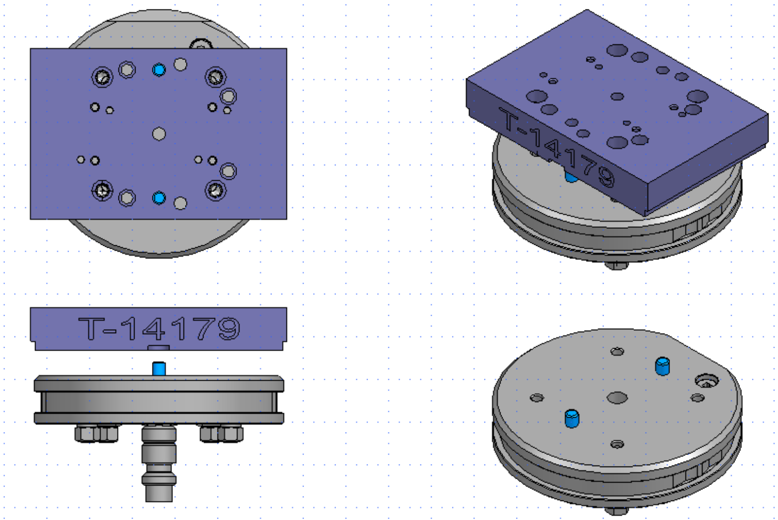


Figure 2: Design 1 Assembly

This design concept illustrates a mounting pattern comprising two dowels for alignment and four threads for securing the fixture to the pallet. Utilizing the pallet would lead to material and time savings in production. The omission of a subplate would additionally reduce the pallet's weight, making it easier to handle.

Design 2 (Mounting Pattern in subplate)

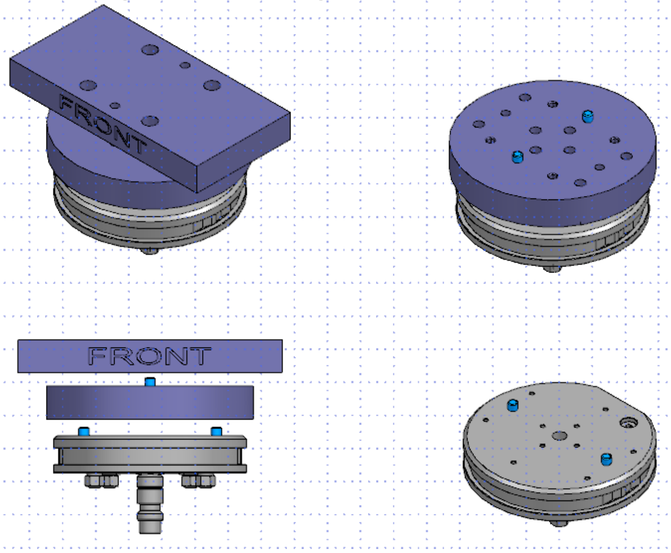


Figure 3: Design 2 Assembly

This design incorporates a subplate with a standard mounting pattern for DRT's fixtures. The mounting pattern comprises four counterbores for bolts and two dowel pins used for alignment, like design 1. On the subplate, there is a pattern for secure attachment to the pallet to prevent any part movement during changes. The subplate provides additional space for accommodating other mounting holes, should fixtures have different mounting patterns.

Design 3 (Subplate with Quick Release Pins)

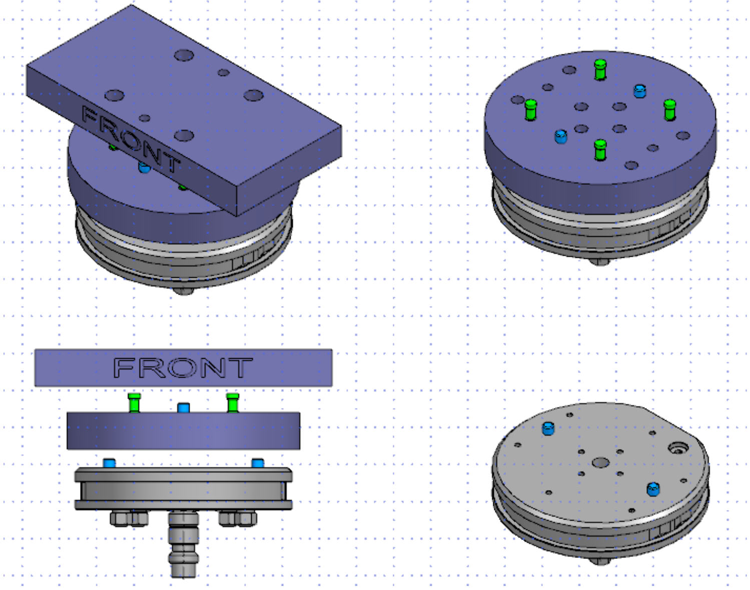


Figure 4: Design 3 Assembly

This design is similar to design two, but it incorporates quick-release pegs (highlighted in green). These quick-release pegs will have a corresponding female counterpart, which will exert pressure on the counterbores of the fixtures to secure them to the subplate. The concept behind this design is to expedite the setup process, as machinists won't need to tighten four bolts. Instead, they can simply push the female coupler onto the peg or make a quarter-turn to release it.

DOWEL PIN DESIGN CONCEPTS

Design 1 (Bullet Nose Pins)

Figure 5: Bullet Nose Pins & Bushing

Pictures are from McMaster-Carr (8)

This design concept illustrates bullet nose pins that would be pressed into the pallet for locating purposes. The matching bushing will be pressed into the fixture. The premise of this concept is to reduce the contact surface and reduce the chance of binding. One issue with this concept is that a bushing is needed in the bottom of the fixture and would have to be pushed in and out before each operation.

Design 2 (Round & Diamond Pins)

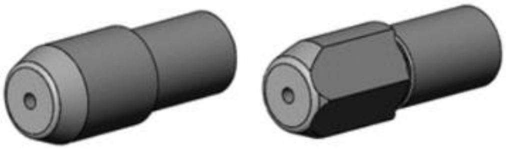


Figure 6: Round & Diamond Pins

Pictures are from McMaster-Carr (8)

This design incorporates a round pin for precise locating of a hole and a diamond pin to locate off another hole but also has relief on the pin to reduce the binding of the fixture to the pallets. This concept has the same premise as the bullet nose pins and should reduce the chance of binding and make the fixture easier to pull off the pallet.

Design 3 (Conical Pins)

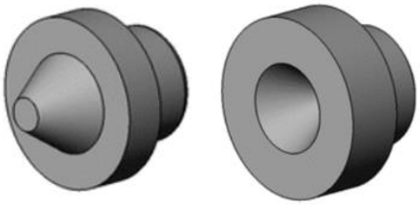


Figure 7: Conical Pin & Receiver

Pictures are from McMaster-Carr (8)

This design consists of using two conical pins for locating purposes. The pin would be pressed into the pallet, and it would have a matching bushing pressed into the fixture. This design should have no binding at all and will allow the operator to separate the pallet from the fixture effortlessly. These pins will have a similar problem as Design one.

DESIGN SELECTION

Pallet Selection				
Criteria	**Weight**	**Design 1**	**Design 2**	**Design 3**
Separation Time	0.1182	3	3	4
Setup Time	0.2142	3	3	3
Repeatability	0.2096	5	3	3
Cost	0.2659	4	3	2
Weight	0.1921	4	3	3
Total	1	3.8772	3	3.1182

Table 1: Pallet Decision Matrix

Dowel Pin Selection				
Criteria	**Weight**	**Design 1**	**Design 2**	**Design 3**
Separation Time	0.1182	2	3	3
Setup Time	0.2142	2	2	2
Repeatability	0.2096	4	3	2
Cost	0.2659	3	4	2
Weight	0.1921	4	4	4
Total	1	3.0693	3.2438	2.5024

Table 2: Dowel Pin Decision Matrix

Based on the information presented in Table 1, design option one emerges as the most favorable choice. This is primarily attributed to the design's efficiency in not requiring a separate plate, resulting in significant cost savings compared to the alternative designs. Additionally, our decision to incorporate round and diamond pins, as determined by the findings in Table 2, contributes to cost-effectiveness. These pins facilitate minimal reworking of existing fixtures on the pallet, further enhancing cost efficiency.

DRAWINGS

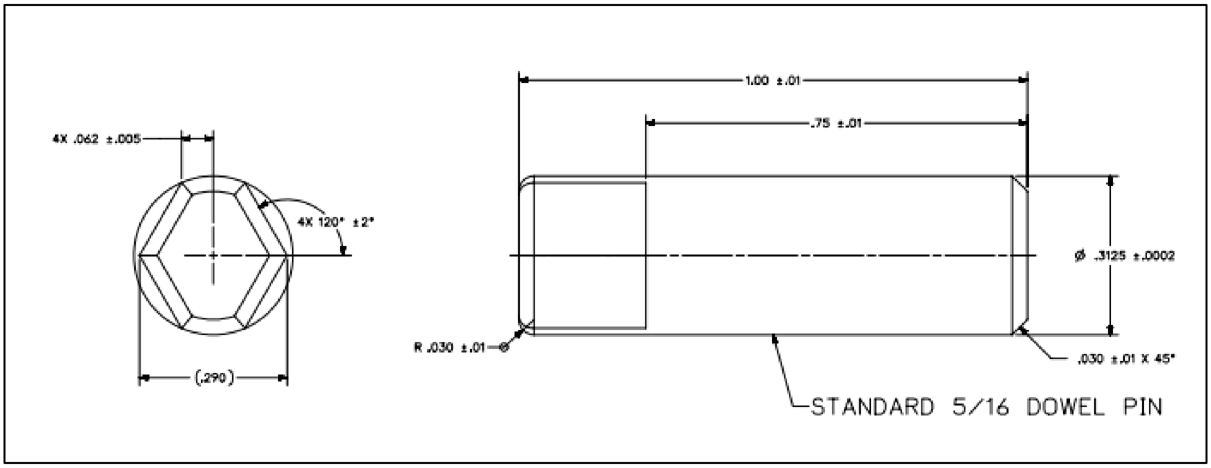


Figure 8: Diamond Pin Drawing

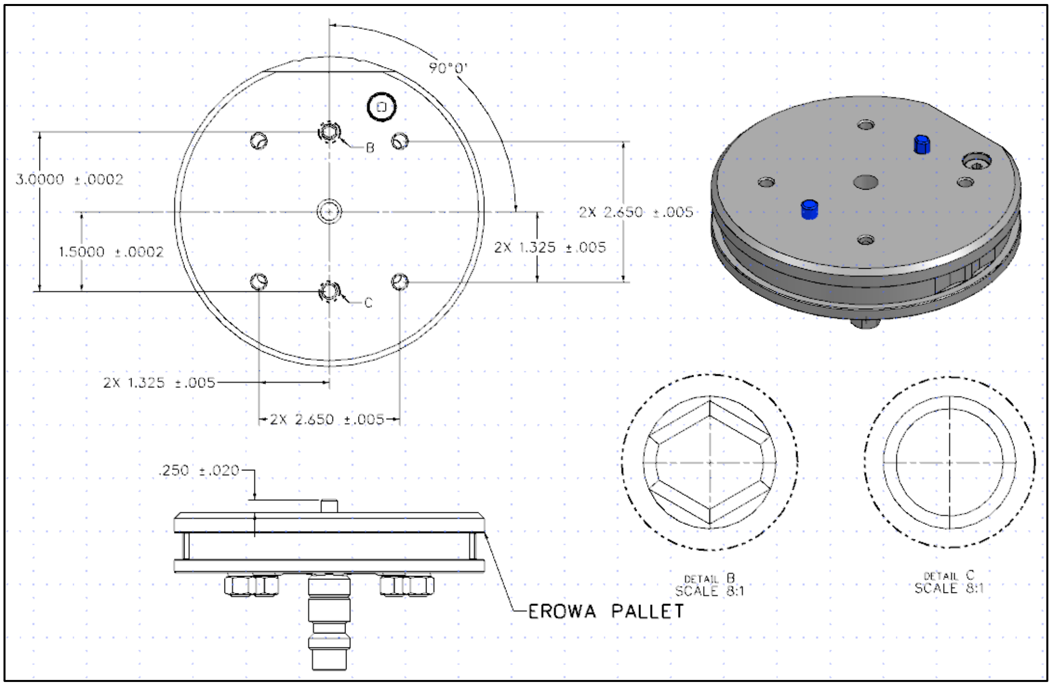


Figure 9: Pallet Assembly Drawing

LOAD CONDITIONS

The pallet and pins will experience loading conditions characterized by cutting forces generated during CNC precision milling. These loading conditions fall under the category of repeated loading. The cutting forces will be influenced by hard materials and carbide end mills. Hard milling involves employing small depths of cut and high tool speeds to achieve precision machining.

DESIGN ANALYSIS

Load Calculations

Cutting Force

Since we do not have the tool geometry information, we are unable to calculate the cutting force using the traditional methods. An alternative approach is to estimate the cutting force by utilizing the ultimate tensile strength of the material being cut along with specific cutting factors. For these calculations, we adhere to DRT standards, which specify a depth and width of cut of five thousandths of an inch. The typical endmill employed is a 0.0196-inch diameter two-flute endmill. The predominant material processed is hardened A2 tool steel.

$$F_c = \sigma * DOC * WOC * E * N_e * Z$$

Equation 1: Cutting Force

Where $F_c, Cutting\ Force, (lbs)$
$\sigma, Ultimate\ Tensile\ Strength\ of\ Material\ being\ cut, (psi)$
$DOC, Depth\ of\ Cut, (in)$

$WOC, Width\ of\ Cut, (in)$
$E, Engagement\ Factor$
$N_e, Engaged\ Teeth$
$Z, Tool\ Wear\ Factor$
$D, Diameter\ of\ Tool$
$N, Number\ of\ tool\ teeth$

$\sigma = 300 * 10^3\ psi$ (From Online Metals and Make It From) (8; 9)

$DOC = WOC = \ 0.005\ in$ (From DRT Milling Standards)

$N = 2\ (From\ DRT\ Standards)$

$$E = \frac{WOC}{D} = \frac{0.005\ in}{0.0196\ in} = 0.2551$$

$$N_e = \frac{N}{2} = \frac{2}{2} = 1$$

$Z = 1.1$ (From Machinery's Handbook, 29th Edition, p. 1,086) (10)

$$F_c = 3 * 10^5 \frac{lbs}{in^2} * 0.005\ in * 0.005\ in * 0.2551 * 1 * 1.1$$

$$F_c = 2.1046\ lbs$$

Shear Force

For these calculations we are assuming that the part and fixture are a rigid body.

Diagram

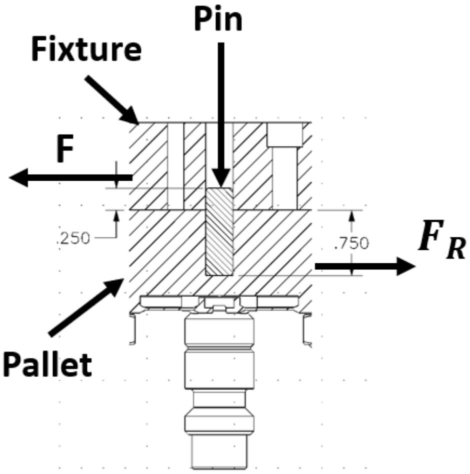


Figure 10: Shear Force Diagram

Calculations

$$\tau = \frac{F}{A_s} = \frac{F}{\frac{\pi D^2}{4}}$$

Equation 2: Shear Stress

Where $\tau = Shear\ Stress, (psi)$
$A_s = Cross\ Sectional\ Area\ of\ Pin, (in^2)$
$D = Diameter\ of\ Pin, (in)$
$F = Force, (lbs)$

$$\tau = \frac{2.1046\ lbs}{\frac{\pi(0.3125\ in)^2}{4}}$$

$$\tau = 27.439\ psi$$

$$\tau = \frac{S_{ys}}{N} \rightarrow S_{ys} = \tau * N$$

Equation 3: Yield Strength

Where $s_{ys} = Yield\ Strength, (psi)$
$N = Design\ Factor$ (Based on Loading Conditions)
$\tau, Shear\ Stress, (psi)$

$N = 8$ (From Repeated Loading Conditions)

$$S_{ys} = \ 27.439\ psi * 8$$

$$S_{ys} = 219.52\ psi$$

Cycle Time

Current Cycle Time	
Task	Duration (Min)
Put Part on Fixture	1
Load Part in Machine	3
Pick Up Origin	20
Load Program	0.5
Set Tools	30
Machine Time	60
Unload Part/Fixture	1
Take part off fixture	6
Total	121.5

Table 3: Current Cycle Time

Cycle Time with Robot (Machine)	
Task	Duration (Min)
Robot Removing Pallet	0.5
Robot Placing Pallet	0.5
Set Tools	5
Pick Up Origin	20
Machine Time	60
Total	86

Table 4: Cycle Time with Robot (Machine)

Cycle Time with Robot (Robot)	
Task	Duration (Min)
Put Part On Fixture	1
Load Fixture on Pallet	3
Load Pallet	0.5
Load Program	1
Load New Tools	5
Unload Pallet	1
Remove Fixture	6
Take part off fixture	1
Total	18.5

Table 5: Cycle Time with Robot (Robot)

Equation

$$Percent\ Change = \frac{New - Old}{Old} * 100$$

$$Percent\ Change = \frac{86 - 121.5}{121.5} * 100$$

$$Percent\ Change = -29\%$$

The addition of forty-four tools enables the robot to significantly reduce tool changeover times for different parts or to repeat runs with the same tool for increased productivity. Incorporating the robot has resulted in a notable 29% reduction in overall run time. The new operation will be more efficiently utilized with continuous machine operation, given the extended machine times required. Much of the setup can be conducted while the machine is running, optimizing productivity. Additionally, the robot can be utilized overnight, leveraging up to twelve hours of machine time depending on the tooling capabilities.

Factor of Safety of Concern

For the factor of safety calculation, we are using the yield strength of the standard pins available at DRT, which is 16,000 psi. Since the cutting force is significantly smaller than the yield strength, the factor of safety is very high. This indicates that the pins will be highly secure and safe during operation.

$$FOS = S_{ys_{Pin}} / S_{ys_{Allowed}}$$

Equation 4: Factor of Safety

Where $FOS = Factor\ of\ Safety$

$S_{ys_{pin}} = Yield\ Strength\ of\ Dowel\ Pin$, (psi)

$S_{ys_{Allowed}} = Calculated\ Yield\ Strength$ (From Equation 3)

$$FOS = \frac{16000\ psi}{219.52\ psi} = 72.886$$

BILL OF MATERIAL

PURCHASED

Item	Cost	Quantity
5/16 Pull Dowel	$2.70 ea.	2
Erowa Pallet	(Supplied by DRT)	2

Table 6: Purchased Items

MANUFACTURED

Item	Cost	Quantity
Diamond Pin	$52 ea.	2

Table 7: Manufactured Items

PROJECT MANAGEMENT

BUDGET

Proposed

Description	Price	
Starting	$ 10,000	
Pin Fabrication	$ 49.65	
Testing	Labor: $ 30	Production Stop: $ 400
Budget Remaining	$ 9,520.35	

Table 8: Proposed Budget

Actual

Description	Price	
Starting	$ 5,000	
Pin Fabrication	$ 49.65	
Testing	Labor: $ 30	Production Stop: $ 0
Rework	$ 150	
Budget Remaining	$ 4,770.35	

Table 9: Actual Budget

Initially, we planned to fabricate test parts, but DRT opted to utilize existing parts from the production floor instead. This decision significantly impacted the budget, prompting DRT to adjust it accordingly. As a result of this change, production continued without interruption, freeing up an additional $400 for fabrication and rework. In the proposed budget, the remainder was allocated for rework, and we successfully stayed within this budget, as illustrated in Table 9.

SCHEDULE

Proposed

Milestone	Start Date	Days Needed	Completion	Actual Completion
Purchase Components	14-Jan-24	1	15-Jan-24	15-Jan-24
Manufacture Parts	15-Jan-24	14	29-Jan-24	28-Jan-24
Testing Current Design	29-Jan-24	7	5-Feb-24	
Assemble Pallets	5-Feb-24	3	8-Feb-24	
Testing Design Part I	8-Feb-24	7	15-Feb-24	
Meeting 1	**13-Feb-24**	**1**	**14-Feb-24**	
Update Design	15-Feb-24	7	22-Feb-24	
Rework or Fabrication	22-Feb-24	7	29-Feb-24	
Testing Part II	29-Feb-24	7	7-Mar-24	
Meeting 2	**5-Mar-24**	**1**	**6-Mar-24**	
General Assistance	7-Mar-24	33	9-Apr-24	
Meeting 3	**26-Mar-24**	**1**	**27-Mar-24**	
Tech Expo	**9-Apr-24**	**1**	**10-Apr-24**	

Table 10: Proposed Schedule

Actual

Milestone	Start Date	Days Needed	Completion	Actual Completion
Purchase Components	14-Jan-24	1	15-Jan-24	15-Jan-24
Manufacture Parts	15-Jan-24	14	29-Jan-24	28-Jan-24
Testing Current Design	14-Feb-24	7	21-Feb-24	16-Feb-24
Assemble Pallets	14-Feb-24	1	15-Feb-24	16-Feb-24
Testing Design	14-Feb-24	7	21-Feb-24	16-Feb-24
Meeting 1	13-Feb-24	1	14-Feb-24	13-Feb-24
Meeting 2	5-Mar-24	1	6-Mar-24	5-Mar-24
Update Design	14-Feb-24	10	24-Feb-24	24-Feb-24
Check Dowel Spread of Pallet	5-Mar-24	3	8-Mar-24	7-Mar-24
Rework of Pallet	8-Mar-24	7	15-Mar-24	15-Mar-24
Fit Testing Part II	15-Mar-24	1	16-Mar-24	29-Mar-24
Repeatability Testing	16-Mar-24	7	23-Mar-24	19-Apr-24
General Assistance	23-Mar-24	17	27-Mar-24	27-Mar-24
Meeting 3	26-Mar-24	1	10-Apr-24	10-Apr-24
Tech Expo	9-Apr-24	1	15-Jan-24	15-Jan-24

Table 11: Actual Schedule

During the testing phase of our project, we encountered both minor and major setbacks. One of the minor setbacks was the spread of the pallet's dowel was off by a thousandth of an inch, necessitating the enlargement of the holes and the creation of a new diamond pin. The major setback occurred when DRT declined to manufacture testing blocks. Consequently, we adapted our approach to use parts already in production on the machine. This adjustment caused a delay of about two weeks as we waited for enough parts for testing purposes.

PLAN TO FINISH

Testing

The plan to measure the repeatability of the pallet involves running parts as they would normally be processed on the machine. Half of the parts will be placed on the pallet with the diamond pin and pull dowel installed, while the other half will be processed using the original configuration. After machining, the profile of the milled pocket will be examined, and the pocket deviation will be recorded for both sets of parts. Using these results, we can calculate the C_{pk} and P_{pk} values to assess the closeness of the two capabilities. The experiment will have nine batches, each comprising six samples, resulting in fifty-four parts on each pallet.

Results

Measured Deviations (Inches)

Normal Pallet (Inches)								
Batch	Sample						Average	Range
	1	2	3	4	5	6		
1	0.00044	0.00061	0.00048	0.00058	0.00045	0.00043	0.00050	0.00018
2	0.00066	0.00066	0.00059	0.00066	0.00065	0.00067	0.00065	0.00008
3	0.00078	0.00057	0.00054	0.00059	0.00075	0.00074	0.00066	0.00024
4	0.00069	0.00050	0.00060	0.00064	0.00061	0.00054	0.00060	0.00019
5	0.00049	0.00052	0.00050	0.00048	0.00054	0.00052	0.00051	0.00006
6	0.00054	0.00045	0.00052	0.00056	0.00050	0.00055	0.00052	0.00011
7	0.00055	0.00034	0.00057	0.00042	0.00054	0.00056	0.00050	0.00023
8	0.00061	0.00074	0.00058	0.00070	0.00076	0.00060	0.00067	0.00018
9	0.00094	0.00070	0.00077	0.00075	0.00069	0.00068	0.00076	0.00026

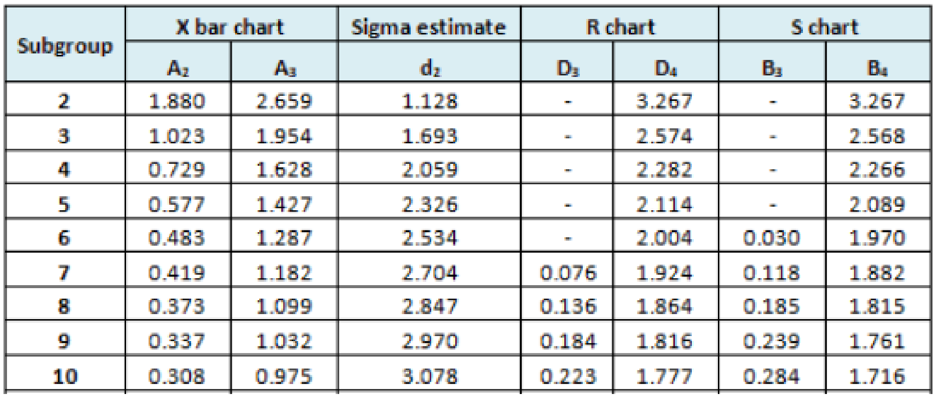
Table 12: Original Pallet Data

Diamond Pallet (Inches)								
Batches	Sample						Average	Range
	1	2	3	4	5	6		
1	0.00044	0.00056	0.00045	0.00032	0.00034	0.00044	0.00043	0.00024
2	0.00038	0.00035	0.00056	0.00036	0.00043	0.00033	0.00040	0.00023
3	0.00058	0.00051	0.00050	0.00051	0.00042	0.00044	0.00049	0.00016
4	0.00065	0.00055	0.00054	0.00057	0.00050	0.00056	0.00056	0.00015
5	0.00038	0.00038	0.00034	0.00055	0.00054	0.00048	0.00045	0.00021
6	0.00051	0.00039	0.00050	0.00049	0.00045	0.00041	0.00046	0.00012
7	0.00084	0.00061	0.00053	0.00066	0.00039	0.00043	0.00058	0.00045
8	0.00064	0.00042	0.00059	0.00068	0.00042	0.00052	0.00055	0.00026
9	0.00068	0.00049	0.00062	0.00068	0.00037	0.00057	0.00057	0.00031

Table 13: Diamond Pin Pallet Data

C_{pk} and P_{pk} Calculations

This control chart will be used in the later equations to determine the control limits. (11)



Subgroup	X bar chart		Sigma estimate	R chart		S chart	
	A_2	A_3	d_2	D_3	D_4	B_3	B_4
2	1.880	2.659	1.128	-	3.267	-	3.267
3	1.023	1.954	1.693	-	2.574	-	2.568
4	0.729	1.628	2.059	-	2.282	-	2.266
5	0.577	1.427	2.326	-	2.114	-	2.089
6	0.483	1.287	2.534	-	2.004	0.030	1.970
7	0.419	1.182	2.704	0.076	1.924	0.118	1.882
8	0.373	1.099	2.847	0.136	1.864	0.185	1.815
9	0.337	1.032	2.970	0.184	1.816	0.239	1.761
10	0.308	0.975	3.078	0.223	1.777	0.284	1.716

Figure 11: R Control Chart

Step 1 Grand Average

This equation calculates the grand average ($\bar{X}$) of the data, representing the overall central tendency. The values used are obtained from Tables 12 and 13 (for variable 1) and Tables 12 and 13 (for variable 2).

$$\bar{\bar{X}} = \frac{\sum \bar{X}_i}{k}$$

Equation 5: Grand Average (X Bar)

Where $\bar{X}_i = Batch\ average$, (From Tables 12 and 13)

$k = 9, number\ of\ batch\ averages$ (From Tables 12 and 13)

Step 2 Average Range

This equation calculates the average range ($\bar{R}$) of the data, representing the typical spread between the highest and lowest values. The values used are obtained from Tables 12 and 13 (for both variables).

$$\bar{R} = \frac{\sum R_i}{k}$$

Equation 6: Average Range

Where $R_i = Batch\ Range$, (From Tables 12 and 13)

$k = 9, Number\ of\ Ranges$ (From Tables 12 and 13)

Step 3 Upper Specification Limit (USL) and Lower Specification Limit (LSL)

These equations define the upper specification limit (USL) and lower specification limit (LSL) for the process, which represent the acceptable range for the final product or service characteristic. The USL is the highest acceptable value, and the LSL is the lowest acceptable value.

Both limits are calculated using the grand average ($\bar{\bar{X}}$) obtained in Equation 5. This factor will determine the allowable deviation from the average that falls within acceptable tolerances. Equation 7 specifically calculates the USL, and Equation 8 specifically calculates the LSL.

$$USL = \bar{\bar{X}} + 0.0002$$

Equation 7: Upper Specification Limit

$$LSL = \bar{\bar{X}} - 0.0002$$

Equation 8: Lower Specification Limit

Where $\bar{\bar{X}} = 0.00059$, (From Equation 5)

Step 4 Estimated Standard Deviation

This equation estimates the standard deviation (σ_{C_p}) of the data based on the average range ($\bar{\mathrm{R}}$) obtained in Equation 6. The specific calculation method should be referenced in the text.

$$\sigma_{C_p} = \frac{\bar{R}}{d_2}$$

Equation 9: Estimated Standard Deviation

Where $\bar{R}$ (From Equation 6)
d_2 (From Figure 11)

Step 5 Population Standard Deviation

This equation calculates the population standard deviation (σ_{P_p}) using the values from Tables 12 and 13 (for both variables) and the grand average ($\bar{\bar{X}}$) obtained in Equation 5. The specific calculation method should be referenced in the text.

$$\sigma_{P_p} = \sqrt{\frac{\sum(x - \bar{X})^2}{n - 1}}$$

Equation 10: Population Standard Deviation

Where $x = sample\ measurement$ (From Tables 12 and 13)

$\bar{X} =$ (From Equation 5)

$n = 54, number\ of\ samples$ (From Tables 12 and 13)

Step 6 Potential Capability

These equations calculate two potential capability indices, $C_p\ and\ C_{pk}$, which assess the inherent variability of the process relative to the specified tolerances. Both rely on Grand Average $(\bar{\bar{X}})$: Obtained from Equation 5, Specification Limits (USL & LSL), and the estimated population standard deviation.

C_p reflects the inherent process variability compared to the specification width (USL - LSL). A higher C_p indicates a process with less inherent variability relative to its tolerances. The specific definition of C_p depends on the calculation method used in Equation 9.

C_{pk} considers both the process center (grand average) and its variability (standard deviation) relative to the specification limits. It provides a more comprehensive picture compared to C_p, especially when the process center is not perfectly aligned with the midpoint of the specification range. A higher C_{pk} indicates a process that is centered within the specification limits and has low variability.

$$C_p = \frac{USL - LSL}{6\sigma_{C_p}}$$

Equation 11: Potential Capability

$$C_{pk} = Min\left(\frac{USL - \bar{\bar{X}}}{3\sigma_{C_p}}, \frac{\bar{\bar{X}} - LSL}{3\sigma_{C_p}}\right)$$

Equation 12: Potential Capability

Where USL (From Equation 7)
LSL (From Equation 8)
σ_{C_p} (From Equation 9)

Step 7 Overall Capabilities

P_p provides a basic measure of capability by calculating the ratio between the width of the specification range (USL - LSL) and six times the population standard deviation ($6\sigma_{P_p}$). A higher P_p value indicates a more capable process, meaning its natural variation is smaller compared to the acceptable tolerance range. P_{pk} offers a more refined assessment by considering the process center (average) in addition to variability.

$$P_p = \frac{USL - LSL}{6\sigma_{P_p}}$$

Equation 13: Overall Capability

$$P_{pk} = Min\left(\frac{USL - \bar{\bar{X}}}{3\sigma_{P_p}}, \frac{\bar{\bar{X}} - LSL}{3\sigma_{P_p}}\right)$$

Equation 14: Overall Capability index

Where USL (From Equation 7)
LSL (From Equation 8)
σ_{P_p} (From Equation 10)

Control Limits

These equations are used to calculate the control limits for statistical control charts. Control charts help us assess whether a process is in control, meaning it's stable and predictable, or if there's evidence of assignable causes of variation.

$$UCL_x = \bar{\bar{X}} + A_2\bar{R}$$

Equation 15: X Bar Chart Upper Control Limit

$$\mathrm{L}CL_x = \bar{\bar{X}} - A_2\bar{R}$$

Equation 16: X Bar Chart Lower Control Limit

$$UCL_R = D_4\bar{R}$$

Equation 17: Range Chart Upper Control Limit

$$\mathrm{L}CL_R = D_3\bar{R}$$

Equation 18: Range Chart Lower Control Limit

Where $\bar{\bar{X}}$ (From Equation 5)
$\bar{R}$ (From Equation 6)
$A_2 = Factor$ (From Figure 11)
$D_4 = Factor$ (From Figure 11)
$A_3 = Factor$ (From Figure 11)

Values

Original Pallet Calculated Values							
$\bar{\bar{X}}$	$\bar{R}$	USL	LSL	UCL_R	LCL_R	STDEV.P	STDEV EST
0.00059	0.00017	0.00079	0.00039	0.000341	0	0.00011	0.00007
Pp	Cp	Ppk	Cpk	UCL_X	LCL_X		
0.60015	0.99373	0.60015	0.99373	0.00068	0.00051		

Table 14: Calculated Values for Original Pallet

Diamond Pin Pallet Calculated Values							
$\bar{\bar{X}}$	$\bar{R}$	USL	LSL	UCL_R	LCL_R	STDEV.P	STDEV EST
0.00050	0.00024	0.00070	0.00047	0.00030	0	0.00011	0.00009
Pp	Cp	Ppk	Cpk	UCL_X	LCL_X		
0.34894	0.71380	0.61052	0.71380	0.00061	0.00038		

Table 15: Calculated Values for Diamond Pin Pallet

Graphs

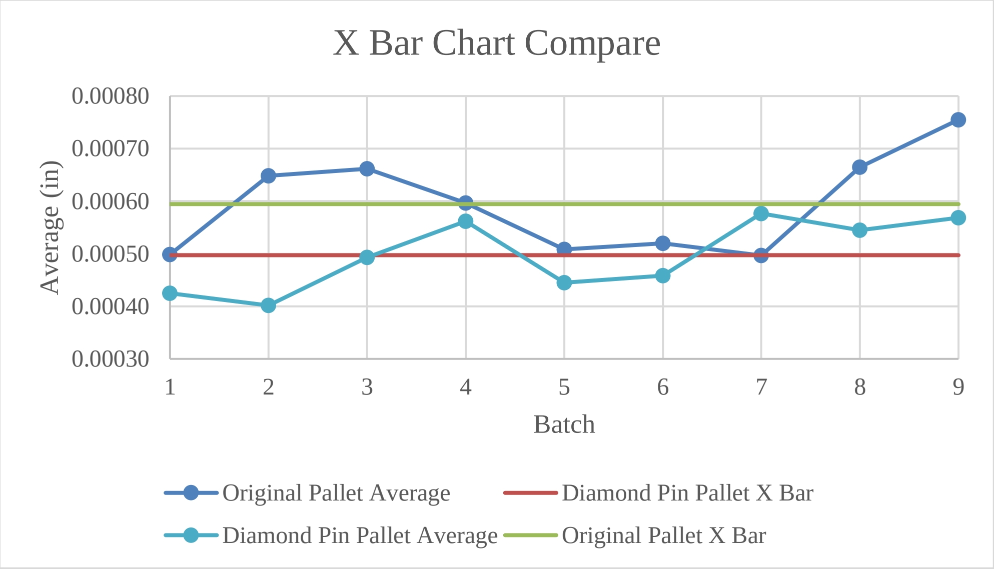


Figure 12: X Bar Chart Compare

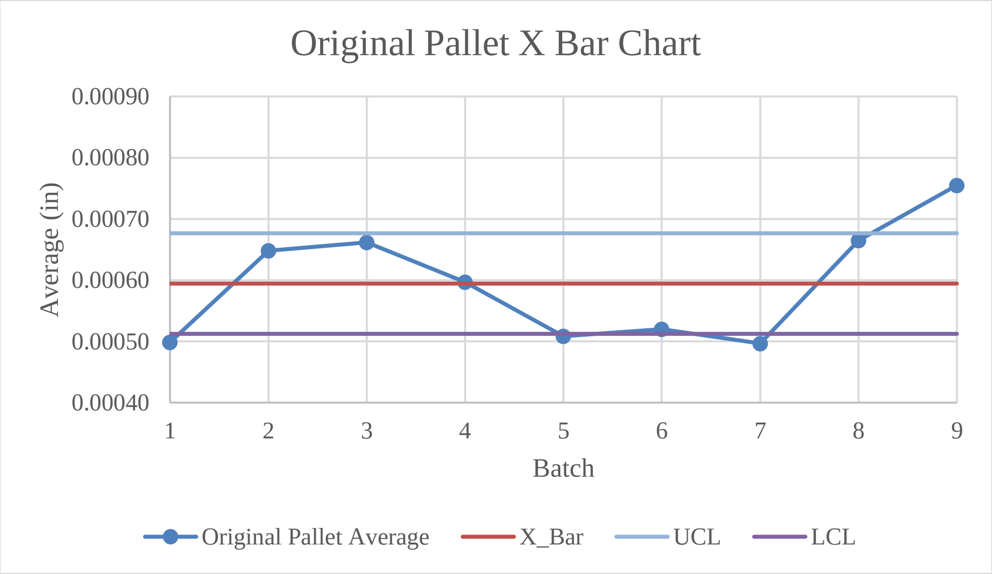


Figure 13: Original Pallet X Bar Chart

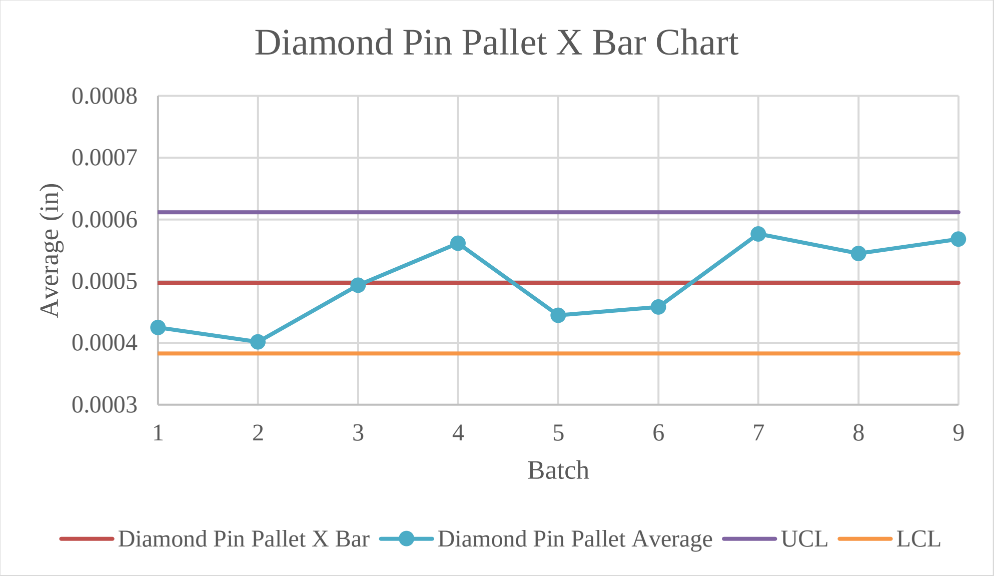


Figure 14: Diamond Pin Pallet X Bar Chart

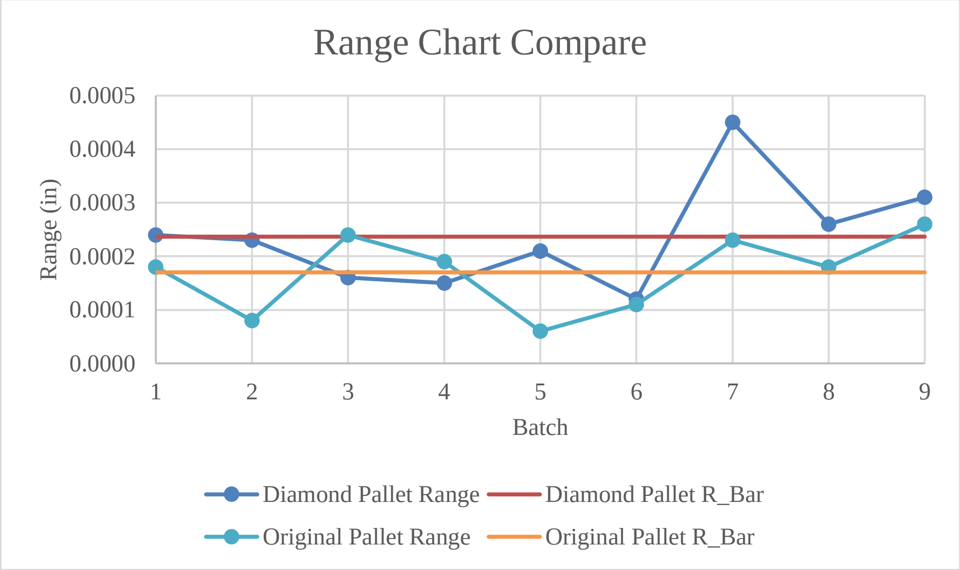


Figure 15: Range Chart Compare

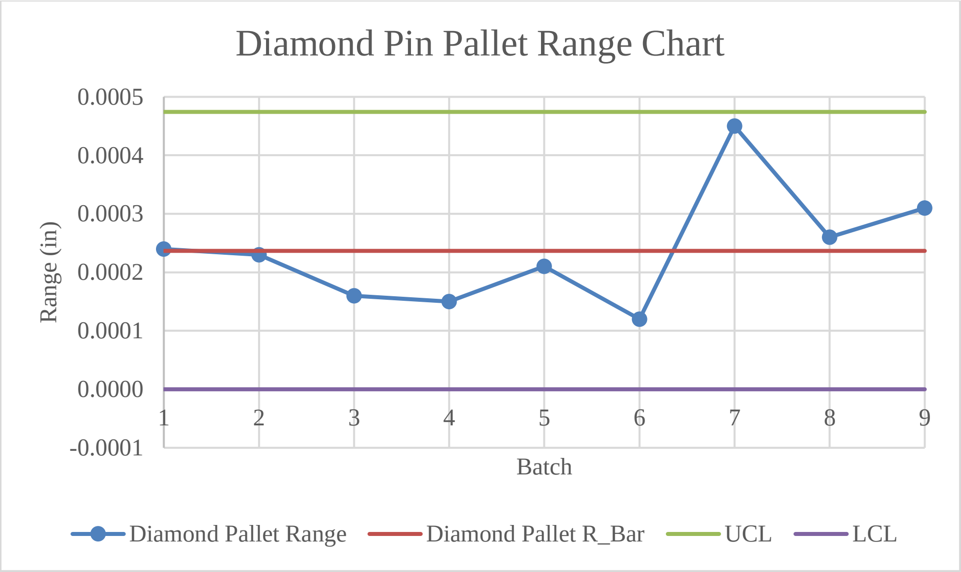


Figure 16: Diamond Pin Pallet Range Chart

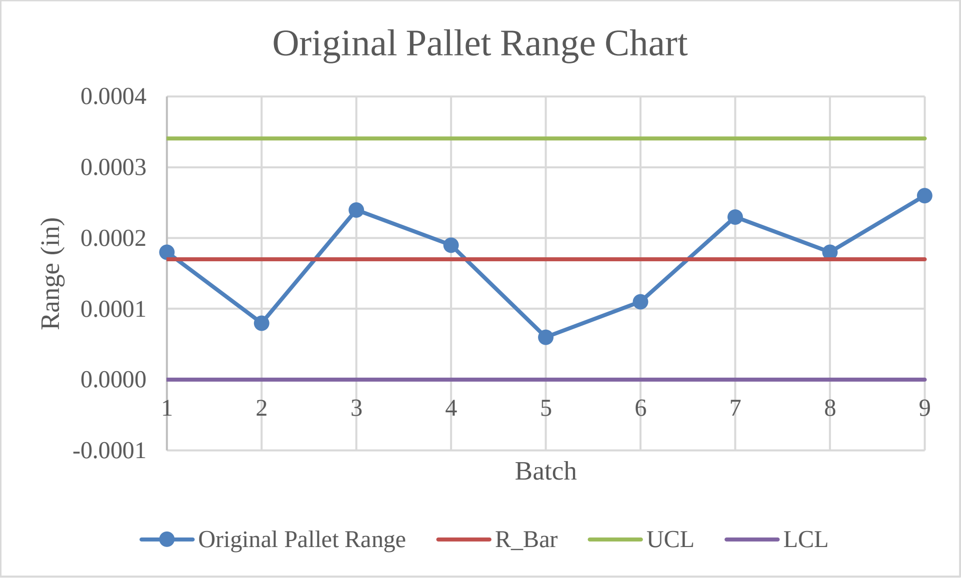


Figure 17: Original Pallet Range Chart

Conclusion

In conclusion, the diamond pin pallet exhibits slightly better overall capability index compared to the standard pin pallet, as indicated by the data in Tables 14 and 15. The grand average of the diamond pin pallet was approximately 0.0001 inches lower than that of the standard pallet, potentially due to slight shifts in the dowel pins within the pallet structure. Figure 13 illustrates that the standard pin pallet shows signs of being out of control and unpredictable, with many points either at or exceeding the control limits. Notably, both the diamond pin pallet and the standard pallet exhibit the same standard deviation, implying consistent variance between samples within a tolerance of 0.0002 inches. However, the C_{pk} value for the standard pallet is higher than that of the diamond pin pallet. This further suggests a reduced capability that is possibly attributed to the small size of the diamond pins allowing for uneven fixture placement. This hypothesis is supported by the fact that the C_{pk} is determined by the average range, and the diamond pin pallet showed a higher average range compared to the standard pallet, especially in the last three ranges which were significantly larger. This discrepancy could be linked to the small size of the diamond pins allowing for excessive clearance, leading to potential misalignment during installation. Overall, the diamond pin pallet performed well, and minor adjustments to the pallet and pin sizes could help eliminate the observed slack in the design. With these adjustments and further testing, the diamond pin pallet should be ready to replace the standard pallets effectively.

SUSTAINABILITY AND MATERIAL USAGE

To enhance the sustainability and efficiency of material usage in the project, several strategic measures can be implemented. First, conducting thorough checks on the pallets' hole spread before manufacturing and installing pins is essential to minimize wasted material and time. This ensures accurate alignment and fit of the components. Another approach is to procure standardized pins from suppliers like McMaster-Carr that match pallet and fixture specifications, buying in larger batches to achieve cost savings and reduce environmental impact. Additionally, manufacturing test blocks to validate part uniformity and operational consistency can enhance sustainability by minimizing material waste. Introducing diamond pins into the project is also key to improving sustainability, as they contribute to longer fixture and pin lifespan by reducing binding between contact surfaces, thus lowering maintenance and replacement requirements. If proven effective, similar principles can be applied across various fixtures at DRT. Replacing traditional round pins with diamond pins to reduce scrap and rework associated with handling, fostering a more sustainable operational approach overall.

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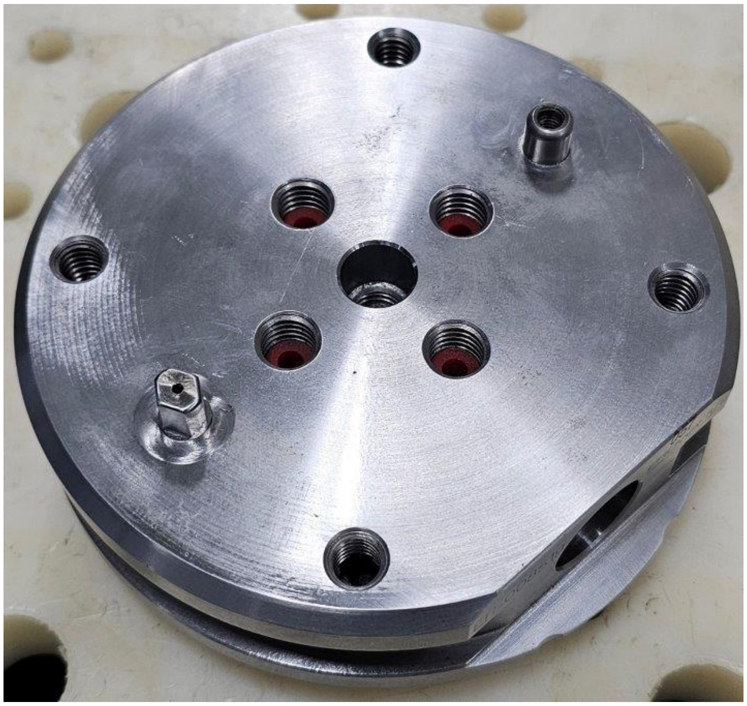
APPENDIX A



This image displays the pallet with the diamond pin and pull dowel pin.

APPENDIX B

This image displays a fixture assembled onto a pallet. The parts would be installed on top of the fixture and then placed into one of the stations in the robot.

APPENDIX C

This image shows off the setup of the robot and the Yasda precision mill. As shown in the image the pallets will be loaded up onto the shelves and when the machine is ready for the next pallet the robot swings over picks up the pallet and loads it into the machine.

APPENDIX D

This is a visual of the other side of the Yasda precision mill and the Erowa Compact 80 Pallet Changer.