Project 2 - Design for Automated Assembly

Due date: May 20th, 2023

Lecturer: Mr. Trung Nguyen

Course: MANU2484 – Design for Assembly and Automation

Tutorial Section Number 1 – Team 9

Team Members: Tran Anh Kiet (s3741189)
Nguyen Hai Anh (s3750778)
Nguyen Tuan Anh (s3740897)

Table of Contents

Table of figures

Executive Summary

The purpose of this project is to propose a plan for STS to automate the Assembly, Insertion, and Retrieval process for the Motor Gearbox Assembly mentioned in Project #1 such as a new automated assembly line. In case the previous design is not suitable, we must design the whole fixture which follows the DFA guidelines for automated assembly.

Before evaluating to automate the assembly line, the features of the original are shown with some errors as bellow:

- Inefficient assembly approach:
- Step 5 needs more holding down.
- Step 6 requires more time for the insertion.
- Parts redundancy: there are many parts that can be eliminated or unnecessary for our new design such as the Strap, Screws, and Gears that can’t be removed or reduced in quantity.

Based on the current design for manual assembly, we will propose an automated assembly that can be improved according to it:

- The number of parts must be minimized or reduced.
- The Cover side now is added with snap fit to attach with the other side without a strap or screws.
- The number of screws is reduced from 5 to 3
- The parts should have a chamfer to easily align and reduce the insertion time.
- The cost and time consuming with time cycle during operation must be reduced.

Also, our new design has some major issues such as:
Some features have thickness smaller than 1.5mm.
We have to redesign the central shaft with the rest of gears because it didn’t fit with each other.

However, the design is changed a little bit due to our divided work such as Tuan Anh worked on redesigning the whole fixture, whereas Kiet works on calculation of the assembly line with Hai Anh figuring out which design of our assembly line might work for our design.
As a result, the performance of the automated assembly line has some expected criteria as below:

- Automated assembly ensures safety and more efficiency from robots than humans.
- The working space between humans and robots is not intertwined with each other.
- The cost is now higher but for line efficiency, which is better due to better orienting efficiency, cost factor.
- The cycle time of the entire automated assembly is 0.67 min with line balancing efficiency of 90.5.

Section I - Design problem and objectives

a) Background

The manager of See These Solutions (STS) was previously pleased with the consultant team's concept when they suggested a new design for the DVD fixture since it improved manual assembly (the handling and insertion procedure). But after attending an Industries 4.0 conference, a few board members were inspired to "modernize" their manufacturing line by making it more automated. Therefore, as the consultant team, we are required to suggest a new, automated assembly line design that will reduce the involvement of people in the production line as much as possible.

b) Establish

- **Automated Assembly cycle time.**

The transfer time: $T_r = 12s$
The maximum service time : $Max\{T_{si}\} = 28.1\ s$
Hence, **the cycle time** for the automated assembly line

$$T_c = T_r + Max\{T_{si}\} = 28.1 + 12 = 40.1s = 0.67\ \min s$$

- **Part Feeding rate & Jamming probability.**

With $q_i = 1\%, m_i = 50\%, T_d = 2\ minutes.$
Then, the yield of good assemblies:

$$P_{ap} = \prod_{i=1}^{n}(1 - q_i + m_i q_i) \text{ where n is number of station}$$

$\Rightarrow P_{ap} = (1 - 0.01 + 0.5 \times 0.01)^7 = 96.55\%.$
The jamming probability of assemblies: $P_{qp} = 1 - P_{ap} = 3.45\%$

- **Assembly line characteristics**

Adopting a conveyor assembly system that can benefit from the combination of a rotary and straight-flow driven rotary assembly system in the line must be preferred in this project. The rationale is simple: this sort of assembly line can provide continuous, synchronous, and asynchronous transmission mechanisms to transfer the carrier around the conveyor belt. Furthermore, conveyor assembly systems with basic parts designs, such as the motor gear, are appropriate for high production. Furthermore, the automation manufacturing line is projected to contain seven stations, each having at least six robotic arm stations for handling and insertion. Furthermore, one person is involved in the last stage of product assembly, which is also the most difficult part to build and cannot be done by robots. Furthermore, this person can determine whether or not the product is experiencing an automatic error.

- **Material Transport time & equipment**

After meeting and talking for an extended period of time with the goal of reducing system cycle time by ensuring that transit time is approximately 10% of the bottleneck station's cycle time. As a result, all of the system's transport components, including the Automated Guided Vehicle and the Conveyor, must be managed by an automated system.

An automated system must handle assembly and recall. The system should be primarily managed by a computer running specialized software or by the system's own controller (including the choice to run/stop the conveyor, turn on/off the PVD chamber, and order the operator). To make this judgment, sensors must be present to determine the current state of the system. The system must also be able to connect to a local or worldwide network in order to provide remote access.

The operator's working range should not overlap for safety reasons; manual workers must also be able to do their tasks without entering the operator's working range. Autonomous guided vehicles, like humans, require a safety function to avoid collisions with unexpected objects. This helps to avoid unnecessary damage, which equals lower maintenance expenses in the long run.

Section II - Proposal of the new Assembly Design

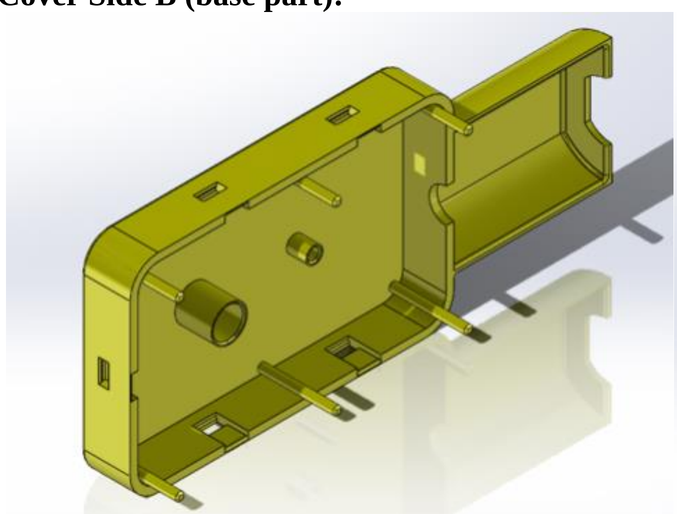
a) Analysis of the previous design of Motor Gearbox Assembly

For the Motor Gearbox Assembly design that we came up in Project #1, it has 7 parts in total include of Motor, Pinion, Small Shaft, Center Shaft, Gear #1, Cover Side A and B. Feed Code and Insertion Code of them are as follows:

	Cover Side A	Cover Side B	Small Shaft	Center Shaft	Gear #1	Motor	Pinion
D (mm)			1.88	33	24		4.55
L (mm)			18.65	36.8	8.27		6.4
L/D			9.92	1.12	0.34		1.41
A (mm)	86	86				36.7	
B (mm)	37	37				20	
C (mm)	17.08	14.7				15	
A/B	2.32	2.32				1.84	
A/C	5.04	5.85				2.45	
Feeding Code	None	None	220	120	0-50	841	150
Insertion Code	31	None	31	30	31	30	31
Orienting Efficiency (E)	None	None	0.75	0.3	0.5	0.14	0.2
Feeding Cost factor (Cr)	None	None	1	1.2	1	1	1
Insertion Cost Factor (Wr)	1.9	None	1.9	1.2	1.9	1.2	1.9

Figure 1: Dimension, Feed Code and Insertion Code of parts.

- **Cover Side B (base part):**



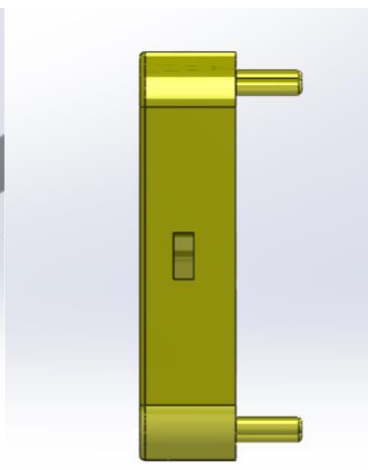


Figure 2: Cover Side B's design of project 1.

Figure 2 shows that Cover Side B doesn't have a cylinder or regular prism and beta and alpha angle equal 360, this led to its orientation does not repeat when rotated about its beta axis through angles of 120° or 90°. Thus, part having no rotational symmetry. The part has the dimensions A = 86 mm, B = 37 mm, and C = 14.7 mm. Then, A/B = 2.32 and A/C = 5.85. Referring to First digit of geometrical classification of parts for automatic handling table, since A/B is less than 3 and A/C is greater than 4, the part is categorized as flat nonrotational. The first digit is 6.

By looking at the silhouette of the part in the X direction (right image of figure 2), part has no symmetry, and the orientation is defined by two main features: chamfer and through groove. Hence, the second digit is 6. Because the orientation is defined by more than two main features and includes slight asymmetry. Hence, manual handling is required. Because the part has small features which are rods (D =1.7mm). Thus, manual handling is required. Based on the automatic handling-data for rotational parts table, we can conclude that **this part requires manual assembly process.**

- **Small Shaft**

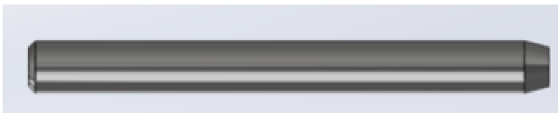


Figure 3: Small Shaft's design of project 1

Figure 3 shows that the Small Shaft has cylindrical shape, so part has rotational symmetry. The part has the dimensions L = 18.65 mm, D = 14.7 mm, then L/D = 9.92. So, the first digit is 2. With beta angle is 0º and alpha angle is 360º, part is beta symmetric. There are chamfers on two end surfaces, the second digit is 2. As this shaft is symmetrical about its beta axis, the third digit is 0. Based on the automatic handling-data for rotational parts table, **the feeding code of this part is 220**, resulting in an orienting efficiency of 75% and a base feeding cost factor of 1.

In term of insertion operation, the small shaft is secured immediately due to hole on Cover Side B and has straight-line insertion from vertically above, so table 2 and row 3 are chosen. The process doesn't need screwing operation or plastic deformation and it's not easy to align because of small dimension, column 1 is selected. According to the Automatic Insertion – Relative Workhead Cost table, **the insertion code of this part is 31**, resulting in a relative workhead cost of 1.9.

- **Gear #1**

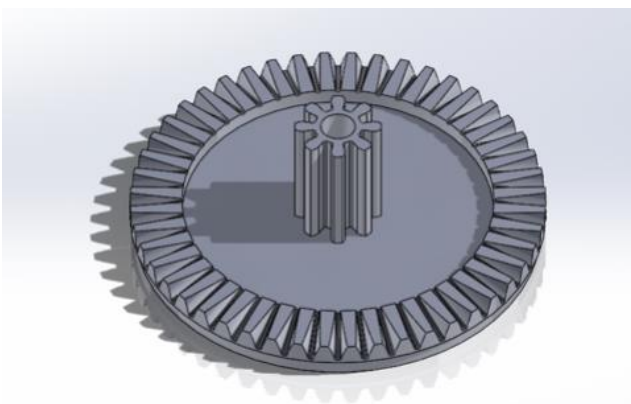


Figure 4: Gear #1's design of project 1.

Figure 4 shows that Gear #1 has cylindrical shape, so part has rotational symmetry. The part has the dimensions L = 8.27 mm, D = 24 mm, then L/D = 0.34. So, **the first digit is 0**. With beta angle is 45^o and alpha angle is 360^o, this part is beta symmetric because beta angle is less than 180 degrees. There is a grove hole on the end surfaces, **the second digit is 5**. Since, part is symmetrical about its beta axis, **the third digit is 0**. Based on the automatic handling-data for rotational parts table, **the feeding code of this part is 050**, resulting in an orienting efficiency of 50% and a base feeding cost factor of 1.

In term of insertion operation, the gear is secured immediately thanks to the Small Shaft and has straight-line insertion from vertically above, so table 2 and row 3 are chosen. The process doesn't need screwing operation or plastic deformation after insertion and it's not easy to align because of small hole inside, column 1 is selected. According to the Automatic Insertion – Relative Workhead Cost table, the insertion code of this part is 31, resulting in a relative workhead cost of 1.9.

- **Pinion:**

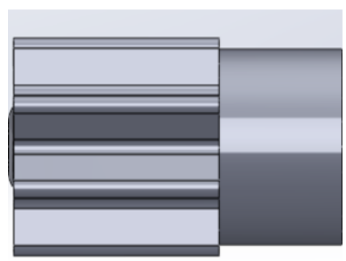


Figure 5: Pinion's design of project 1.

Figure 5 shows that Pinion has cylindrical shape, so part has rotational symmetry. The part has the dimensions L = 6.4 mm, D = 4.55 mm, then L/D = 1.41. So, **the first digit is 1**. With beta angle is 0^o and alpha angle is 360^o, this part is beta symmetric. There is a grove hole on the end surfaces, **the second digit is 5**. Since, part is symmetrical about its beta axis, **the third digit is 0**. Based on the automatic handling-data for rotational parts table, **the feeding code of this part is 150**, resulting in an orienting efficiency of 20% and a base feeding cost factor of 1.

The Pinion is secured immediately after the insertion process and has straight-line insertion from vertically above, so table 2 and row 3 are chosen. doesn't need screwing operation or plastic deformation after insertion and it's not easy to align, column 1 is selected. According to Automatic Insertion – Relative Workhead Cost table, the insertion code of this part is 31, resulting in a relative workhead cost of 1.9.

- **Motor:**

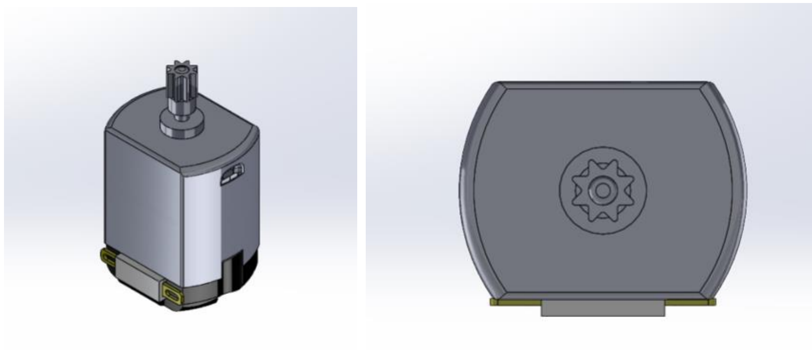


Figure 6: DC motor's design of project 1.

Figure 6 shows that Motor doesn't have a cylinder or regular prism and beta and alpha angle equal 360, this led to its orientation doesn't repeat when rotated about its beta axis through angles of 120° or 90°. Thus, part having no rotational symmetry. The part has the dimensions A = 36.7 mm, B = 20 mm, and C = 15 mm. Then, A/B = 1.84 and A/C = 2.45. Referring to First digit of geometrical classification of parts for automatic handling, since A/B is less than 3 and A/C is less than 4, the part is categorized as cubic nonrotational. **The first digit is 8.**

Looking at the silhouette of the part in the X direction (right image of Figure 6), we see a step below the rectangular shape, and we realize that this feature alone can always be used to determine the part's orientation. This means that if the silhouette in the X direction is oriented as shown in Figure 6, the part can be in only one orientation and, therefore, **the second digit of the classification is 4**. There is the step seen in the Y-direction. Thus, the appropriate **third digit is 1**. Based on the automatic handling-data for rotational parts table, the feeding code of this part is **841**, resulting in an orienting efficiency of 14% and a base feeding cost factor of 1.

In term of insertion operation, the Motor is secured immediately thanks to slot in Cover Side B and has straight-line insertion from vertically above, so table 2 and row 3 are chosen. The process doesn't need screwing operation or plastic deformation after insertion and it's easy to align, column 0 is selected. According to the Automatic Insertion – Relative Workhead Cost table, the insertion code of this part is 30, resulting in a relative workhead cost of 1.2.

- **Center Shaft:**

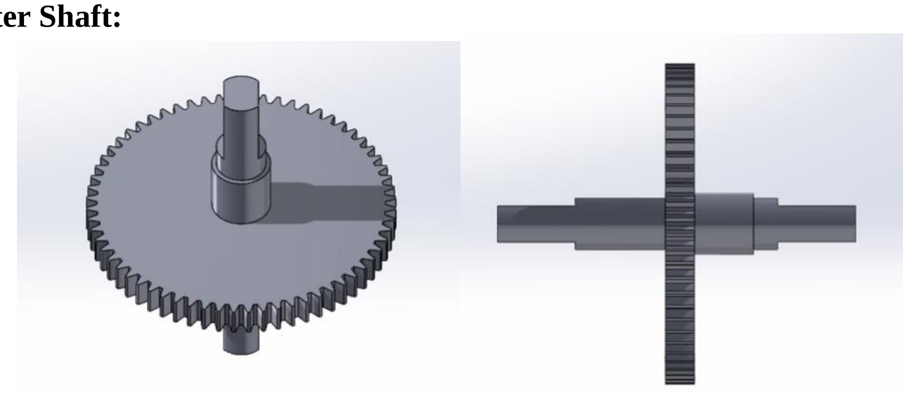


Figure 7: Center Shaft's design of project 1.

Figure 7 shows that the Center Shaft has cylindrical shape, so this part has rotational symmetry. Its dimensions are L = 36.8 mm, D = 33 mm, then L/D = 1.12. So, the first digit is 1. With beta angle equal 360°/64 tooth = 5.625° and alpha angle is 360°, this part is beta symmetric because beta angle is less than 180 degrees. There are steps on external surfaces which create a concentric reduction or increase in diameter, the second digit is 2. Since, part is symmetrical about its beta axis, the third digit is 0. Based on the automatic handling-data for rotational parts table, **the feeding code of this part is 120**, resulting in an orienting efficiency of 30% and a base feeding cost factor of 1.2

In term of insertion operation, the shaft is secured immediately after the insertion process due to hole in Cover Side B and has straight-line insertion from vertically above, so table 2 and row 3 are chosen. The process doesn't need screwing operation or plastic deformation after insertion and it's easy to align, column 0 is selected. According to the Automatic Insertion – Relative Workhead Cost table, the insertion code of this part is 30, resulting in a relative workhead cost of 1.2.

- **Cover side A**

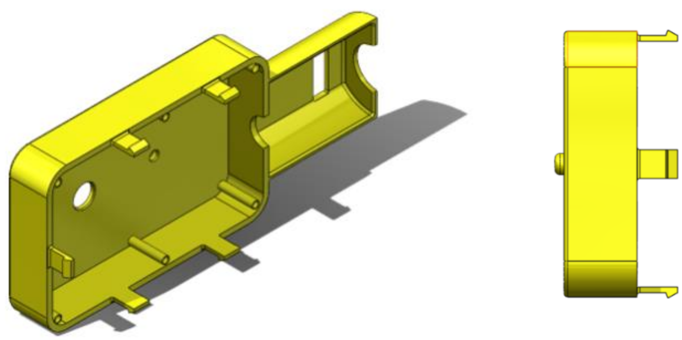


Figure 8: Cover Side A's design of project 1.

Figure 8 shows that Cover Side A doesn't have a cylinder or regular prism and beta and alpha angle equal 360, this led to its orientation does not repeat when rotated about its beta axis through angles of 120° or 90°. Thus, part having no rotational symmetry. The part has the dimensions A = 86 mm, B = 37 mm, and C = 17.08 mm. Then, A/B = 2.32 and A/C = 5.04. Referring to First digit of geometrical classification of parts for automatic handling table, since A/B is less than 3 and A/C is greater than 4, the part is categorized as flat nonrotational. Thus, the first digit is 6.

By looking at the silhouette of the part in the X direction (right image of figure 8), part has no symmetry and the orientation is defined by more than two main features and including slight asymmetry. Hence, manual handling is required. Because the part has small features which is holes (D =1.5mm). Thus, manual handling is required. Based on the automatic handling-data for rotational parts table, we can conclude that **this part requires manual assembly process.**

In term of insertion operation, the Cover Side A is secured immediately thanks to snap-fit mechanism and has straight-line insertion from vertically above, so table 2 and row 3 are chosen. The process doesn't need screwing operation or plastic deformation after insertion and it's not easy to align, column 1 is selected. According to the Automatic Insertion – Relative Workhead Cost table, the **insertion code of this part is 31**, resulting in a relative **workhead cost of 1.9**.

b) Explain the implications of the Codes.

By minimizing automated assembly time, the Feed and Insertion Codes aim to reduce the cost of feeding, orienting, and inserting each piece in an assembly. According to the Feed Code, part geometry is an important factor in decreasing time and costs. Because the majority of the pieces in this project's design are cylindrical, the orienting efficiency of each part... Besides that, the lowest cost base factor is 1, implying that the feeding cost can at least be constant with respect to the base cost.

The part design must be alpha and beta symmetric at the same time to obtain a orienting efficiency of 50% and a base cost factor of 1. Only the central and minor axes in this project meet these requirements, whereas the others are either alpha symmetric or beta asymmetric.

In order to lower the relative work head cost factor, the insertion method for putting different components together should also be chosen based on the Insertion Code. To prevent increasing the baseline insertion cost owing to varying equipment complexity, insert the line vertically from the top. Furthermore, no final fastening is required to hold part position and orientation without gripping, reducing insertion effort as well as time and money. Last but not least, this part should be designed to be easy to align and install without the need for insertion. As a result, the minimal insertion cost factor will be 1, while the base insertion cost will remain unchanged. However, in the case of high-speed automatic assembly, the pieces must be fastened immediately to avoid slippage throughout the operation.

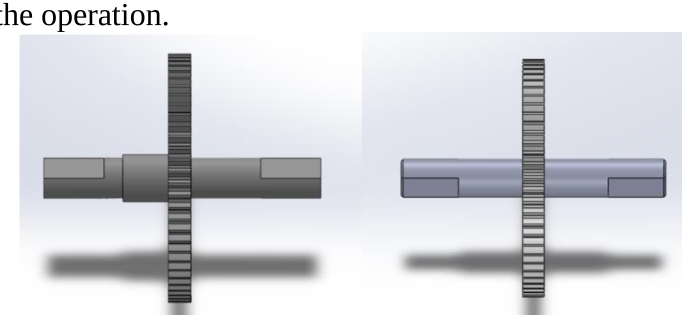


Figure 9: Center Gear Shaft from Project #1(left) and Project #2(right).

The first modification concerns the central gear shaft. The gear position is specifically relocated to the shaft's center. Furthermore, the two sides of the shaft are exchanged for the same. Finally, the shaft's two ends are chamfered to facilitate automatic installation. All the aforementioned adjustments boost orienting efficiency from 30% to 50%.

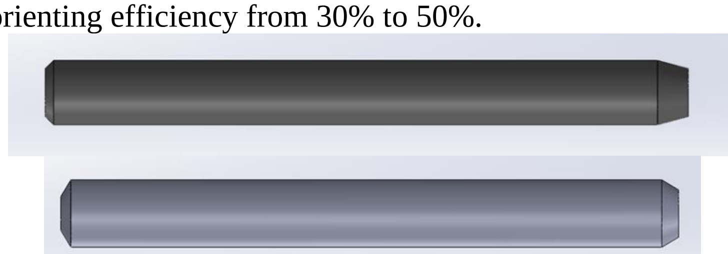


Figure 10: Small Shaft from Project #1(above) and Project #2(below).

The length of the small shaft has been expanded from 18.65mm to 19.65mm, and the diameter has also been increased by 2mm, a 0.12mm increase over before. Furthermore, the two ends of the shaft are chamfered the same to increase orienting efficiency from 50% to 75% rather than each end of the same kind as before.

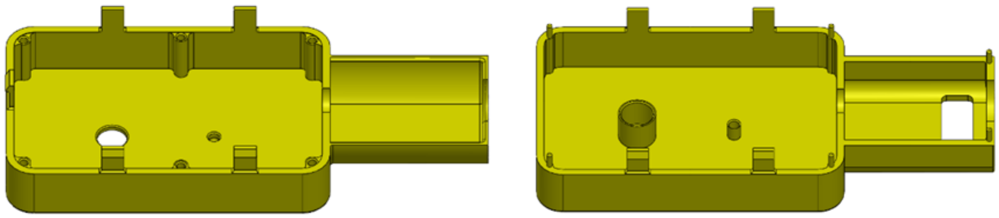


Figure 11: Cover size A from Project #1(left) and Project #2(right).

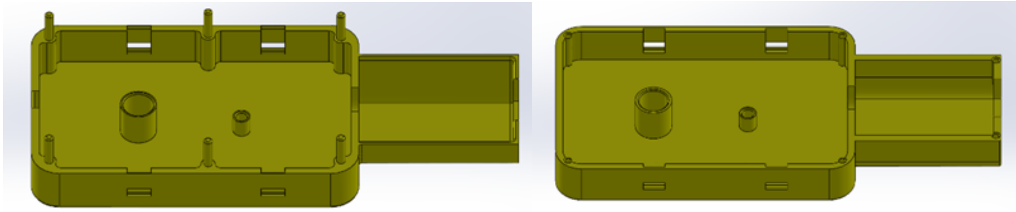


Figure 12: Cover size B (base part) from Project #1(left) and Project #2(right).

The final alteration will be in the size of the two covers, which will be slightly adjusted to better suit the project's needs in terms of thickness of each part and tolerance, but not too much, detailed specifics on parameters. will be demonstrated by the design drawing below the appendix. The six pillars on the cover's wall will then be eliminated, leaving only the snap fit; the size of the snap fit will also be altered somewhat to make it operate better. This section's parameters will be left in the support calculation in the appendix section. The final feature to be adjusted is the location of the motor; the size and form will be altered somewhat because certain mistakes happened in project #1 after a test 3D printing. There was no place to wire the motor portion in the cover size A. Another error is that the space in this location is too wide, causing the motor to be unstable when inserted, resulting in unstable functioning.

Section III - Proposal of New Automated Assembly Line

a) Line Layout

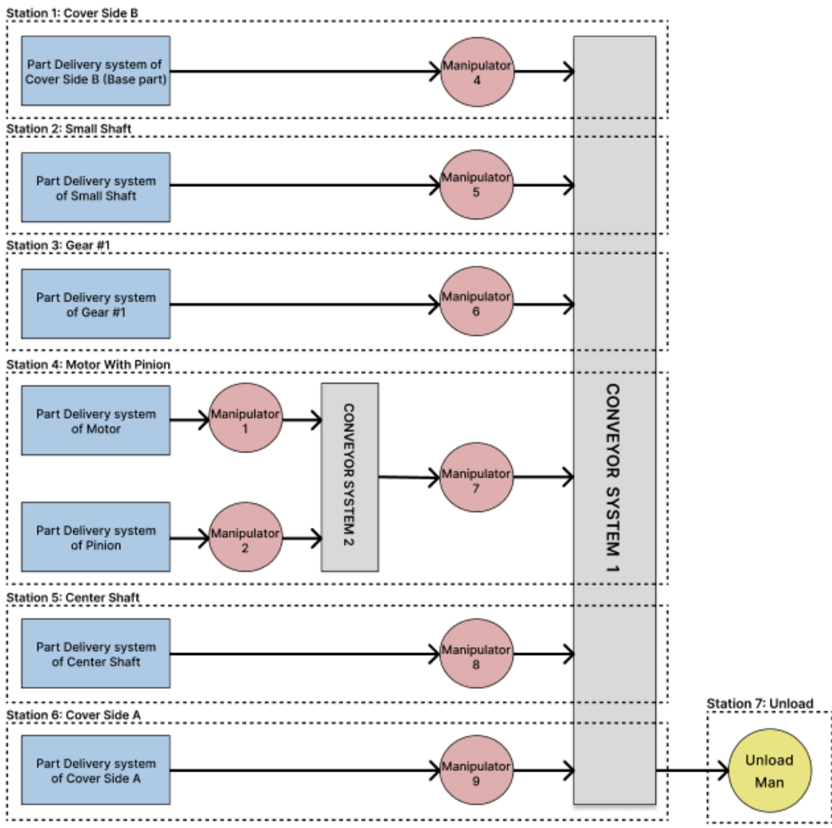


Figure 13: The general layout of the automated Motor Gearbox Assembly line.

<u>Assembly Line Overview:</u>

As seen in the figure above, the automated assembly line to assemble the Motor Gearbox Assembly will be divided into 7 stations. The first station is used to reorient and transfer the Cover Side B to the assembly line. Station 2, 3, 5, 6 is to reorient, transfer Small Shaft, Gear #1, Center Shaft and Cover Side A to Conveyer System 1 and insert the Base part. The fourth station is used to reorient Motor, Pinion and transfer to the assembly line. The last station is to retrieve the completed unit from the line.

Note that a group of Hopper, Parts feeder, Orientor, Feed track, sensors will be a Part Delivery system. And all parts in the Motor Gearbox Assembly have their own Part Delivery system. The detailed operation of the assembly line is that initially, at station 1, a Hopper acts as a container into which the Cover Sides B (base part) are laded at the workstation. Then the Parts feeder will move the Cover Side B from the Hopper one at a time for delivery to the assembly work head. Next, an Orientor will allow properly oriented parts to pass through and reorient parts that are not properly oriented. To force the part to travel toward the assembly work head, we use a Powered feed track. Moreover, near the top and end of the feed track, there is a high-level sensor and a low-level sensor which are used to detect the condition of the Feed track. Then Cover Side B will be placed on the conveyer.

All stations except station 7 and 4 will have the same structure and function as station 1. In these stations, after parts are transferred to the end of their feed track, A Manipulator will pick and attach it to Cover Side B. At station 4, there are sub-workstations at this stage that are utilized to attach Pinion to DC motor. And Manipulator 7 will put Motor with Pinion into Cover Sides B. After the Motor Gearbox Assembly is completely assembled, it will go to the final station – station 7. In this station, a human operator sits at the end of the Conveyer System 1 to unload the completed unit from the assembly line. The Cover Sides B are transferred around stations thanks to a single direction conveyor in–line assembly system – Conveyer System 1 and the motor are transferred around station 4 thanks to a single direction conveyor in–line assembly system – Conveyer System 2.

Table 4 in appendix provides a summary of the purpose, work elements, time of work elements of each workstation. There is no need to stop the conveyer systems when manipulators are inserting parts into the base part.

<u>Work elements time:</u>

Time for the worker to retrieve a completed unit:

It takes 5 minutes to package 25 units $= 5/25 = 0.2min/unit = 12s/unit$. So, the time is 12s.

Transfer time on conveyer between stations:

With the time between units is 12s, so 12s is the time for base part move to from station to the next station**.** And 12s * 6 = 72s is the time for the Base part go to all station and move the completed Motor Gearbox Assembly to Station 3.

Time of the Part Delivery system:

We have the feed rate of the Hopper is 90 parts per minute or 5400 parts per hour, so the cycle time $T_c = 60/5400 = 0.011\text{minutes} = 0.66\text{s}$.

The feed track is designed to hold 20 parts, length of each unit = 86 mm =0.086m, so the minimum length from hopper to end of feed track = 20 * 0.086 = 1.72m. With speed of 0.5 m/s

- ⇨ Transfer time t = 1.72/0.5 = **3.44s**

So, transfer time in the Part Delivery system is 3.44 + 0.66s = **4.1s**.

The service time of the robot

We have the working range of the robot D_{robot} is 1.125m, then the distance from robot to workstations is 0.5m.

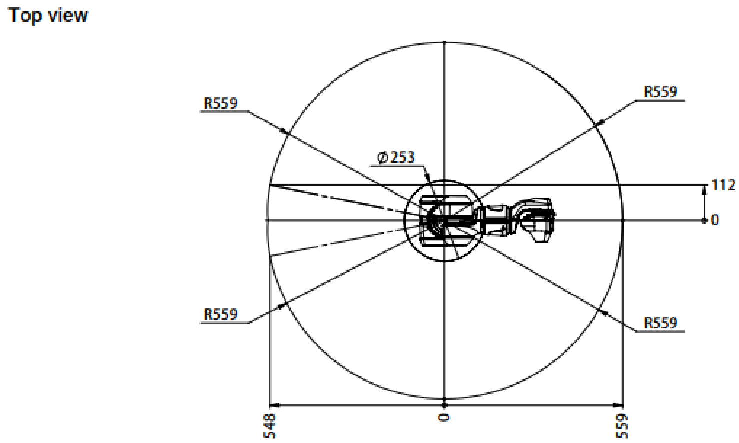


Figure 14: Working range of the robot in top view. [5]

The distance from picking position to placing position of the robot is:

$$L = 0.5m \times 90° \times \frac{\pi}{180} = 0.785m. \text{ [10]}$$

And we need 5 minutes to package 25 units, then the time between units is $5/25 = 0.2min/unit = 12s/unit$. So, this leads to the cycle time of the robot is 12s and the time for picking and placing or haft cycle time is 6s.

⇨ Speed of this action is $= \frac{0.785m}{6s} = 0.13m/s$

In this assembly line, we will wonder if Base part goes to Station 4 - Motor with pinion before the assembly of Motor and Pinion arrives. So,

Time for base part moves to Manipulator 7: 17.86s + 6s + 12s*3 = 59.86s

Time for Motor moves to Manipulator 7: 17.86s + 6s + 12s + 6s = 41.86s

Thus, Motor with Pinion Assembly goes to Manipulator 7 (used for inserting it to Base part) earlier than the time for base part moves to Manipulator 7 and the transfer time won't conflict.

<u>The cycle time and line balancing efficiency</u>

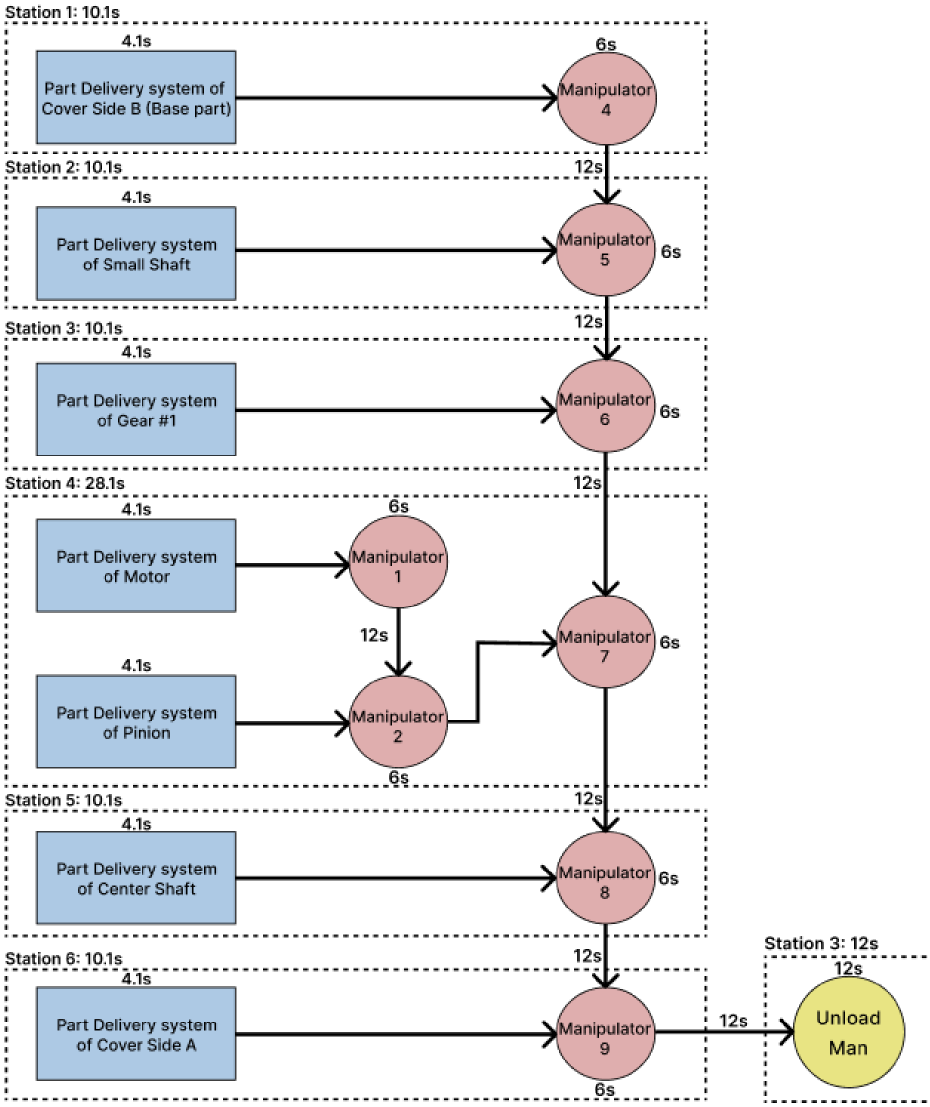


Figure 15: Time of assembly line diagram.

The transfer time $T_r = 12s$
The maximum service time $Max\{T_{si}\} = 28.1s$
Hence, **the cycle time** for the automated assembly line $T_c = T_r + Max\{T_{si}\} = 28.1s + 12s = 40.1s = 0.67\ minutes$.
For our assembly line, the fraction deflects rate, probability that the deflect will jam and the average downtime are:

$$q_i = 1\%, m_i = 50\%, T_d = 2\ minutes.$$

Then,
The yield of good assemblies:

$$P_{ap} = \prod_{i=1}^{n}(1 - q_i + m_i q_i) \text{ where n is number of station}$$

$$P_{ap} = (1 - 0.01 + 0.5 \times 0.01)^7 = 96.55\%.$$

The jamming probability of assemblies: $P_{qp} = 1 - P_{ap} = 3.45\%$
The average actual production time per assembly with 7 stations:

$$T_p = T_c + \sum_{i=0}^{n} m_i\, q_i T_d = 0.67 + 7(0.5 \times 0.01 \times 2) = 0.74\, minutes.$$

⇨ **Line balancing efficiency** $E = \frac{T_c}{T_p} = \frac{0.67}{0.74} = 90.5\%$

b) Hardware for Automation

- **The feeding machine:** (figure 17)

This machine is to supply the cover side, gears, and dc motor with a pinion. This will be responsible for feeding the parts to the assembly line.
Our feeder selection is **Hybrid Vibratory Feeder**: [1]
The requirement for this hardware is to deliver a new component to the assembly line and needs to hold a certain number of components or parts that is need to be delivered to the system.
This machine has the feeding rate of the machine is 90 parts per minute. The dimension of the supply hopper is 240 mm wide and 851 mm long. [1]
The price of this machine is around 800-2000$. [2]

- **Vibratory feeder troughs:** (figure 18)

This feature is to contain the components at the end of the conveyor 2 and the manipulator will collects parts from this feature. [3]
the price of feeder is around 1000-15000$. [3]

- **Manipulator:** (figure 19)

This is the machine such as a gripper that will be responsible for picking, moving, and placing components from the feeding machine to the assembly line. The working range of the manipulator must be at least 1m to the feeding machine.

The feeding machine is placed next to the manipulator so that it needs to have a degree of freedom in view at 360 degree in any direction to be flexible in reaching next station.

We aim to assemble each fixture in 30s, each manipulator will have around 6s to place fixture's part in the correct position. The time for picking and placing part is estimated at 12s, which leave rest for humans to move the fixture from the feeder. The trajectory for this is estimated at 3m, giving us the rated end effector speed of approximately 1.2m/s

Since our design is very small, we have chosen the following manipulator or ABB IRB 14050:
Not only this manipulator has at most 90 degree of freedom in any direction, it has handling capacity of 0.5 kg and reach capacity of 0.559m, which simply saying that this is the most optimal manipulator that meet all the requirements of delivering the full fixture with the rated speed of 25mm/s. [4]
The price of this manipulator is 39$. [5]

- **<u>Conveyor system 1:</u>** (figure 20)

The conveyor will transport the part in between 3 stations
The conveyor must have a width of at least 1.5m with wall on two sides without making parts fall over
The conveyor must have a speed of at least 1.3 m/s so that it could reduce the downtime of other stations when waiting for conveying parts
In addition, the conveyor must have a central gap in between so that when assembling the part, it will be easier to assemble.
This double-mini belt conveyor that has a split chassis easily transport parts that protrude above or below the belt. The system is 2.5 m long and 0.14 m wide. [7]
The price of this conveyor belt is around 800$ for any specific customized conveyor belt. [8]

- **<u>Conveyor system 2:</u>** (figure 22)

The second conveyor is to carry the motor with pinion. The system is 0.83312 m in length and 0.24892 m in wide.

- **<u>End-effector:</u>** (figure 23)

There are many types of a gripper if we decide what is the most optimal for our assembly line.
A total weight of our new design should be not greater than 1g so that the required holding force is calculated as follows:

$$F = m \times g = \frac{1}{1000} \times 9.81 = 0.00981(N)$$

We know:
The end effector can approach the parts from the top face
The minimum load of end effector is smaller than 0.00981(N)
The weight of end effector is not greater than 3 kg
For an example with servo module:

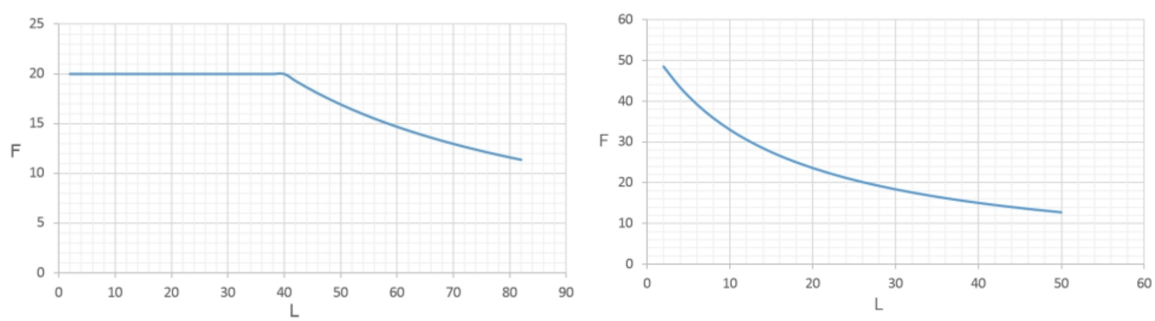


Figure 16 Force v Length of End-effector IRB 14050

Observing two figures, we see that the greater the lenth L of fingers, the lesser the force of gripping. The lowest should be 11N, which is the most optimal force that greater than we calculated. [8]

- **<u>The PLC controller:</u>** (figure 24)

When this controller receives a signal from the sensor, it will make sure that all machines work in

a synchronization manner. This machine needs to have some cyber protection in case of this machine connects to the outside network. The controller needs to run at the frame rate of 3 ms to ensure the respond of the system.
This PLC can process at 3ms for each fram and also scalable for the system with cyber control.
The price of this machine is 15000-20000$ per piece. [10]

Section IV - Performance Comparison & Recommendations

- Performance Comparision:

Table 1: Bill of Materials for materials of the Proposed Automated Line

No.	Hardware	Quantity (units)	Unit Price ($)
1	Cover size B (base)	1	0.0215
2	Small Shaft	1	0.0167
3	Gear #1	1	0.0167
4	Pinion	1	0.35
5	Motor	1	0.35
6	Center Shaft	1	0.0167
7	Cover size A	1	0.023
Total Price ($)			1.0073

Table 2: Bill of Materials for Hardware of the Proposed Automated Line

No.	Hardware	Quantity (units)	Unit Price ($)
1	The feeding machine	1	2000
2	Feeder trough	1	15000
3	Manipulator	1	39
4	AGV	1	6590
5	Conveyor system 1	1	800
6	Conveyor system 2	1	800
7	PLC system	1	20000
Total Price ($)			45229

Table 3: Comparison between Manual Line and Automated Line

Line Type	Investment Cost	Upkeep (%)	Cycle Time (mins)	Production Rate (pcs/hr)	Operation Risk
Automated Assembly	118229	100%	0.67 min	179.1	Down time due to failure probability Interaction between human workers and robots
Manual	94000	62.5%	4.91	146.6	Worker health

Assembly			min		Interaction between human workers and machines

The investment cost for manual assembly: the number of workstations x cost per workstation + cost of tools and equipment = 6 x 3500(workstation) + 70000 (CNC machine) + 3000 (units)= 94000$.

The investment cost for automated assembly = 45229 + 3000 (units) + 70000 (CNC machine) = 118229$.

With an upkeep of the automated assembly, we are able to produce more units in an hour and still maintain the working of the assembly line in a long term run.

The cycle time for the manual line obtained from the first project is 4.91 min, but for our new cycle time; we are able to produce more products with less cycle time. In terms of our cycle time, the automated line is more efficient than the manual line.

- Recommendations:

With the capacity to meet a wide range of products, this automatic assembly line may be categorized as programmable automation, which is sufficient to meet the current Industry 4.0 production trend and has the potential to be modified. Integration of computer vision and sensor fusion techniques will be included in the future. As a result, it enables long-term production with cutting-edge technology that may be tailored to specific business requirements. Furthermore, when compared to standard automated production lines, our proposed line is very cost-effective while guaranteeing output objectives are satisfied.

In addition, there are other possibilities for the planned line, which is to consolidate stations 4 and 5 into 1, and to switch from using 1-handed robots to 2-handed robots. This surely helps to minimize production time because pieces are neither entangled or impeded by other elements of the product in these two stations, allowing them to be grouped together in one station to save production time. export.

For the reasons stated above, our team hope the STS company would consider implementing our line to boost long-term revenues while saving time and money.

Section V – Conclusions

In conclusion, our team has expectedly proposed the desgin of an automated assembly line for STS company. First, the design of our new fixture for the new assembly line could overcome any problems from the manual assembly line. Our parts now have a little higher orienting efficiency for our new design, meaning that the feeding cost can reduce a little bit. In terms of production line, the six automated station is proposed with a robot manipulator ỈB 14050 and an end effector to pick and place. As a result, the comparison shows that the automated assembly line can provide a more production rate than a manual assembly line. However, the risk of our system is extremely high, and the maintenance cost must be reconsidered. Hence, this is a good buisness between our automated assembly line and STS company.

References

[1] "Hybrid Vibratory Feeder – Conveyor System for Gentle Parts Handling — Performance Feeders | Performance Feeders," Aug. 13, 2013. [Online]. Available: https://performancefeeders.com/custom-applications/custom-conveyor-systems/hybrid-vibratory-feeder-conveyor-system-for-gentle-parts-handling. [Accessed: May 21, 2023]

[2] "Vibratory Bowl Feeder Price, 2023 Vibratory Bowl Feeder Price Manufacturers & Suppliers | Made-in-China.com," *www.made-in-china.com*, May 21, 2023. [Online]. Available: https://www.made-in-china.com/products-search/hot-china-products/Vibratory_Bowl_Feeder_Price.html. [Accessed: May 21, 2023]

[3] "Vibrator Feeders - Vibratory Dosing Feeder Manufacturer from Mumbai," *IndiaMART.com*, May 21, 2023. [Online]. Available: https://www.indiamart.com/vibratorsindia/vibrator-feeders.html. [Accessed: May 21, 2023]

[4] "Product specification IRB 14050," May 2023 [Online]. Available: https://assets.ctfassets.net/gt89rl895hgs/7BeleiEkIdhIA2hFO0IogH/038744852914ea4212dce34feb40492f/3HAC064627_PS_IRB_14050-en.pdf. [Accessed: May 21, 2023]

[5] "Single-arm YuMi IRB 14050," *webshop.robotics.abb.com*, May 21, 2023. [Online]. Available: https://webshop.robotics.abb.com/us/catalog/product/view/id/60/s/single-arm-yumi-irb-14050-assembly/. [Accessed: May 21, 2023]

[6] "[Hot Item] Hot Sell Agv Chassis Automated Guided Vehicles 200kg Load Compact Structure Agv Robot with High Quality Agv Controller Support Secondary Development (TZAGV-B02)," *Made-in-China.com*, May 21, 2023. [Online]. Available: https://tongzhutech.en.made-in-china.com/product/fdZTMBYyEgWt/China-Hot-Sell-Agv-Chassis-Automated-Guided-Vehicles-200kg-Load-Compact-Structure-Agv-Robot-with-High-Quality-Agv-Controller-Support-Secondary-Development-TZAGV-B02-.html. [Accessed: May 21, 2023]

[7] "Belt conveyor for contoured components," May 21, 2023. [Online]. Available: https://montech.com/us/en/solutions/belt-conveyor-for-contoured-components/?fbclid=IwAR17D_Qo3TXBnRprKDpo6bntgGxhSxmaiLQvup8EQ7TMi0q-7hHi27kzxEs. [Accessed: May 21, 2023]

[8] "Customized Conveyor Systems Aluminium Double Speed Chain Conveyor - Buy Speed Chain Conveyor,Pallet Conveyor Product on Alibaba.com," *www.alibaba.com*, May 21, 2023. [Online]. Available: https://www.alibaba.com/product-detail/Customized-conveyor-systems-aluminium-double-speed_62208943291.html?fbclid=IwAR0P0NRLc6_2hLQuNSIv-uSikZXCasJEKoGtvYR2Knp_yZH58x9DT7ljUnc. [Accessed: May 21, 2023]

[9] "AC500," *PLC Automation*, Jan. 03, 2023. [Online]. Available: https://new.abb.com/plc/programmable-logic-controllers-plcs/ac500. [Accessed: May 21, 2023]

[10] "Cách tính độ dài cung tròn cực hay, chi tiết - Toán lớp 10," *vietjack.com*, May 21, 2023. [Online]. Available: https://vietjack.com/toan-lop-10/cach-tinh-do-dai-cung-tron-cuc-

hay.jsp?fbclid=IwAR3XG7BhvfZPJA10-VtBxzUn84-dbaTFWsF8ml7LotBox8hEeESGJ9wvOlo. [Accessed: May 21, 2023]

Appendices

Figure 17 Hybrid Vibratory Feeder.

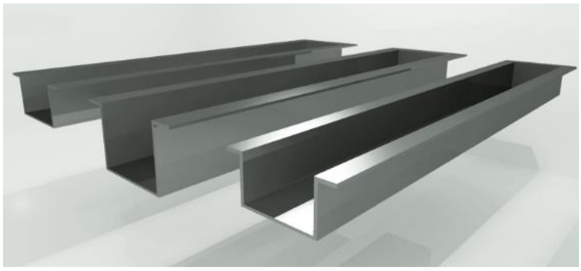


Figure 18 Vibratory feeder trough.

Figure 19 IRB 14050 manipulator.

Figure 20 belt conveyor for contoured components.

Figure 21 single belt conveyor.

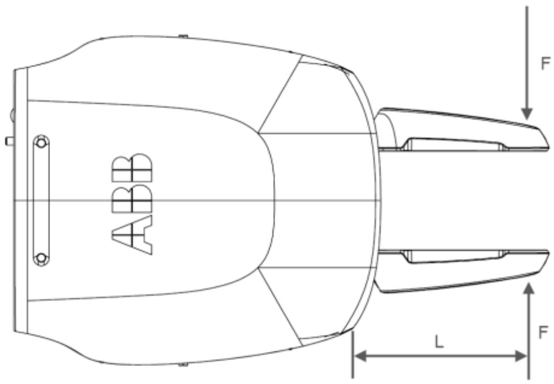


Figure 22 End effector of IRB 14050.

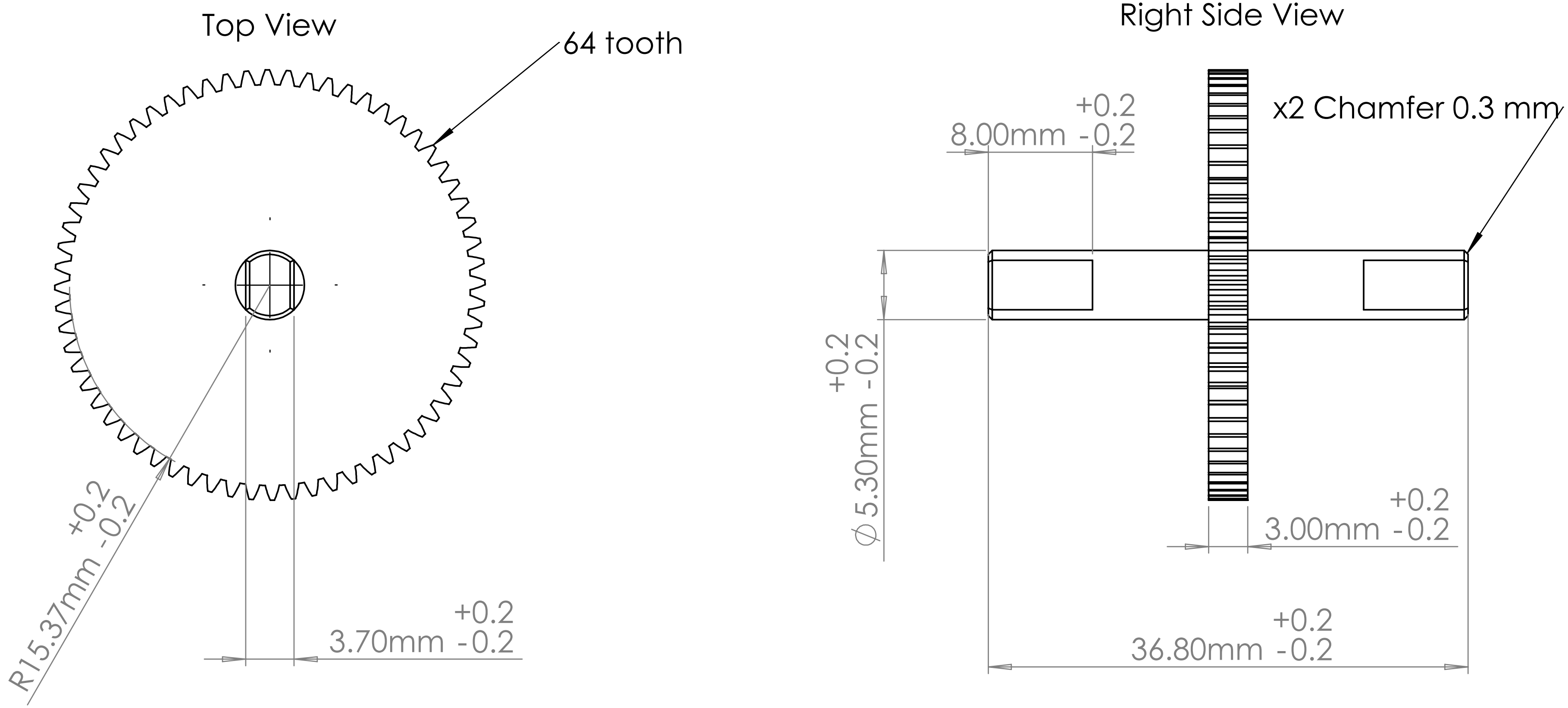

Figure 23 PLC controller.

Table 4: Description and work elements time of station.

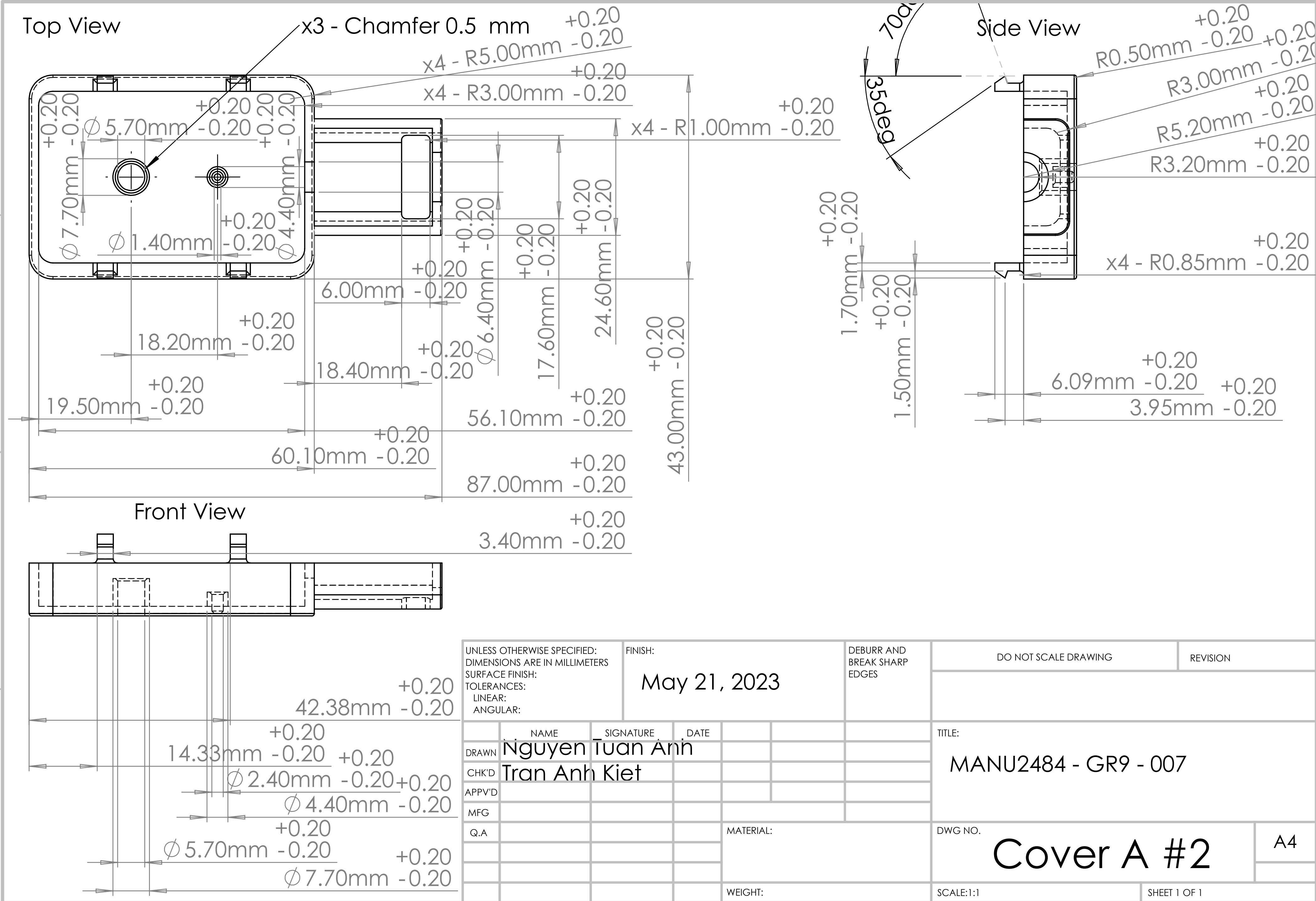
Station	Workstation number	Name of Workstation	Purpose	Work elements	Time of work elements
1	1	Part Delivery system of Cover Side B	Feeding	Feed Cover Side B to the work heads for assembly.	4.1s
	2	Manipulator 4	Placing to conveyer	Pick Cover Side B (base part) and places it to Conveyer System 1	6s
2	3	Part Delivery system of Small Shaft	Feeding	Feed Small Shaft to the work heads for assembly.	4.1s
	4	Manipulator 5	Inserting parts to Base part	Manipulator 4 picks Small Shaft from Station 1 and attaches to hole in Cover Side B	6s
3	5	Part Delivery system of Gear #1	Feeding	Feed Gear #1 to the work heads for assembly.	4.1s
	6	Manipulator 6	Inserting parts to Base part	Manipulator 6 picks Gear #1 from Station 1 and attaches to Small Shaft	6s
4	7	Part Delivery	Feeding	Feed Motor to the work heads for assembly.	4.1s

		system of Motor			
	8	Manipulator 1	Placing to conveyer	Manipulator 1 picks Motors from Station 1 and places to Conveyer System 2	6s
	9	Part Delivery system of Pinion	Feeding	Feed Pinion to the work heads for assembly.	4.1s
	10	Manipulator 2	Inserting to Motor	Manipulator 2 picks Pinions from Station 1 and attaches to Motor's Shaft	6s
	11	Conveyor system 2	Transporting	Conveyor system 2 transfers Motors to Manipulator 2	12s
	12	Manipulator 7	Inserting parts to Base part	Manipulator 7 picks Motor with Pinion from Conveyer System 2 and places to Cover Side B	6s
5	13	Part Delivery system of Center Shaft	Feeding	Feed Center Shaft to the work heads for assembly.	4.1s
	14	Manipulator 8	Inserting parts to Base part	Manipulator 8 picks Center Shaft from Station 1 and attaches to hole in Cover Side B	6s
6	15	Part Delivery system of Cover Side A	Feeding	Feed Cover Side A to the work heads for assembly.	4.1s
	16	Manipulator 9	Inserting parts to Base part	Manipulator 9 picks Cover Side A from Station 1 and insert to Cover Side B	6s
7	17	Unload Man	Unload the completed Motor	A human operator will manually retrieve completed unit from	12s

			Gearbox Assembly	Conveyor system 1	
Transfer	18	Conveyor system 1	Transporting	Conveyor System 1 let Base part go to all station and move the completed Motor Gearbox Assembly to Station 3	72s



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH: May 21, 2023	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	
	NAME	SIGNATURE	DATE	TITLE: MANU2484 - GR9 - 006	
DRAWN	Nguyen Tuan Anh				
CHK'D	Tran Anh Kiet				
APPV'D					
MFG					
Q.A				MATERIAL:	DWG NO. Center Gear Shaft #2	A4
				WEIGHT:	SCALE:1:1	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH: May 21, 2023	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING / REVISION

	NAME	SIGNATURE	DATE
DRAWN	Nguyen Tuan Anh		
CHK'D	Tran Anh Kiet		
APPV'D			
MFG			
Q.A			

TITLE: MANU2484 - GR9 - 007

MATERIAL:

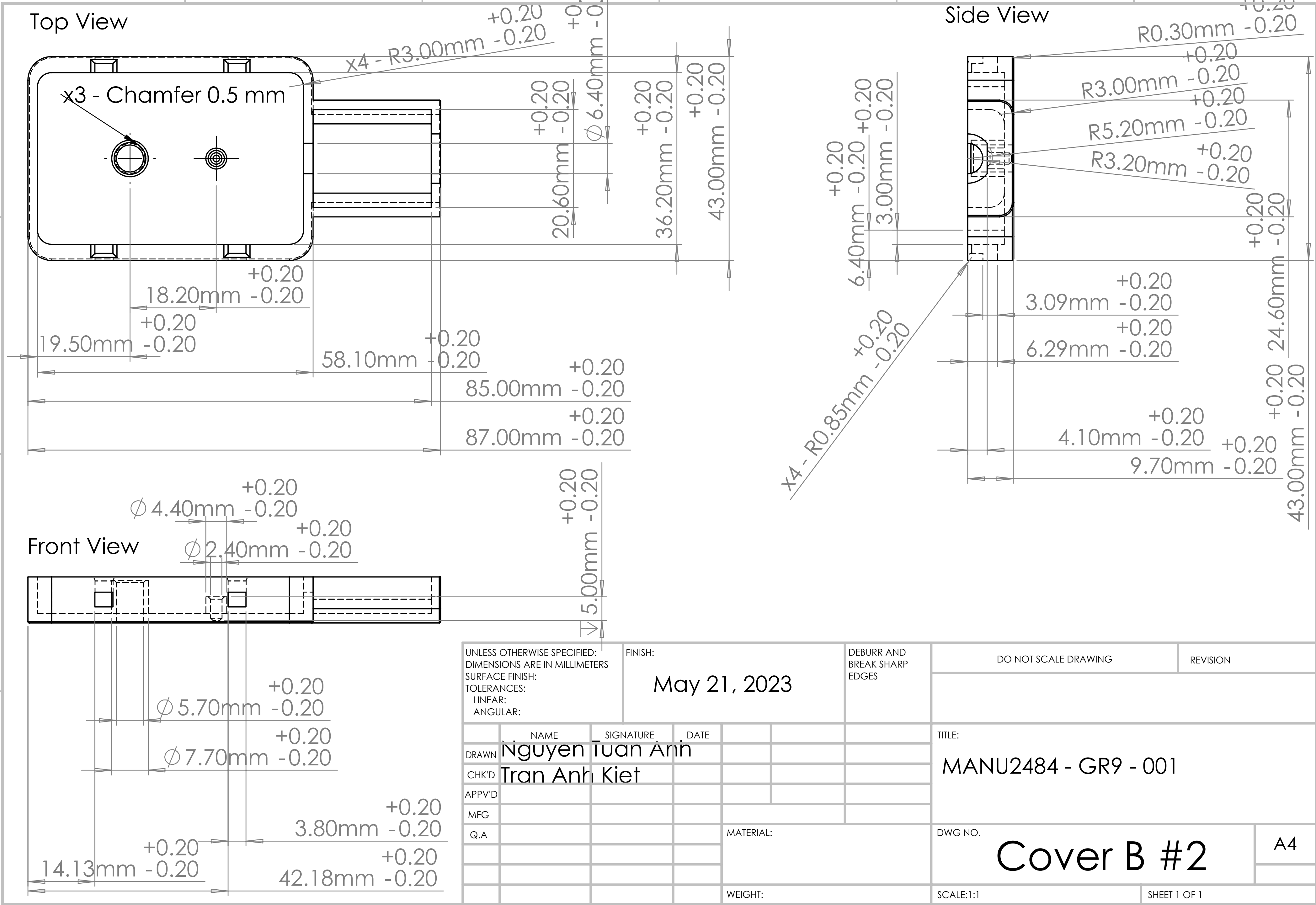
WEIGHT:

DWG NO. Cover A #2

A4

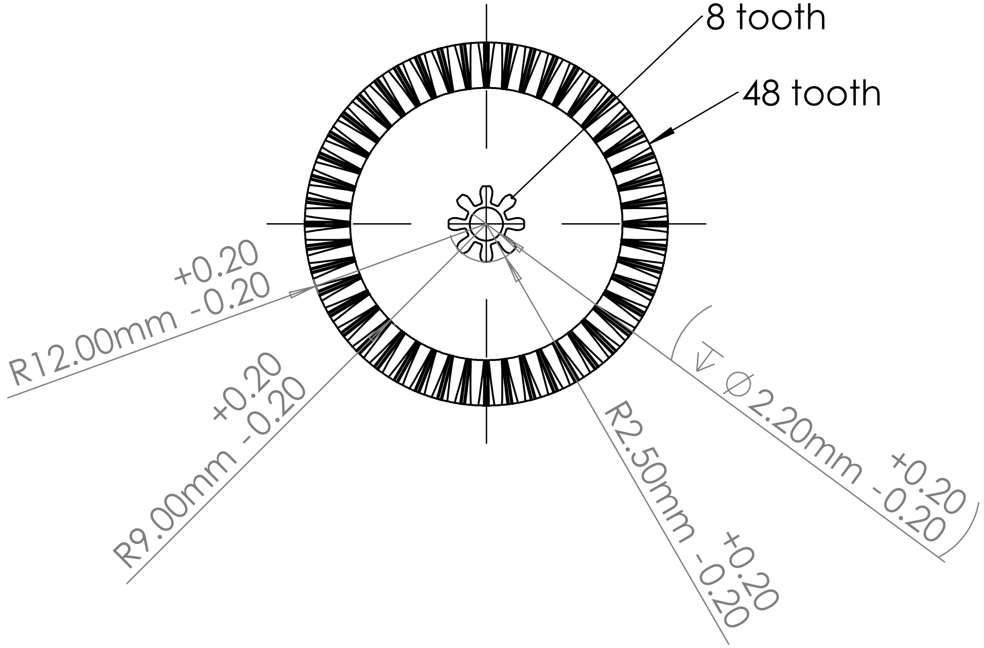
SCALE:1:1

SHEET 1 OF 1

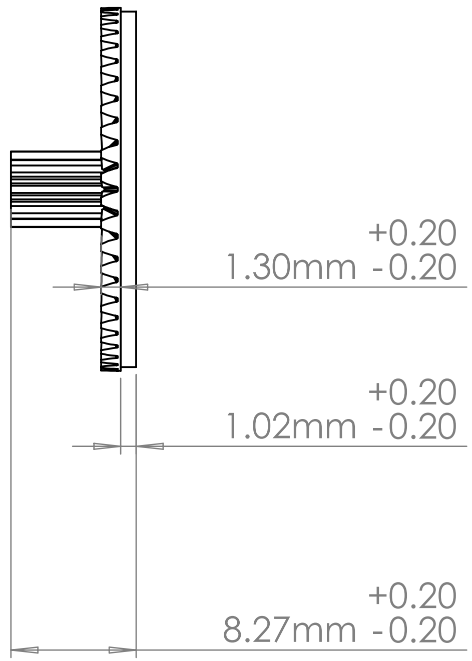


Top View
x4 - R3.00mm +0.20 -0.20
x3 - Chamfer 0.5 mm
⌀6.40mm +0.20 -0.20
20.60mm +0.20 -0.20
36.20mm +0.20 -0.20
43.00mm +0.20 -0.20
18.20mm +0.20 -0.20
19.50mm +0.20 -0.20
58.10mm +0.20 -0.20
85.00mm +0.20 -0.20
87.00mm +0.20 -0.20
Side View
R0.30mm +0.20 -0.20
R3.00mm +0.20 -0.20
R5.20mm +0.20 -0.20
R3.20mm +0.20 -0.20
3.00mm +0.20 -0.20
6.40mm +0.20 -0.20
24.60mm +0.20 -0.20
43.00mm +0.20 -0.20
x4 - R0.85mm +0.20 -0.20
3.09mm +0.20 -0.20
6.29mm +0.20 -0.20
4.10mm +0.20 -0.20
9.70mm +0.20 -0.20
Front View
⌀4.40mm +0.20 -0.20
⌀2.40mm +0.20 -0.20
5.00mm +0.20 -0.20
⌀5.70mm +0.20 -0.20
⌀7.70mm +0.20 -0.20
3.80mm +0.20 -0.20
14.13mm +0.20 -0.20
42.18mm +0.20 -0.20
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
May 21, 2023
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
Nguyen Tuan Anh
CHK'D
Tran Anh Kiet
APPV'D
MFG
Q.A
TITLE:
MANU2484 - GR9 - 001
MATERIAL:
DWG NO.
Cover B #2
A4
WEIGHT:
SCALE:1:1
SHEET 1 OF 1

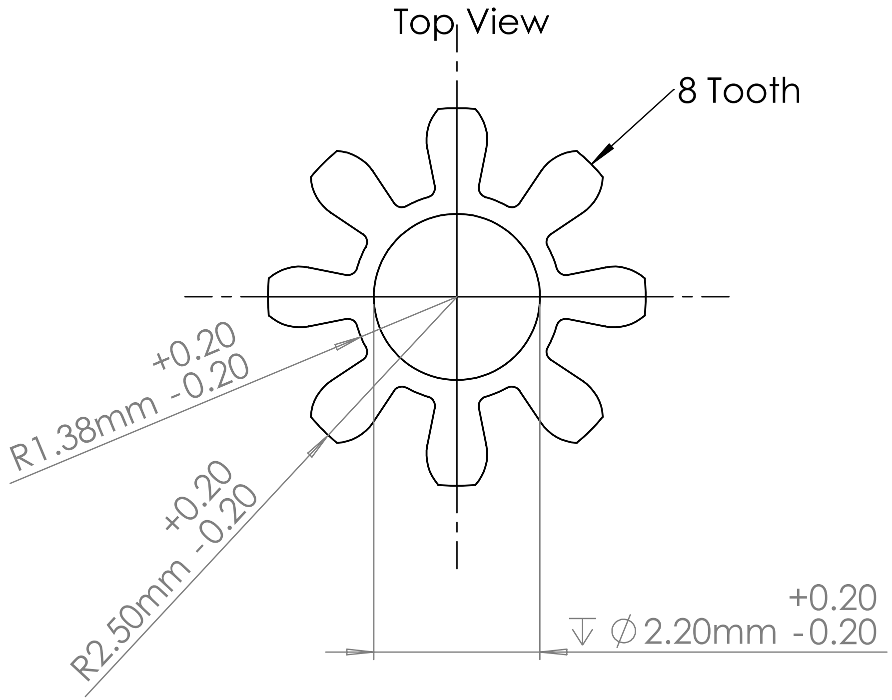
Top View

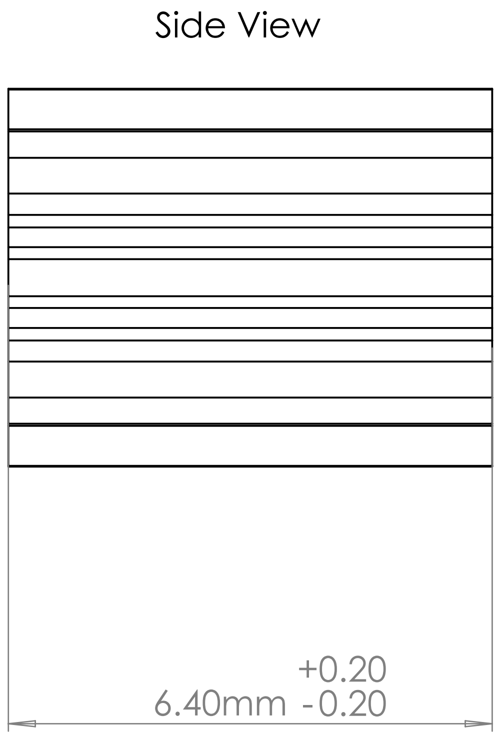


Side View



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH: May 21, 2023		DEBURR AND BREAK SHARP EDGES		DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE		TITLE: MANU2484 - GR9 - 003	
DRAWN	Nguyen Tuan Anh					
CHK'D	Tran Anh Kiet					
APPV'D						
MFG						
Q.A				MATERIAL:	DWG NO. Gear for Small Shaft #2	A4
				WEIGHT:	SCALE:2:1	SHEET 1 OF 1





UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH: May 21, 2023	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION

	NAME	SIGNATURE	DATE
DRAWN	Nguyen Tuan Anh		
CHK'D	Tran Anh Kiet		
APPV'D			
MFG			
Q.A			

TITLE: MANU2484 - GR9 - 004

MATERIAL:

WEIGHT:

DWG NO. Pinion #2

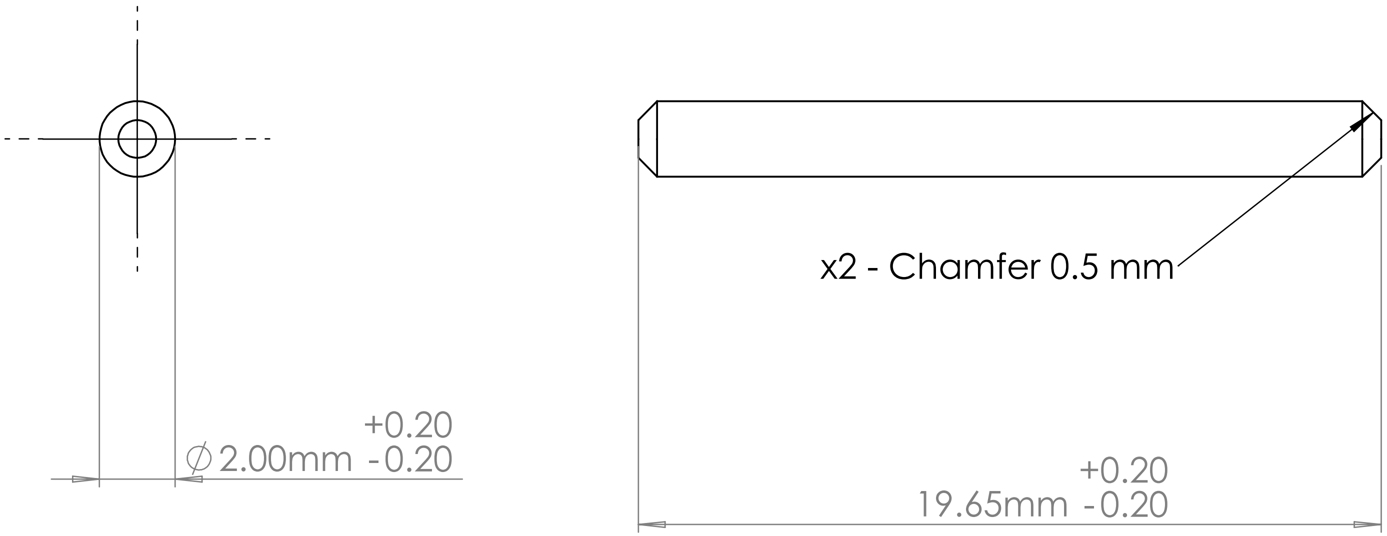
A4

SCALE:10:1

SHEET 1 OF 1

Top View

Side View



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH: May 21, 2023	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	

	NAME	SIGNATURE	DATE
DRAWN	Nguyen Tuan Anh		
CHK'D	Tran Anh Kiet		
APPV'D			
MFG			
Q.A			

TITLE: MANU2484 - GR9 - 002

MATERIAL:

WEIGHT:

DWG NO. Small Shaft #2

A4

SCALE:5:1

SHEET 1 OF 1